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Unifying weak signals definitions to improve construct understanding*

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ABSTRACT

The research into the perception of early signals, the so-called weak signals, started in the field of strategic planning in the 1970s. Soon, research dispersed into new, specialized fields, such as foresight, sense-making, and entrepreneurial alertness.

Each field used different terms for weak signals and framed the research in its own theoretical and methodological basis, which led to many different descriptions of weak signals.

To put a stop to the growing number of definitions, this paper presents a contrarian approach. The usual simple combinations are likely to omit relevant meaning when underlying definitions only partially overlap. Therefore, his paper used a three-step approach including cluster analysis to unify 68 reviewed definitions into one. Cluster analysis includes more meaning by summarizing data.

The analysis resulted in the defining of weakness in terms of distance to a perceiver's frame of reference. Distance explains the difficulty of perceiving weak signals more clearly than keywords like novel, ambiguous, or ill-defined. Distance also helps to quantify the amount of weakness in signals.

Our approach may help others to find clarity and retain meaning when constructs are fuzzy. Defining weakness in distance opens up comparative studies between signals of various levels of weakness.

1. Introduction

The widespread surprise that accompanied the emergence of the COVID-19 pandemic in 2020 illustrated the difficulty decision-makers have with accurately perceiving the early signals of disruptive developments (Jones, 2020). The same difficulty, namely the strategic surprise about the oil crisis in the 1970s (Baumeister & Kilian, 2016; Issawi, 1978) prompted scientific research into the elusiveness of early signals (Ansoff, 1975).

The research into the perception of such elusive early signals, the so-called weak signals, started in the field of strategic planning in the 1970s (Ansoff, 1979; Molitor, 1977). Soon, research on weak signals dispersed into new, specialized fields, such as foresight, sense-making, and entrepreneurial alertness. Each field used different terms for weak signals such as "minimal sensible structures" (Weick, 1995 p.109) or "strategic issues" (Dutton, Fahey, & Narayanan, 1983 p. 311). Each field framed the research in its own

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theoretical and methodological basis, and this led to a myriad of different terms, definitions and operationalizations of weak signals.

Present-day scholars of weak signals are faced with a body of research that appears consistent, but on second look is not. Their studies often start with summing up several definitions, just to proceed with a definition of their own to clarify what phenomenon is precisely under study. Proper reasoning for individual papers, but for the little cohesion there is in the weak signal field, quite detrimental. This situation represents a serious scientific gap because research results regarding weak signals cannot be compared once the definitions differ fundamentally.

This paper wants to put a stop to the growing number of definitions with a contrarian approach. Instead of choosing a more or less commonly accepted definition, or trying to logically construct one anew, this paper aims to unify 68 reviewed definitions into one. The definitions were decomposed into keywords. Then, hierarchical clustering was used to group keywords into meaningful clusters. Finally, the clusters were combined into a new definition.

Clustering has the benefit that studies from specialized research disciplines can be validated if they reside in the same clusters, thereby unifying the knowledge on weak signals. By providing clear insight and order to the aspects related to weak signals, the unified definition can be a starting point for a new way of defining weakness. If the unified definition were to be adopted in future studies, weak signal research would gain cohesion and subsequent theory building would become much more robust (Fig. 1).

In the next section, a short background of weak signal research is offered. In section 2, the set-up of the literature review that delivered the 68 descriptions is presented. In section 3, the analysis of the description keywords is explained. In section 4, the unifying definition is developed. In section 5, our choice for a rather complex approach is discussed. In section 6, the findings and its implications for future research are presented.

2. Background

It is hardly surprising that managerial weak signal research took off in the 1970s in the wake of an economic shock only a few had seen coming. At the time, a small group of developing countries agreed to cut oil production as a political weapon against developed countries. The oil embargo came as a strategic surprise, even to the experts who did foresee oil price increases (Baumeister & Kilian, 2016; Issawi, 1978). The embargo evolved into a global recession, and this unforeseen impact prompted strategy scholars to theorize about the prevention of the next strategic surprise (Ansoff, 1979).

