IDENTIFYING AND EVALUATING DISRUPTIVE TECHNOLOGIES USING TECHNOLOGY SCANNING

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Abstract
The identification of disruptive technologies and the evaluation of their impact on the own business is a major challenge for technology intelligence. Technology trends such as additive manufacturing ("3D printing") and the Internet of Things with its applications such as Industrie 4.0 in production technology are seen by companies as both major opportunities and threats to their business models on an abstract level, yet the identification and especially evaluation of specific technologies impacting a company's business in the future is still difficult.
Disruptive technologies threaten market incumbents as these technologies enable addressing new or latent customer requirements or evaluation dimensions in a given market rather than improving on the fulfillment of existing evaluation criteria. When the value customers place on requirements and evaluation criteria (i.e. the evaluation context) changes, this can lead to rapid devaluation of products or services using traditional technologies.
Technology Scanning is the technology intelligence sub-discipline responsible for finding weak signals of technological trends, and as we conjecture also for finding signals on technology-driven impeding changes in evaluation contexts in relevant markets. To do so, Technology Scanning uses a toolbox of methods including forecasting, scenario analysis, and trend analysis methods.
We have previously stated the need for practitioners to have a framework of design recommendations for technology scanning based on the specific company's strategic goals on the identification of disruptive technologies, and outlined a research agenda on providing such a framework.
As part of this research agenda, in this paper we present an overview of requirements for identifying and evaluating disruptive technologies in a company's context, and give an analysis of existing methods and design options (processes, organizations etc.) for technology scanning regarding these requirements. We proceed to outline a method to systematically detect possible changes in evaluation contexts to assist identifying and evaluating disruptive technologies using cross-industry analogies.
We find that concepts from technology intelligence need to be complemented with concepts from market intelligence and environmental scanning to properly evaluate upcoming disruptive changes.

Keywords: Disruptive Technologies, Technology Intelligence, Technology Scanning

Introduction

Technological trends such as additive manufacturing ("3D printing"), the Internet of Things (IoT) and its applications (such as Industrie 4.0) signal that traditional industries like the consumer goods, automotive and machine tool industries will soon undergo changes similar to those digitalization has already induced in industries like travel, media and services (Manyika et al. 2013).
Unlike traditional technology-induced changes, where a mature technology is being replaced by a new technology fulfilling effectively the same function, this trend concerns the application of mature technologies from a different field to new applications and markets.
The replacement of mature technologies by new technologies is due to diminishing returns in further development of the mature technology, and recent leaps in the development of the new technology (S-curve theory) (Schuh et al. 2011). For instance, a new type of engine could be radically more efficient, or a new material could significantly speed up machining processes. The new technology fulfils the same customer requirement as the old technology – just (radically) better, potentially allowing for new applications. The evaluation of such technological changes

can thus mainly be done by comparing the potential new technologies to the existing technology on a technological level, with a cursory look on potential competitive and market effects.

In contrast, the transfer of an in-principle mature technology from one field to another is often not aimed at fulfilling the existing customer requirements in a better way, but at addressing fundamentally new (or latent) customer requirements. For example, when smartphones were developed they were much more versatile than traditional mobile phones, at the expense of being worse phones in terms of reception quality. A purely technology-based evaluation of such trends will not result in correct assessments. Furthermore, as these technologies originate and mature outside the company's technology and market context, competencies for assessing, piloting and developing these technologies are lacking in companies. Yet often new entrants who do use these technologies can, through the fulfilment of customer needs currently untapped by the incumbents, convert these technologies into *disruptive* innovations, threatening the incumbents in the market (Christensen 1997). In a market where a technology can be used as a basis for disruptive innovation, it is also called a *disruptive technology*.

Technology intelligence is responsible for finding and evaluating relevant technology-related information for an organization (Lichtenthaler 2002; Wellensiek et al. 2011). Technology scanning is the function of technology intelligence tasked with listening to signals from outside the organization's identified technological and business context (Wellensiek et al. 2011). It thus falls on technology scanning to identify such disruptive technologies (Bucher et al. 2003). Currently, however, technology scanning can be observed to be a success factor for conducting radical (technology shift-driven) innovation, but not for bringing disruptive technologies into a market (Govindarajan et al. 2011, p. 129). One reason for this may be that technology scanning, largely done by internal R&D experts, still focuses too much on the technological aspects in evaluating potentially relevant trends and signals. However, certain theoretical reasons also allow the conclusion that it may be outright impossible to evaluate potentially disruptive technologies in a way to allow clear categorization into relevant and not (yet) relevant, but that observation needs to be geared into allowing organizations to react more flexibly and swiftly as new information emerges.

What is clear is that companies are in need of methodical guidance regarding the reaction to (and, if possible, anticipation of) emerging disruptive technologies. At the same time, they need to maintain their focused attention to incremental technological changes and radical technology shifts inside their business and technology context, as these still form the vast majority of technological changes.

With this research we aim to contribute to forming such methodical guidance by driving towards the derivation of technology scanning architectures suitable for use for companies with different strategic goals regarding their technological portfolio. In this paper, after giving an overview about the state of the art in the relevant theoretical foundations, we present preparatory results for this research by deriving requirements for technology scanning. These requirements are based both on traditional views of technology scanning as "fuzzy-front-end" to technology intelligence but also on incorporating competitive and business perspectives and a focus on requirements derived from the theory of disruptive technologies. We then discuss influences between the design options of technology scanning and the fulfilment of the identified requirements to technology scanning, and finally outline a concept for a method improving technology scanning outcomes when facing certain disruptive technologies.

Research Methodology

This paper describes the interim result of a conceptual research aimed to identify and validate requirements to technology scanning, design options for technology scanning and the influences of certain design options on the fulfilment of these requirements.
The identification of these requirements and influences is done in preparation for progressing with a larger research question of designing suitable model architectures for technology scanning for various companies exposed to technological change (see Figure 1).

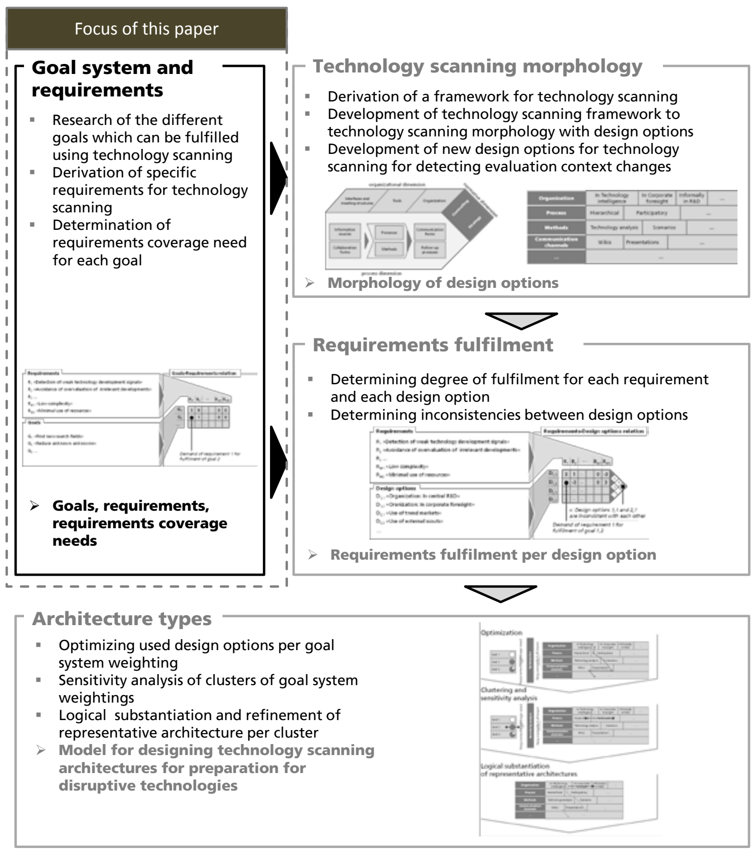

Figure 1: Research design of deriving technology scanning architectures (Schuh et al. 2015)

The preliminary results of this research are based on a condensation of results of a literature review, observations from benchmarkings of technology management and technology intelligence as well as observations from industry consulting on trend analysis, disruptive technologies and technology intelligence conducted along the guidelines of mirroring ideas derived from conceptual research on reality (Ulrich 1984, p. 23).
Literature has been considered from the fields of technology intelligence, corporate foresight, forecasting, disruptive technologies and related fields. Some authors separate national scanning initiatives from the analysis of company-based foresight initiatives (Rohrbeck, Bade 2012, p. 3), however as we separate discussion of individual design options of technology scanning, we do include national scanning activities in the scope of our research for design options where insight

is transferable, such as research on methods and the way networks of companies share knowledge.

State of the art

The scope of this research can fundamentally be divided into three areas: Technology scanning as the corporate function which needs to be designed in order to fulfil certain requirements; strategic assessments as the activity which is conducted by technology scanning; and relevant technology-related changes as the objects to be analyzed by technology scanning (see Figure 2).

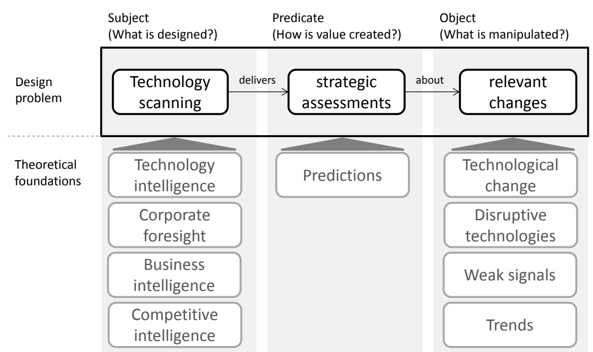

Figure 2: Relevant research fields and theoretical foundations

Technology scanning and technology intelligence

The organization of technology intelligence in general has been researched by LICHTENTHALER (Lichtenthaler 2002, 2004, 2007).

Technology scanning is the part of technology intelligence dealing with information from outside the company's context which turns out to be relevant to the company (Wellensiek et al. 2011; Bucher et al. 2003, p. 153). The objects of technology scanning are trends and signals, unlike technology monitoring and scouting, which deal with specific technology fields within defined search fields (Wellensiek et al. 2011).

By its nature, technology scanning is future-oriented (*"How will current observable trends and developments coming from outside our organization affect the company?"*), and can be classified to be part of the strategic foresight functions of a company (Krystek, Müller-Stewens 2006).

BUCHER et al have analyzed the use of technology scanning for detecting disruptive technologies (Bucher et al. 2003). However their definition of technology scanning entails focusing on functional search fields derived from corporate strategy or technology roadmaps. These search fields may be much broader than the ones typically used in technology monitoring, and it has shown that indeed in many companies technology intelligence is not yet able to make proper use of such function-oriented search fields

Corporate foresight or Strategic foresight, business intelligence and competitive intelligence

As similar concepts on future-oriented management functions involving technology are named differently in the literature, it makes sense to also address concepts from related areas when exploring technology scanning, such as corporate scanning and strategic foresight (Boe-Lillegraven, Monterde 2015, p. 63).

Strategic foresight can be seen as ultimately going back to ANSOFF's studies on strategic management in uncertain environments (Ansoff 1975; Rossel 2012). BATISTELLA has researched the requirements of the organization of corporate foresight, dividing the evaluation of the organization into efficiency and effectiveness (Battistella 2014, p. 63). Due to the closeness of technology scanning and corporate foresight, we can draw from this analysis. ROHRBECK has researched goals and roles of corporate foresight, as well as its design (Rohrbeck, Gemünden 2011). NICK has shown that undirected Scanning is gaining in importance in strategic foresight as the macro-environment exerts more influence on an individual company's success (Nick 2008, p. 184). VECCHIATO and ROVEDA point out that foresight is not merely concerned with predicting the manifestation of trends (*"state" uncertainty*) but rather also is concerned with predicting and analyzing the *consequences* of known change events and the *impact of envisioned reactions* to such events (*"effect and response" uncertainties*) (Vecchiato, Roveda 2010).