Prevention of strategic surprises was to be accomplished through a broader awareness of emerging developments, instead of improvement of predictions. Information about an emerging development with a likely future impact was called a weak signal. Weak signals would become stronger over time, when more information would become known (Ansoff, 1979; Mintzberg & Waters, 1982; Molitor, 1977).

The process of perceiving weak signals began when managers became aware of environmental developments, thereby turning a piece of information from the background noise into a signal (Ansoff, 1979; Ilmola & Kuusi, 2006). For instance, the moment that Apple top-manager Steve Jobs presented the first iPhone at MacWorld 2007, the broadcasted launch of the iPhone was just noise. When Microsoft top-manager Steve Ballmer saw a video of the broadcast and became aware of the iPhone, the video turned into a signal of possible market change (Skrinak, 2012).

Literature described the weak signal process in three stages: (1) signal perception; (2) signal interpretation; and (3) signal enactment as a result from interpretation. Perception not only refers to observing information but also to filtering the information at specific moments in the process to reduce the amount of information to process, and to increase its relevance. Interpretation refers to sense-making of information, and enactment refers to deliberate judgments about action-taking based on interpretations.

The perceptual filters are situated in between the process stages. The first filter contains a top-manager's conscious or subconscious decisions on what information to include in the process. The second filter consists of a top-manager's reference frame of beliefs and knowledge on the environment. The third filter consists of the loss of information through communication about possible interpretation and actions (Ilmola & Kuusi, 2006; Lesca, Caron-Fasan, & Falcy, 2012).

The weak signal process stands in stark contrast with the strong signal process. Strong signals are signals that companies deliberately look for as part of their ongoing market and environment scanning for strategy formation. Although both processes have the same three stages of perception, interpretation, and action, the flow of weak and strong signals through the stages differs significantly (see Fig. 2).

Weak signals run the risk of rejection at every stage and are difficult to interpret thanks to their ambiguity and incompleteness.

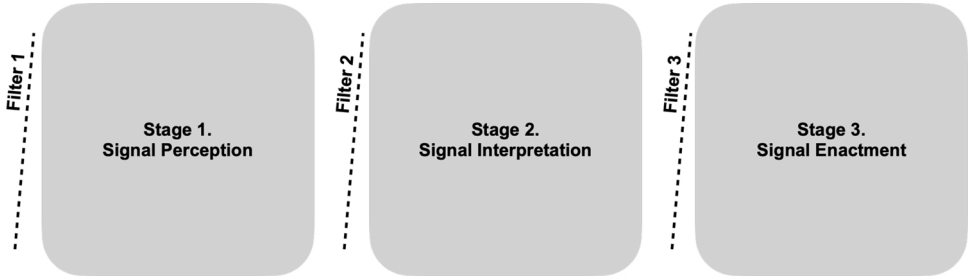


Fig. 1. Perceptual filters and stages in the weak signal process (Ansoff, 1979).

Strong signals are obvious in their relevance and meaning and pass seamlessly from perception into action, thus representing routine decision-making (Aguilar, 1967; Mintzberg & Waters, 1982). Steve Ballmer's rejection of the iPhone as a serious competitor is an example of a weak signal getting discarded during the interpretation stage. At the time, Ballmer interpreted the iPhone as too expensive and inconvenient, because he was unaware of the new subscription business model that would get the iPhone widely adopted (Chang & Bass, 2016).

In the 1980s, two trends started to emerge in weak signal research. Previously siloed research started to mesh under the name of complexity studies, and, simultaneously, new disciplines became aware of their interest in the future and started to contribute (Kuosa, 2011). For instance, linguists explored the role of language as a means of expressing future impacts in the present. Organizational learning perceived the weak signal process as a learning cycle. Information theorists looked upon the process as the transition of information from one system to another. In other words: each discipline researched the process through its distinct lens (Giaoutzi & Sapio, 2013). Both trends led to new viewpoints and findings, but also to increasing fragmentation (Kuosa, 2011).

Ideally, a shared understanding of the terms "weak" and "signal" should form the robust foundation of all weak signal research. Such a foundation would guide theory building to form a coherent body of knowledge. In reality, fragmentation has led to dozens of definitions ranging between rather extreme poles. "Weak" referred to objective traits like industry volatility, or perceived developments like future trend combinations. "Signals" ranged from undefined pressures to specific events. Such fragmentation made it quite imaginable that theoretical contributions were based on distinct weak signal constructs, or, worse, incompatible constructs. When scholars are unaware of construct discrepancy or incompatibility, they build theory as robust as quicksand.

After decades of weak signal research, literature reviews did start to call for clarification of the construct but their efforts did not lead to consensus on a prevailing construct (Carbonell, Sánchez-Esguevillas, & Carro, 2015; Hiltunen, 2008; Saritas & Smith, 2011). Hence this paper. An updated literature review was done to derive a prevailing construct.

3. Literature search

The literature review focused on theoretical and empirical papers about the ways top-managers detect (perceive) and interpret weak signals. In line with other multi-disciplinary reviews, a two-step approach was chosen to develop a composite search result of papers from searches within distinct, yet related disciplines (El Akrouchi, Benbrahim, & Kassou, 2015; Forbes & Milliken, 1999; Rohrbeck & Bade, 2012; Rossel, 2012). The first step was designed to pinpoint the disciplines with substantial research on weak signals. The second step was a keyword search, specific to each discipline.

3.1. The first search step: pinpointing weak signal disciplines

The first step in the literature review was based on the systematic literature search approach developed by Tranfield, Denyer, and Smart (2003). They used a focus sentence to develop a list of keywords to use in search. For our search, we used a focus sentence that describes the weak signal process: "Top-managers perceiving weak signals from the environment for strategy formation." The list of keywords is created from synonyms for each term in the focus sentence. Keywords were found by using the most similar suggestions in the online synonym finder www.Thesaurus.com. For instance, the synonyms for signal were sign, cue, clue, information, knowledge, intelligence, information, issue, and stimulus.

Various combinations of keywords are used for search queries in the Web of Science Database and in SCOPUS. Titles from the query results were read to assess the effectiveness of a query to render sufficient papers on weak signals. Reading the titles led to three observations. First: there is not one combination of keywords (query) that yields more than a handful of relevant papers. Second: very relevant papers only appear in one or two queries, but never in the majority of queries. Evidently, the research is too dispersed into discipline specific jargon to rely on an overarching query. Or, to put it differently, a systematic search using a query did not yield the intended results because of the variety of terms used in different disciplines. Our third observation was important to opt for another search strategy than the systematic search on the basis of a query: Our search indicated that several disciplines emerged that have more papers on weak signals than others. It is exactly this result that inspired us to move from a systematic review to a scoping review (Arksey & O'Malley, 2005). A scoping review explores a concept by investigating how different disciplines describe that concept.

The observations led to two actions. Firstly, the most relevant titles from eight queries were added to a master list of must-have papers. The master list served as a quality check in step two of the search. The majority of listed titles should be returned by a

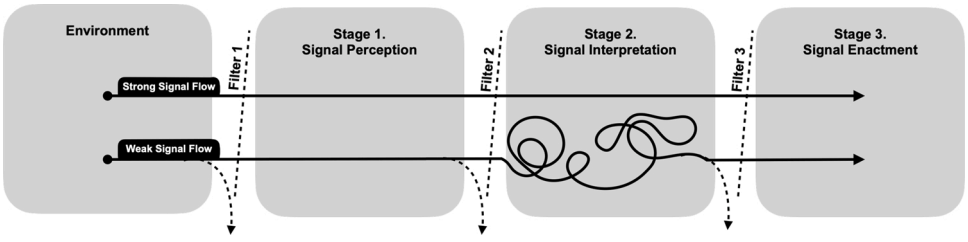


Fig. 2. The flow patterns for weak and strong signals, where strong signals flow seamlessly into enactment, and weak signals are either being discarded or interpreted with relative difficulty.

discipline specific query to qualify as a relevant discipline. The master list is included in Table 1.

Secondly, four disciplines were selected for further queries because they were represented by multiple relevant papers: foresight, sense-making, entrepreneurship research, and strategic choice.