Strategic assessments

Technology scanning is concerned with finding relevant technology-related information from outside the organization's technological and business context. As the word relevant implies, discovered information is subjected to assessments, which ANSOFF considers to be information filters (Ansoff, McDonnell 1990, pp. 58–65). Such assessments are usually derived in a common intelligence process consisting of the *determination of information needs*, *information acquisition*, *information evaluation*, and *information communication* (Wellensiek et al. 2011). The evaluation of gathered information (and thus the formation of statements about relevance of trends and signals, which shall be called *predictions*) is seen as more difficult and value-creating than the acquisition of information (Schuh et al. 2014). In addition, the communication of results has strong impact on the added value of foresight functions (Boe-Lillegraven, Monterde 2015).

Predictions

While predictions have long been the information generated by future-oriented processes, in recent decades a shift has changed the way predictions are dealt with. The assumption that the future can be fully predicted has been replaced by the notion of unpredictability, and seeing predictions as probability-based statements about potential futures. This is most exemplified by scenario techniques, which are inherently geared towards generating mutually exclusive alternative future predictions (Mietzner, Reger 2005, p. 235).

The influence factors for accurate predictions were analyzed in a program of IARPA (the U.S. Intelligence community research program) by TETLOCK et al (Tetlock, Gardner 2015).

The nature of predictability of major events is disputed by TALEB on the basis that events with major consequences are mostly either unknowable (unknown unknowns) or very unlikely, pointing to distributions of likelihoods of events with major consequences incompatible with the theory of prediction assuming normal distributions for errors (Taleb 2010). This especially poses theoretical blocks to meaningful methods of forecasting low-probability high-impact events, such as the ones weak signals are commonly considered to point to (Holopainen, Toivonen 2012, pp. 200–201). TETLOCK however argues that prudent forecasting can offer valid predictions of consequences of such events after the fact, as the consequences themselves are delayed, even if the event itself was not predictable (Tetlock, Gardner 2015, pp. 231–249).

Technological change

ARNOLD has analyzed the reaction and success of companies under the influence of various types of technological change, termed “technology shocks” (Arnold 2003). Technological change is widely accepted to follow “S-curve” trajectories, that is, after a time of emergence, a technology rapidly develops until nearly depleting its potential, at which point technology development stops and likely a new technology supersedes the previous approach (Schuh, Klappert 2011).

Disruptive technologies

Disruptive technologies, as one form of technological change, have been identified by CHRISTENSEN as technologies used by new entrants into a market to disrupt the current incumbent market structure starting from a niche or low-end market segment (Christensen 1997; Christensen, Raynor 2003; Christensen et al. 2015). Further research in the field has extended this definition to see disruptive technologies as technologies enabling innovation which delivers value to the customer on dimensions which previously were not known to be relevant to customers in a specific market (Danneels 2004).

Foresight frameworks for finding disruptive technologies and deriving reaction strategies have been proposed (Vojak, Chambers 2004; Keller, Hüsig 2009; Kostoff et al. 2004; Drew 2006). Such frameworks however tend to focus on either addressing only the technological factors such as finding suitable technologies for a known problem, or address a broad search for market-related changes. Current research still falls short on providing actionable concepts on integrating such activities into companies’ strategy, R&D and marketing activities and rather focuses on individual methods employable for finding disruptive technologies.

Weak signals and trends

ANSOFF has stated that major changes have weak signals (with varying degrees of specificity) predicting their manifestation (Ansoff 1975). Weak signals have been analyzed and distinguished from trends and incremental changes according to dimensions such as the impact of the signal in case manifestation, and the likelihood of manifestation of the signal (Holopainen, Toivonen 2012, pp. 200–201). GÜEMES CASTORENA et al classify change drivers emitting such signals into *break points* breaking current trends, *early warnings* reflecting common patterns leading to radical change and *emerging topics* reflecting upcoming topics in a set of environments suitable to incubating new topics (see Figure 3).

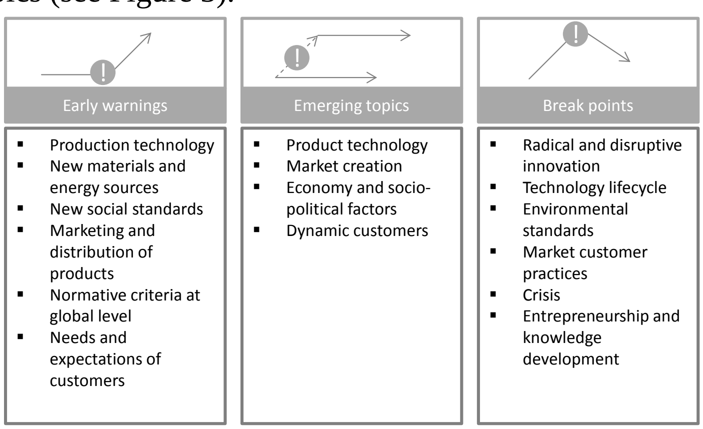

Figure 3: Change drivers (after (Güemes Castorena et al. 2013))

Requirements for technology scanning

Before analyzing design options for technology scanning, it is necessary to systematically derive the requirements technology scanning needs to fulfil. We will derive these requirements using th system-theoretic view of technology scanning architectures. To design an architecture for technology scanning, the goal is not only to design technology scanning itself as a system, but rather embed it into its supersystems which include its embedding in the surrounding organization system and environment (see Figure 4).

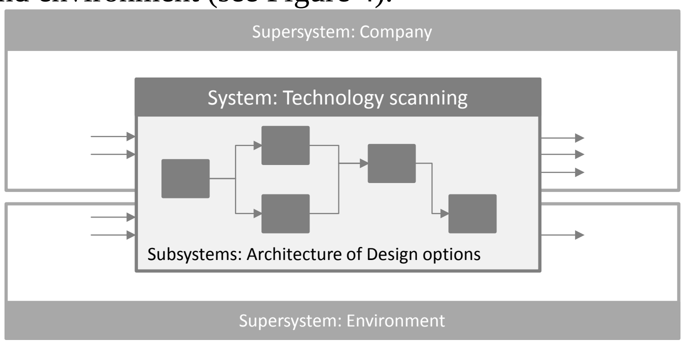

Figure 4: Generic architecture of technology scanning in a system-theoretic view

Considering the design of technology scanning itself as design problem in systems theory, we have to define requirements regarding the *outputs* of technology scanning (Patzak 1982, pp. 163–165). Due to the design of the embedding into the supersystems in an architecture, we furthermore have to define requirements to its impact, i.e., the effect of the output of technology scanning on (certain) outputs of the embedding organizational system. We stress the difference between these requirements to the *impact* of technology scanning and the *goals* of the organization to use technology scanning in the first place: the goals are related to what the company wants to do with the information (such as setting a trend, being prepared for beginning a development, challenging R&D strategy) whereas the requirements to the impact of technology scanning concern internal factors and capacity-building needed to achieve these goals (such as being more flexible in the face of change) (Schuh, Kabasci 2014). Lastly the design of technology scanning itself is not unconstrained, so the inherent *design constraints* of technology scanning itself (like limited use of resources) also have to be considered.
We thus propose to structure requirements to technology scanning by three main components: Requirements to the *outputs* of technology scanning themselves, requirements to the *impact* of technology scanning and requirements to the *functioning* of technology scanning.