Foresight was selected as it focused on methodologies to improve the weak signal process (Bell, 2001; Rossel, 2012). Sense-making was selected because it focused on the perceptual side of signal detection and interpretation (Maitlis & Christianson, 2014). Entrepreneurship research was selected because of the contrast between its research line of entrepreneurial discovery in SMEs and sense-making's problem driven research line in large companies (Ardichvili, Cardozo, & Ray, 2003). Strategic choice was selected for its focus on strategic issues in uncertain business environments (Child, 1997).

Among the relevant disciplines that were discarded was upper echelon theory because it focused more on management characteristics than perceptions. Research disciplines focusing on lower management levels, objective forecasts, specific environments, or different tasks were also disregarded.

3.2. The second search step: weak signals in four selected disciplines

The second search step consisted of queries within the four disciplines, which were checked against the master list for quality. For example, for the field of foresight the keywords *future** and *forecast** were added. For the field of strategy, the keywords *strateg** and *management* were added. All papers on the master list were in the combined search results. Papers were read and if relevant, hitherto excluded references were found, these were added to the final list of papers.

In total, 152 papers were selected and analyzed: 17 were literature reviews, 54 were theoretical papers and the remaining 81 papers were empirical studies.

Of the 152 papers under review, only 68 papers gave a specific description of weak signals. Most papers with weakness descriptions belonged to foresight (23 papers), strategic choice (20 papers) and sense-making (20 papers). Entrepreneurship research was underrepresented with five papers. In entrepreneurship research, papers foremost refer to weakness without explicitly describing its meaning (see Table 2).

During the review, three routes to find a prevailing weak signal construct were considered. The first route was to induce a new definition on the basis of characteristics of the weak signal process described in the reviewed papers. However, that would mean yet another definition and thus only increase the overall fuzziness in the weak signal field.

The second route was to choose a promising description from the reviewed ones. For instance, the description that was most used already could be a valid candidate. The description most used occurred only five times. And, choosing one description would not contribute to greater validity of the body of research on weak signals. Therefore, this route was also discarded.

The third route was to develop a unifying definition through cluster analysis of keywords, which integrated most meanings in the reviewed descriptions. The commonalities within clusters could provide a means to link and validate studies as long as their description's keywords resided in the same cluster. This route was selected, so statistical analysis was done on the keywords from all descriptions under review instead of descriptions in their entirety.

4. Analysis of the search results

The goal of the paper was to find a unifying definition of weak signals, that could validate studies with partial overlapping definitions. Two conditions had to be met before such a definition could be developed. Firstly, the lack of consistency within the set of definitions should be statistically confirmed. That means that the set of definitions should be heterogeneous and definitions should be different from each other. In that situation a unifying definition did not yet emerge in the current set of definitions and hence a scientific gap is visible that we can fill. Secondly, possible effects of the literature review set-up on the lack of consistency should be controlled for. That means, for example, that the selection of the literature should be wide enough to reveal major aspects of the

Table 1
Master list of papers used to determine the quality of search queries. Times cited was taken from Google Scholar; August 30, 2019.

Master List Seminal Papers	
Reference	Times Cited
Aguilar, F. J. (1967). Scanning the Business Environment. New York: Macmillan.	2.884
Ansoff, H. I. (1975). Managing strategic surprise by response to weak signals. California Management Review, 18(2), 21–33.	2.128
Auster, E., & Choo, C. W. (1994). How senior managers acquire and use information in environmental scanning. Information Processing & Management, 30(5), 607–618.	190
Ilmola, L., & Kuusi, O. (2006). Filters of weak signals hinder foresight: Monitoring weak signals efficiently in corporate decision-making. Futures, 38 (8), 908–924.	159
Lesca, N., Caron-Fasan, M. L., & Falcy, S. (2012). How managers interpret scanning information. Information & Management, 49(2), 126−134.	40
Milliken, F. J. (1990). Perceiving and interpreting environmental change: An examination of college administrators' interpretation of changing demographics. Academy of Management Journal, 33(1), 42–63.	684
Nadkarni, S., & Barr, P. S. (2008). Environmental context, managerial cognition, and strategic action: an integrated view. Strategic Management Journal, 29(13), 1395–1427. https://doi.org/10.1002/smj.717	557
Weick, K. (1979). Cognitive processes in organizations. In Research in organizational behavior. Greenwich, CT: JAI Press.	1.127

Table 2
Number of weak signal descriptions per research discipline.