Requirements to the outputs of technology scanning

The most basic requirements to technology scanning address its direct results, i.e., statements, forecasts and evaluations, which we will subsume under the word *information.*
One obvious requirement pertaining to such information is their *accuracy* (Fye et al. 2013; Tetlock, Gardner 2015; Battistella 2014, p. 64).
Observing the information generated by technology scanning as a whole, one can find different ways in which technology scanning can be inaccurate even though the information it does give is correct: it can lack *exhaustiveness.* On the other hand if some information it gives is factually

inaccurate, it lacks *precision*. *Exhaustiveness* of the information is important because as many relevant information objects as possible need to be found in order to make further use of them (Ansoff, McDonnell 1990, pp. 58–65). *Precision* on the other hand is important as identifying too many irrelevant signals and trends will reduce credibility in the scanning process and consume valuable management attention.

To avoid spending too much time parsing information, *relevance* of the resulting communicated information to management is important (Calof, Fleisher 2008, p. 855). Depending on the purpose of the use of such information furthermore their *specificity* is important to their customer (Ansoff 1975, pp. 23–24).

Information regarding the future can furthermore be required to have a long *time horizon*, i.e., predicting events or situations further into the future (Ansoff 1975, pp. 22–23). Whereas the time horizon deals with the extent to which the information looks into the future, *timeliness* of the information refers to the timespan taken between the genesis of the signal the information refers to, and when notice of it reaches the organization.

Accuracy

Accuracy of foresight information is a straight-forward requirement to foresight functions, as wrong information leads to wrong decisions. In recent years, largely due to research programs funded by IARPA, the U.S. Intelligence Community's research arm, empirical scientific research into the accuracy of forecasts has taken place and drivers and challenges for the accuracy of a forecast have been identified (Fye et al. 2013; Tetlock, Gardner 2015). Evaluating accuracy of future-oriented information is difficult as many predictions are ambiguously worded (Fye et al. 2013, p. 1222; Tetlock, Gardner 2015, pp. 46ff). An unambiguous forecast would be one where key questions such as *whether?*, *who?*, *when?* and *how?* would be answered. For instance in the case of disruptive technologies the prediction

> *"In 2 years Technology A will allow companies from Industry Segment X to enter your market and displace your product P by addressing a need for further flexibility."*

would be perfectly unambiguous, and could be inaccurate on many dimensions: *Who* will be the new entrants? *When* will the displacement happen? *Which* products will be displaced?

In the case of technology scanning we would argue that accuracy of predictions only has to address the question of *whether* a signal is a relevant threat or opportunity for the company. Technology scanning has the task to establish an initial contact with a relevant trend or signal, but further follow-up functions such as technology monitoring are tasked with delivering detailed information on identified relevant observation objects (Wellensiek et al. 2011). These follow-up questions are thus tasked with answering more detailed questions about the observed trends from the point where their relevance to the company is established.

Relevance

Even though the task of technology scanning is to provide first-contact overview information, any information derived from foresight processes needs to be relevant to the addressees to be considered in decision-making. While *filtering irrelevant trends and signals* and thus ensuring relevant *content* is part of ensuring the *accuracy* of generated information (since technology scanning is only meant to provide information about relevant signals and trends), the *information scope itself also needs to be relevant* in order to be useful. The *relevance* requirement details to what extent the *who?*, *when?* and *how?* aspects of a prediction need to be considered by technology scanning, even though they do not need to be answered fully for an accurate technology scanning result.

This means three things: The information needs to consider a timeframe in the scope of the addressee's decision making process: Information about events which already happened are of limited use in a long-term strategic planning process (unless their future implications are analyzed) whereas information about potential future trends is of little use in determining current operative decisions. As some avenues of strategic reaction such as strategic partnerships may only be available or affordable for a short time after a trend has emerged, *timeliness* of the information delivered matters for various decision-making functions.

Furthermore specificity or remaining degrees of uncertainty and vagueness, of information is an important factor regarding the type of decisions which can be based on foresight information.

ANSOFF determines specificity of information to be a requirement to information generated from foresight, categorizing it into five categories: *Sense of threat or opportunity known; Source of threat or opportunity known; threat or opportunity concrete; response concrete; and outcome concrete* (Ansoff 1975, p. 24). These information requirements form a direct trade-off between timeliness and specificity of information (Ansoff 1975, pp. 22–23). That is, when one needs foresights to account for potential surprises, one either needs to look only into the short term, or accept vague predictions.

Demand for large time horizons for predictions is known to be directly negatively related to accuracy of predictions, independent of method used (Fye et al. 2013, p. 1223). Given that the future cannot be accurately predicted, information with a long time-horizon needs to allow for various potential outcomes, greatly reducing its specificity.

Thus a three-way tradeoff between timeliness, time-horizon and specificity of information seems to exist, on which the demand for foresight information needs to be positioned (see Figure 5).