Research Discipline	Number of papers
Foresight	23
Strategic Choice	20
Sense-Making	20
Entrepreneurship Research	5
Total	**68**

construct 'weak signal'. Only then could a cluster analysis on keywords lead to a sound basis for a unifying definition.

In the next paragraphs, the consistency among different definitions is established, and the effects of review set-up discussed. The final paragraphs describe the clustering of keyword meaning.

4.1. Consistency of definitions

Lack of consistency among selected definitions was statistically confirmed with a frequency table of the keywords present in the 68 reviewed descriptions. The descriptions were tabulated in chronological order to extract and analyze the keywords from the descriptions to find the meanings of weakness. Extraction of keywords began with the first description. Its keywords were used to create column headers. When subsequent descriptions led to new keywords, new headers were created. When descriptions offered keywords synonymous to an earlier keyword, these were added to the header belonging to the first synonym. For instance, the column labelled with the keyword *important* was supplemented with synonyms such as *significant*, *high impact*, and *critical*. In all, 30 keyword columns were created.

A frequency table was made, and keyword frequencies ranged from 43 to 1. The most frequent occurring keyword referred to the phenomenon underlying a weak signal. Phenomena could be an event, trend, or change in the environment. It was present in 63 % of the descriptions (f = 43). The keyword with the second-highest frequency (f = 28) was present in 41 % of the descriptions and referred to the emerging character of weak signals. Many keywords occurred a few times only, 23 out of the 30 keywords occurred in 10 % or less of the definitions that we studied. From the 30 keywords, eight keywords had even a frequency score of 1 (see Fig. 3). If descriptions and definitions of weak signal in the extant literature had been coherent, fewer keywords, a smaller frequency range, and a higher overall average frequency of occurrence for keywords were to be expected.

If we would combine the first four most used keywords, a possible weak signal definition would be '*an emerging phenomenon with significant impact*'. With that definition, however, we would discard the other 26 keywords, some of which do point at relevant aspects of the weak signal construct. One of the main issues with this definition ('*an emerging phenomenon with significant impact*') is that it does not indicate a difference between a strong and weak signal. So, selecting and then combining the keywords that occur most frequently does not lead to a unifying definition of weak signal.

Therefore, we concluded that the weak signal construct was defined inconsistently in the extant literature, meaning that the construct remains vague and fuzzy, and hence there is a need for a unifying definition.

4.2. Controlling for set-up effects

The literature review was performed on papers from the period between 1965 and 2019. The period spanned multiple strategic surprises, such as the oil crisis in the 1970s, the burst of the Internet bubble in the 1990s, and the financial crisis starting in 2008. Since strategic surprise gave the research into weak signals its momentum, it may also have framed the way weak signals were described. If that were the case, the construct investigated in the aftermath of the oil crisis may be different from that investigated after the financial crisis. The degree of difference is important here. If subsequent definitions are fundamentally different, unification becomes unfeasible. If that were the case, constructs may be incompatible from one period to another, rendering unification illogical. If, however,

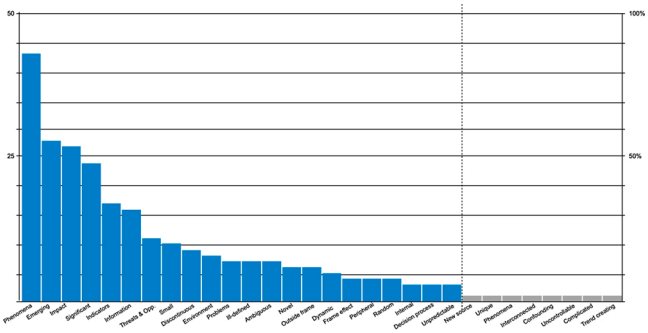


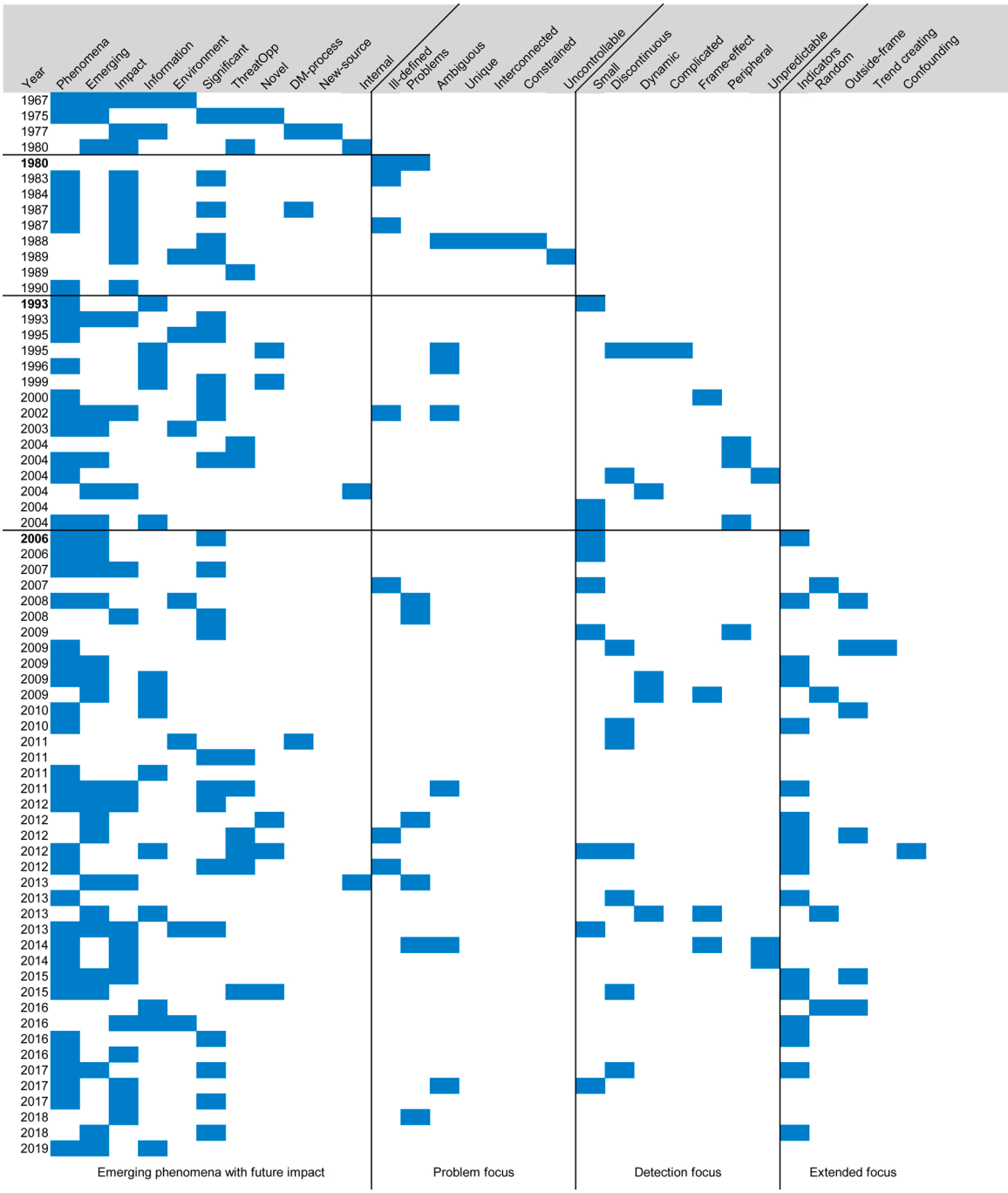
Fig. 3. Frequencies of keywords in weak signal descriptions; eight keywords with frequency (f = 1) were not included in hierarchical clustering.

definitions do evolve by emphasizing different aspects of the same construct over time, unification becomes possible.

Furthermore, the reviewed papers came from four research disciplines (foresight, sense-making, entrepreneurship research, and strategic choice). It was assumed that the disciplines would have a significant overlap, which would mean that constructs were compatible. If disciplines did not overlap significantly, constructs may be incompatible from one discipline to another, again rendering unification illogical.