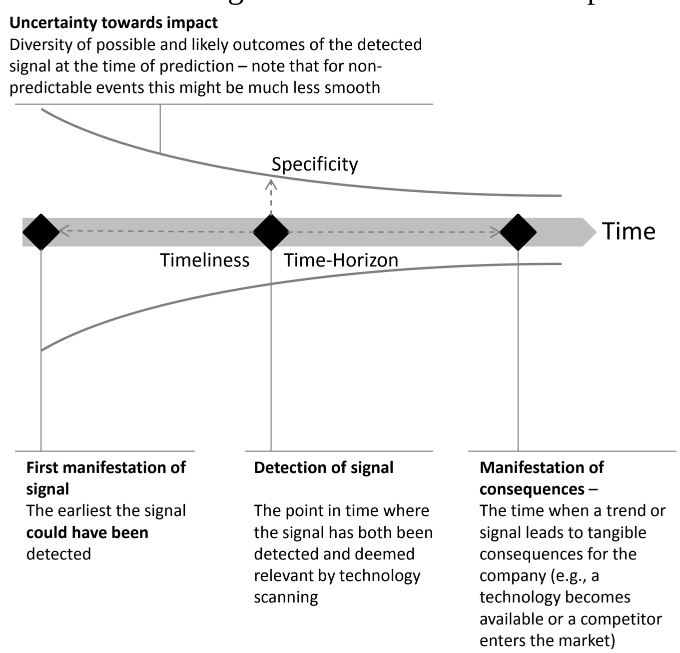

Figure 5: Trade-off between timeliness, time-horizon and specificity

However, current research about disruptive trends suggests that for these trends, it is not possible to increase specificity of foresight information gradually with time, but rather that until the disruptive event has happened (but potentially before its consequences manifest) it is not possible to get specific but accurate forecasts (Christensen 1997). Thus the trade-off curve for such trends looks more like Figure 6.

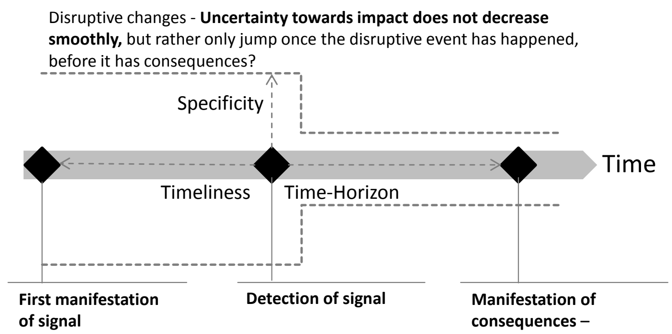

Figure 6: The need for continuous observation in the case of disruptive events

Information gained from technology scanning can be about already existing matters (which however are unknown to the information customer and whose impact to the information customer needs to be predicted), predictions about the development of observable signals or predictions beyond observable signals.

Information models differ between widely known and accepted *trends* or *strong signals*, or initial yet fuzzy *weak signals* (Holopainen, Toivonen 2012, p. 201). Here, detection of weak signals means more timely access to information about the events these signals point to than trend analysis.

The requirement of timely or early information can vary greatly depending on the situation: timely or early information may mean “before the competition knows” or “before it is generally an accepted trend” to seize opportunities with long lead times such as developing a new product line; “when the trend is clear” to avert risks by stopping obsolete R&D projects and to seize quick-win opportunities; or “early enough to react before the consequences arrive” to avert risks by divestments, portfolio changes and similar measures (Rossel 2012, pp. 229–230; Ansoff 1975; Krystek, Müller-Stewens 2006, p. 175).

By its definition, technology scanning is tasked with finding information from outside the company’s technological and market frame of reference. Thus, if the company were to be in a position to generate a technological change of relevance itself (and would thus have exclusive information on it either as developer or as party to joint development efforts) it would not be covered by technology scanning but rather by technology monitoring and scouting activities (Wellensiek et al. 2011). We thus disregard the requirement of *information exclusivity*, as the only leverage the company has to ensure exclusive access to information is to have it at an earlier stage (e.g., through better networking with fundamental R&D centers and universities, or by employing weak signal detection methods), which we have covered by the *timeliness* requirement.

Requirements pertaining to the impact of technology scanning results

One direct requirement to results of foresight functions is that they *enable* appropriate *action*. For technology scanning, we consider the dimensions of this action to be *avoiding surprises* in the first place, *promoting decision making* in the face of uncertainty, and *resilience* towards unexpected events or wrong decisions.

Avoiding surprises ensures that stakeholders are informed about significant developments before being overwhelmed by the consequences of these developments (Ansoff 1975).

Promoting decision making in the company, or enabling the company and its individuals to act in risk-affected situations and under incomplete information is seen as a major contributing factor to leveraging benefits from discontinuities, especially concerning disruptive changes (Christensen 1997).

Resilience describes the ability of the organization to withstand an unexpected change and deal with uncertainty (Amanatidou, Guy 2008, pp. 543–544; Ansoff 1975; Zolli, Healy 2013; Tetlock, Gardner 2015; Taleb 2010).

Organizational learning describes the capability to incorporate new information into the built-up consensus of the organization (Amanatidou, Guy 2008, pp. 543–544; Lichtenthaler 2007; Rossel 2012, p. 235; Kaivo-oja 2012; Battistella 2014, p. 65; Lichtenthaler 2002; Drew 2006, p. 245). As however an organization is made of key individual stakeholders, individual *mindsets* also have to be addressed to allow organizational learning about future developments.

Mindset change refers to the capability to change established mindsets in decision makers in order to allow ideas derived from new trends to be turned into action (Boe-Lillegraven, Monterde 2015; Amanatidou, Guy 2008, pp. 543–544; Vecchiato, Roveda 2010, p. 1532).

Finally, technology scanning can only operate if it is trusted and supported by decision-makers whose resources are needed to enable participative activities. *Support and trust* pertain to the creation of credibility of the results of technology scanning in the organization (Battistella 2014, p. 64).

Enabling action

CHRISTENSEN mentions the need for entrepreneurial units dealing with disruptive innovations to be independent, and small enough to seize niche opportunities (Christensen 1997, pp. 89–118).

One needs to evaluate whether technology scanning as a primarily information-gathering and analyzing activity can support the promotion of entrepreneurship and decision making in a company.

ANSOFF states that several entrepreneurial activities including development of products and supplier networks can take place already at diffuse information levels (Ansoff 1975, p. 28). As it is the purpose of technology scanning to provide technology-relevant information at the early weak signal level, one can conclude that technology scanning can increase the possibility for entrepreneurial spirit in case of opportunities by delivering unspecific early information in the right way to stakeholders which can initiate early external action.

We define *resilience* as the ability to thrive in *unexpected* situations and bounce back from negative shocks. By *unexpected*, it is implied that the situation was *not forecast as to be expected*, that is, the situation was either *not forecast at all*, or was one of *more potential scenarios deemed unlikely*.

ANSOFF stresses the need for two capabilities to prepare for strategic surprises, one of which is crisis management, as even with diligent foresight capabilities not every strategic surprise could be expected (Ansoff 1975, p. 22). ZOLLI et al determine effective and fast feedback mechanisms to detect when a fundamental change *has already happened* as a key success factor for resilient organizations (Zolli, Healy 2013, p. 11). TETLOCK et al also see this detection of major events after the fact, but before the delayed consequenses as a use for forecasting functions even if the event itself could not be reliably foreseen (Tetlock, Gardner 2015, pp. 241–242).
It thus should be evaluated whether technology scanning can contribute to resilience by quickly detecting such changing circumstances after the fact, before the impact.

Organizational learning
ROSSEL criticizes the linearity of intelligence functions based on the ANSOFFian weak signal theory and instead sees detection of signals as a starting point for organizational learning processes (Rossel 2012, pp. 235ff). KAIVO-OJA also stresses the importance of knowledge management and organizational learning for managing weak signals by directly applying NONAKA's Theory to the domain of weak signals (Kaivo-oja 2012, p. 207).
ANSOFF mentions (lack of) surveillance as a filter to why information does not reach appropriate stakeholders, but also mentality as a blockade to consider information which is relevant, but contrary to the accepted status quo (Ansoff, McDonnell 1990, pp. 58–65).
Drew mentions both a mindset for change and a capability for absorbing new knowledge as key needs to be addressed by foresight activities in order to deal with disruptive technologies (Drew 2006, p. 245).

Support and trust
Creation of trust in the process has been analyzed to be a main requirement to foresight activities, as only trusted processes will have an impact on managers' decisions (Battistella 2014).
For long-range scenario analysis, whether the participating individuals were content with results and process is also seen as a major requirement to ensure the results are used effectively (Mietzner, Reger 2005, p. 233).

Requirements to the functioning of technology scanning
Resource efficiency concerns the time and cost invested into technology scanning activities (Battistella 2014, p. 64).
Low complexity addresses limiting the amount of interfaces, processes and day-to-day business interruptions created by technology scanning activities towards other related functions and management. Generally, complexity is seen as an impediment to the functioning of any management task. We thus conclude that this is also the case for technology scanning, and that any increase in complexity must be offset by larger gains in other requirements.

Summary
Requirement to technology scanning could be identified on three levels: regarding its direct output regarding information quality and accuracy and relevance of predictions. Its impact can be addressed by requiring contributions to organizational learning, decision-making capacities in

light of incomplete and ambiguous information, and safeguarding trust in the process of technology scanning. And its functioning can be ensured by limiting resource usage and complexity.
See Table 1 for a summary of the requirements to technology scanning.

Table 1: Summary of requirements to technology scanning

Requirement	References
Output	
- Accuracy	(Battistella 2014; Tetlock, Gardner 2015; Fye et al. 2013)
o Exhaustiveness	(Rohrbeck, Gemünden 2011)
o Precision	(Wellensiek et al. 2011)
- Relevance	(Mietzner, Reger 2005)
o Specificity	(Ansoff 1975; Mietzner, Reger 2005)
o Time horizon	(Rohrbeck, Gemünden 2011)
o Timeliness	(Holopainen, Toivonen 2012; Ansoff 1975)
Impact	
- Enabling action	(Christensen 1997; Ansoff 1975; Drew 2006)
o Avoiding surprises	(Ansoff 1975)
o Promoting decision making	(Christensen 1997; Mietzner, Reger 2005; Drew 2006)
o Resilience	(Ansoff 1975; Taleb 2010; Tetlock, Gardner 2015; Zolli, Healy 2013)
- Organizational learning	(Battistella 2014; Rossel 2012; Kaivo-oja 2012; Lichtenthaler 2002; Drew 2006)
o Mindset change	(Boe-Lillegraven, Monterde 2015; Vecchiato, Roveda 2010; Drew 2006; Rohrbeck, Gemünden 2011)
- Support and trust	(Battistella 2014; Mietzner, Reger 2005)
Functioning	
- Resource efficiency	(Battistella 2014)
- Low complexity	(Mietzner, Reger 2005; Rohrbeck, Gemünden 2011)

Discussion of Design Options for Technology Scanning

When designing technology scanning activities, various dimensions need to be considered and consistently selected. Obvious design dimensions include methods and sources used to generate information, organization and process of the activities generating the information, and interfaces and communication forms to dispense the information and achieve impact on decision-making.
LICHTENTHALER has analyzed contingency factors influencing the design of technology intelligence. For the organization of technology intelligence, these were the *form of coordination and centralization of technology intelligence* based on decision competences, R&D culture, corporate culture and decision-making processes; *responsible function* based on corporate culture, decision-making process and competence; *organization and communication form* based on heterogeneity and focus on individual versus organizational learning; and *methods and information sources* based on industry segment and addressee of the information (research or development) (Lichtenthaler 2002, pp. 349–351).
AMANATIDOU and GUY have derived influence factors for the impact of national foresight activities, namely "*institutional structures and settings*", "*governance and policy-making culture*", "*socio-cultural factors*" *on public perception of foresight*, and the "*nature of innovation processes*" *and the surrounding innovation system* (Amanatidou, Guy 2008, p. 548).
BATTISTELLA has analyzed the organization of corporate foresight in the dimensions of structure, coordination, decision processes, and control systems (Battistella 2014, p. 62).
In his study on the selection of foresight methods, POPPER divides foresight methods by their *nature* and *capabilities.* Natures in this regard are the three types *qualitative, quantitative* or

semi-quantitative. Capabilities on the other hand are not types, but rather a mixture of the four attributes *creativity*, *expertise*, *interaction* and *evidence* (Popper 2008, pp. 64–65).

LICHTENTHALER categorizes methods into their means of information generation (extrapolative, explorative, and normative) and the induced means of learning (individual or organizational) (Lichtenthaler 2005, p. 395). LICHTENTHALER has also identified three main processes for technology intelligence: the *hierarchical*, *participative* and *hybrid* process (Lichtenthaler 2007, pp. 1114–1122).