Our analysis can indicate whether a unifying definition of weak signal is feasible. If time-span and discipline were a significant influence, a cluster analysis would show this with the clustering of keywords in periods, and/or in disciplines. The bigger such

Table 3
Keywords ordered per year of first occurrence (blue cells refer to keyword presence). (For interpretation of the references to colour in this Table legend, the reader is referred to the web version of this article).



influence of time and discipline the less feasible a unifying definition.

4.3. Time-span

The keyword frequency table gave quick insights into temporal effects. The table rows represented the descriptions in chronological order, and the columns represented the occurrence of new keywords in chronological order. Cells were colored blue when a description contained a certain keyword, thus creating a color pattern over time (see Table 3).

The table's color pattern indicated that the focus of weak signals changed slightly through the years. Before 1980, weakness mostly referred to emerging phenomena with future impact. During the 1980s, additional keywords focused on the problems of weak signals like its ill-defined sources, problem focus, or uncontrollable impact. During the 1990s, new keywords focused on why signals were so difficult to detect. They were small, dynamic, in the periphery, and so on. From the 2000s, keywords focused on the capture of weak signals in their earliest stage. For instance, weak signals started to refer to indicators of a phenomenon instead of the phenomena themselves or signals still outside the frame (see Table 3). The emerging and disappearance of keywords did raise the suspicion that the descriptions of weak signals might have evolved into distinct meanings over time.

Another observation indicated the existence of a hitherto implicit bias in weak signal research. From the outset, weak signals were seen as an emerging phenomenon. Their weakness would reduce over time, as more would become known. The emergence was described in five levels of knowledge that ranged from "merely sensing" to "knowledge of concrete outcomes" (Ansoff, 1975). Although the keyword "emerging" was included in many descriptions, keywords referring to levels of weakness like "peripheral" or "outside frame [of reference]" were only found in studies after 2004. If most studies were referring to "weak" as the opposite of strong instead of multiple levels, "weak" was likely referring to mixed levels. This would imply a bias for less weak, or stronger signals.

The results from Table 3 also indicate why just combining the four most used keywords (see Fig. 2) into one definition ('*an emerging phenomenon with significant impact*') would not result in a unifying definition but would rather result in a definition reflecting the early ideas on weak signals and ignoring more recent thoughts on the construct.

4.4. Multi-disciplinary overlap

Foresight, sense-making, entrepreneurship research, and strategic choice each had a distinct research line on managerial perceptual processes in the weak signal category.

Foresight described weak signals as ambiguous indications of forthcoming impactful disruption (Ansoff, 1975), and viewed the sense-making process as a series of perceptual filters that decreased the number of signals processed. Some signals remained unseen, and others were ignored or rejected when they did not match the belief system of the observers (Ghanizadeh Poshtekooh, 2014; Goosen, 2014; Holopainen & Toivonen, 2012; Ilmola & Kuusi, 2006). The discipline contributed significantly to developing formal methods to overcome the limiting effects of perceptual filters (Carbonell, Sánchez-Esguevillas, & Carro, 2017; Dhami, Belton, & Careless, 2016; Fritzsche, 2017; Li, 2017; Smith, Collins, & Mavris, 2017).

Sense-making was the process described for the perception of a type of strategic challenges called wicked problems (Daft & Weick, 1984; Maitlis & Christianson, 2014; Weick, 1979). Definitions of wicked problems were by no means clear and uniform, but referred foremost to ambiguous, incomplete and unanticipated information (Daft & Weick, 1984; Kiesler & Sproull, 1982; Starbuck & Milliken, 1988). The main difference between foresight and sense-making was the direction of reasoning: foresight had a prospective view and sense-making a retrospective.

Entrepreneurship research focused on the factors that influenced the process of opportunity discovery. Opportunity discovery consisted of new fits between external information and company resources. The external information in this field was described as unexpected. Signal meaning depended on individual interpretation, which seemed to point to signal ambiguity (Shane, 2000).