TALEB fundamentally denies the predictability of certain classes of events, namely so-called *unknown unknowns*, due to lack of knowledge both about the statistical probabilities of individual highly unlikely and rare events happening (Taleb 2010). He instead urges for exposure to many different unknowns (e.g., innovation projects) in order to hedge risks of exposure to a single unknown. Given the nature of unknown unknowns, it follows to deduct that only methods observing instances of known and validated patterns can provide accurate forecasts. Especially quantitative, evidence- and expertise-based methods are vulnerable to unknown unknowns based on this argument.

FYE et al have shown that quantitative foresight methods produce the best accuracy in terms of timespan *when* a development will occur, whereas expertise-based methods are better at predicting *whether* a development will occur at all (Fye et al. 2013, pp. 1227–1229).

As technology scanning delivers information on subjects outside the scope of the organization, it can only rely on openly available information or on information coming from a network of experts. Generating and validating proprietary information is not an option, as the organization by definition lacks competences in the analyzed fields, otherwise this would be a task for technology monitoring or scouting. Such openly available information generates additional concerns regarding accuracy, which can be addressed by following a set of best practices on validating and filtering the information (Calof, Fleisher 2008, pp. 856–857).

Ensuring the relevance of results of technology scanning could be seen as a requirement to be fulfilled mostly by the communication phase of the technology intelligence process, as this is where the gathered and analyzed information is selected and aggregated. Indeed in business intelligence it is seen as the job of the internal analyst to filter and aggregate the collected information by relevance (Calof, Fleisher 2008, p. 855). On the other hand, such a relevance analysis after the analysis would clearly lock-in the ANSOFFian mentality filter to the accepted views of the organization, as the evaluation is done by internal personnel. Based on the TALEBian argument that events of high impact tend to be very unlikely before their occurrence, most information which would prove very relevant in hindsight would not pass this filter in early stages.

Gathering and analyzing strategically relevant information is seen as not suitable for delegation (Krystek, Müller-Stewens 2006, p. 176). Thus, to ensure the conveyance of relevant information the addressees of technology scanning must either conduct the scanning functions themselves (potentially as a staff function) or be heavily involved in participative analysis processes, rather than being provided only with communication of results.

Methods demanding quantifiable input are seen as less suitable for dealing with the ambiguous and unspecific information available to deliver timely information to strategic processes (Krystek, Müller-Stewens 2006, p. 176).

Studies show that in order to get timely information on relevant signals and trends involvement of employees and bottom-up input collection channels are success factors (Lichtenthaler 2007, p. 1124; Schuh et al. 2014).

ANSOFF states that the less specific information is needed, the more expert opinion and creativity methods are adequate, whereas for very specific information, quantitative modeling and forecasting is better (Ansoff 1975, p. 25).

ANSOFF states that weak signals of potential, yet very uncertain, threats should lead to an increase in strategic flexibility to allow swift reaction (Ansoff 1975, p. 23). This clearly would lead to a rise in resilience in these cases. Thus, methods that derive unlikely but possible predictions would serve to increase the resilience of the organization. While ANSOFF made this point referring to evidence-based methods considering weak signals, from today's perspective it can be argued that this point has even stronger value regarding the use of creativity- and interaction-based methods such as scenario technique.

Decision making has been shown to be driven by concise visualizations of the outcome of information gathering more so than by the generated information itself (Boe-Lillegraven, Monterde 2015, p. 77). Scenario-based methods are known to improve organizational learning and mindset change, at the cost of high resource input and complexity of involving managers from various functions (Drew 2006, pp. 245–247). To derive specific benefits, scenario-based analyses are supposed to filter delivered scenarios by their relevance to decision-making (Mietzner, Reger 2005, p. 233). It has been shown in case studies that mindset change in individuals, from management positions to line engineers, is best ensured by participative processes (Boe-Lillegraven, Monterde 2015, p. 75).

Obviously the more different methods are used and the more information sources are analyzed, the more complex synthesizing and aggregating the resulting information will be and the more resources will be used. Furthermore participative processes add complexity and require slack resources of employees (Lichtenthaler 2007, p. 1124).

In summary, a wide array of technology scanning design options exist, of which long-term looking participative approaches aimed more at delivering impulses rather than specific actionable information are prevalent. Such approaches help organizational learning and mindset change, but do not help much with shaping the actual decision. A complementing factor of short-time oriented detection of outside signals which have so far not been clearly evaluated as relevant seems lacking but necessary to detect disruptions before their impact is felt. Such a complementing approach would be suited to fulfil requirements of relevance to short-term decision making and decision-making capacity in the face of uncertainty, without using too many resources and needing high complexity.

Proposed Concept for a Method for Finding Changed Evaluation Contexts

One conclusion so far is that technology scanning can only deliver accurate results when searching for known patterns of change, whereas unknown patterns of change cannot be anticipated in a proper way. Thus, in order to prepare a method looking for disruptive change, known patterns of such change should be derived and validated.

An important question is whether disruptive change is know-able, i.e. its patterns discoverable and ex-ante predictable. If this were not the case, one could not move disruptive technologies from TALEB's "black swan domain" of unknown unknowns to the domain of predictability (Taleb 2010). Furthermore, if disruption by individual technologies were to be very unlikely even if filtered the best identifiable patterns pointing towards disruption, by TALEB's argument this would entail disruption to be distributed by a "fat-tail" distribution, making prediction of individual disruptions impossible even in the face of observable patterns (Taleb 2010).

CHRISTENSEN has stated that the specific market applications for disruptive technologies are indeed unknowable up front (Christensen 1997, p. 117). Arguments have also been made that the currently low level of predictability of disruptive changes is a sign for disruptive technologies being only ex-post observable and thus their detection being of little practical value (Danneels 2004). On the other hand, time lags between detectable change event and consequences as observed by TETLOCK (Tetlock, Gardner 2015) and operationalized for foresight by VECCHIATO and ROVEDA (Vecchiato, Roveda 2010) offers another potential avenue of response: Observing when a disruptive technology has entered the market by observing the mentioned patterns, and swiftly reacting with pre-formulated response strategies enabled by knowing the patterns of disruption.

Progress has been made by HÜSIG et al both for identifying the disruptive potential of given technologies (Hüsig et al. 2005) and for identifying the potential of a market to be disrupted (Klenner et al. 2013). VOJAK and CHAMBERS have proposed to observe how products are composed and integrated for determining likely sources for disruption (Vojak, Chambers 2004).

Quantitative patterns for identifying emerging technologies are known (Babko-Malaya et al. 2013). As disruptive technologies are usually not characterized by the emergence of wholly new technologies, but rather the adoption of technologies into a market where they enable low-end or niche entry (Christensen 1997), it remains to be seen whether such patterns can be extended to recognize the spill-over of technologies into different fields of application.

Disruptive technologies by definition cannot disrupt a market without business model changes, as the initial innovations making use of them enter a market from a niche or previously unattractive position. This leads to the question of other forms of business model innovation also both help drive disruptive technologies and can be signals for their emergence in a given market. GASSMANN et al have successfully systemized and analyzed business model innovations into observable patterns (Gassmann et al. 2013; Bucherer et al. 2012).

Based on the definition of disruptive technologies, disruptive change comes through changing evaluation contexts, i.e., a change in the needs whose fulfilment the end customer expects from a product and against which the end customer evaluated a product versus its competition and substitutors. As a result, we propose to develop a method to identify changing evaluation contexts. Considering the state of the art on identifying disruptions leads to the realization that only those disruptions can be anticipated which evolve in similar patterns as those which already happened in different industries. Thus we propose a method based on the following analyses:

- An analysis of needs arising from current market megatrends.
- A cross-industry analysis of current technological trends and which needs are addressed by those trends and by what levers.
- An application of these needs to the specific company's market segment with an analysis of how this would affect current market structure.
- A continuous monitoring of applications fulfilling the identified needs with the largest potential of disruption in adjacent market segments (potential substitutors and entrants).

We have conducted such analyses for the wider technological trend of digitalization, and applied it in trend foresight workshops with several industry customers. We have found that such a method aides both at strategy formulation (widening the view of potential action by the company itself to leverage the trend from which potential disruptions emerge) and search field definition (narrowing the scope of technologies which need to be actively monitored by instead focusing on monitoring applications of a certain pattern). The fulfilment of the identified requirements by our concept is outlined in Table 2.

Table 2: Interim assessment of fulfilment of technology scanning requirements by our proposed concept

Requirement	Fulfilment
Output	
- Accuracy	By systematically evaluating needs as they are changing in different industries, patterns of disruption are captured and evaluated. This means that this method will not capture disruptions happening due to completely new needs being addressed which have never disrupted another industry, but will have been validated by having caused disruption before.
- Relevance	Analyzing and matching needs in different industries provides unspecific, yet long-term information on how one's own industry segment might evolve, and the monitoring of the introduction of these needs in one's own industry segment provides timely, short-term and specific information of an emerging disruption.
Impact	
- Enabling action	The concept utilizes the generation of potentially disruptive ideas in one's own market, and thus also allows for filling a pipeline of innovation projects with those ideas deemed to have significant chances of success at low costs of implementation.
- Organizational learning	By collecting ideas from the stakeholders, the concept forces stakeholders to immerse in the mindset of the assessed trend and gives a framework to apply this mindset in the organization's competence fields.
- Support and trust	Specific examples help transfer abstract concepts of disruption into specific credible scenarios. Details on both how a given need managed to gain customer importance in different market segments as well as on how it was technologically possible to address it in a product help showing stakeholders that a given development may not be as far-fetched to their market as they initially expected, and foster embracing the foresight process.
Functioning	
- Resource efficiency	The concept allows for reduced monitoring on a technological level, instead focusing on monitoring applications, for which less technological insight is needed and the need to build up competences in fields alien to the organization is reduced until actual action needs to be taken.
- Low complexity	Compared to the build-up of consistent scenarios for one's own market, the transfer of patterns of disruption from different industries takes less involvement from stakeholders and can be outsourced to consultants to a large extent.

Conclusions

In this paper, we have analyzed requirements for technology scanning with due consideration to the recognition of (potentially) disruptive technologies. The main contribution of this paper has been a derivation of a requirements model for technology scanning considering the dimensions of output, impact and functioning of technology scanning. We have given a broad overview as to how design elements of technology scanning help fulfil these requirements and outlined a concept for a technology scanning design to prepare for disruptive technologies based on these requirements.

Contrarily to common approaches found in practice, our research suggests that in order to use technology scanning as a meaningful strategic tool to react to technology changes of strategic impact outside the company's context, it should (also) be scoped as a continuous short-term analyzer for immediate reaction in a flexible organization rather than or at least in addition of a periodic long-term trend analyzer for strategic planning. While the latter is a necessary and useful activity to fuel innovation pipelines and update search fields to consider further in ongoing technology monitoring activities, continuous but short-term-scoped observation in an integrated framework of technology and market analysis can find signals of major relevant changes which market analysis alone would ignore due to insignificance and technology intelligence alone would not consider due to being out of scope for the company. The quality of information delivered by technology scanning is important to justify decisions and gain trust. However technology scanning may be even more important in ensuring that reaction to changes can be swift and coordinated once these changes go from the prediction stage to the observation stage.

Further research on the nature of disruptive change is also needed. Patterns of disruption such as the ones identified by HÜSIG can help predict disruptions (Hüsig et al. 2005), but an analysis on the likelihood of a disruption actually manifesting itself in the face of these indicators pointing to disruption is needed to determine whether such predictions can form the basis of quantitative analysis and monitoring of disruption in the traditional sense, or have to remain further means of exploratory future analysis like scenarios, as is currently the case.

Likely we will have to concede that not every radical change can be either predicted or even prepared for. Totally new forms of innovation will arise and totally new needs will be discovered from time to time, and the first industry hit by these discoveries will be unprepared. However, in topics like Digitalization one can observe that industry after industry is struggling to adapt to similar innovation patterns as have been witnessed before – and not for lack of trying. We believe that new research can substantially aid practitioners in enabling swift and appropriate reaction when major change is needed while also keeping in mind that steady business evolution when possible is a value in itself for any organization.

Our research will continue with a deeper analysis of the methods and processes which have been employed in various foresight situations, and how these can be combined and adapted to address the requirements identified. Furthermore, we will investigate which requirements are of greater importance to what kind of companies based on the goals these companies have from their involvement with technologies outside their established strategic context.

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