Strategic Choice was the process of organizational learning with which a company adapts to changes in its environment (Child, 1997). Strategic choice pointed out a shortcoming of sense-making with regards to weak signal analysis. Sense-making focused solely on threats, while strategic choice showed that threats were interpreted differently, led to a different sense-making process, and resided in a different mental schema than opportunities (Anderson & Nichols, 2007; Jackson & Dutton, 1988; Jennings & Lumpkin, 1992). The link between foresight and strategic choice was direct, because the disciplines shared explicit references to the original weak signal descriptions to define stimuli (Ansoff, 1980; Dutton & Jackson, 1987). Thus, next to foresight's weak signals and sense-making's problems, the literature review should include research on opportunities to raise the generalizability of the analysis results.

After analysing the definitions, as they are created in the four distinct disciplines, we could have decided to combine aspects from each of these disciplines. A possible combined definition would then be: *Weak signals are ambiguous, incomplete and unanticipated indications of forthcoming impactful disruption or forthcoming opportunities that may require disruption.* This attempt to define weak signals may be an improvement compared to the previous attempt in this article using keywords ('*an emerging phenomenon with significant impact*'). The improvement is visible in the aspect of '*ambiguous, incomplete and unanticipated indications*' and in the combination of both threats and opportunities. However, a fundamental aspect of weak signals is still unclear in this second definition. Why are weak signals so often ignored and filtered out? Is that just because the ambiguous, incomplete and unanticipated nature of the indications? We will show how further analysis can lead to a more clear and unifying definition.

4.5. Effects of time-span and multi-disciplinary overlap

A cluster analysis was done to check if the inconsistency in the construct definitions was an effect of the combination of four

research disciplines or the time of publication. If there were an effect of combined disciplines, the inertia within and between clusters would be caused by time-span and/or disciplines. A two-step hierarchical cluster analysis using Ward's criterion was performed in R (Team, 2019).

In the analysis, signal descriptions were treated as observations of categorical data (N = 68), and keywords as variables. The eight keywords with the lowest frequency (f = 1) were not included in the clustering. The research discipline labels were included as a supplementary qualitative variable. The number of clusters was set to four to force the emergence of a discipline per cluster or a period theme as a group of partitioning variables. Two results indicated that the clusters did not represent disciplines. Firstly, the analysis returned four clusters, but three clusters contained mixed disciplines. The smallest cluster was supposed to represent the five descriptions from entrepreneurship research. Instead, it contained three descriptions from strategic choice. Secondly, as many as nine variables were most responsible for the partitioning. These variables described three aspects of a signal: its origin, the type of information that a signal held, and its effects (see Table 4).

The variables describing a signal's origin included the company internally as well as the perceptual periphery. Variables describing the type of information included phenomena as well as perceptions. Variables describing effects included effect on the perceiver's reference frame as well as the perceiver's company. The types did not overlap with the period themes logically inferred from Table 3.

Hence, neither time-span nor discipline were responsible for inconsistency and hence fuzziness in weak signal definitions. Instead, it resulted from individual variation in meaning. This outcome made it plausible that the weakness concept could benefit from clarification, if significant clusters of meaning would emerge.

4.6. Unification of keywords though clustering

The frequency table was used for a second cluster analysis. This time, inertia gain was used as the criterion to determine the number of clusters. A dendrogram was used to interpret the quality of the partition. Six clusters were chosen.

Visual inspection of the dendrogram showed that the clusters were not equal in size. This was expected because of the fuzziness of the descriptions and the presumed bias for stronger signals in the research.

Despite their size, the clusters represented the descriptions in a meaningful way because they were constructed from single categories of the keyword variables. With their unique combination of variable categories, clusters summarized the descriptions that explained most of the variance in the descriptions. The new definition was to be developed from these summaries so that it could become apparent if and how reviewed or future studies connected to each other and the new definition. The summarization is presented first, and then the development of the definition is described in section 4.

Table 5 presents the sets of significant keywords ($p < .05$) and their categories per cluster (see Table 5).

4.7. Summaries of clusters

The first cluster summarized descriptions that referred to weak signals as phenomena in the environment. This cluster did not contain descriptions with keywords indicating novelty, threat and opportunity perception, seeming randomness of information, or from the periphery (outside the focus). This was interpreted as an indication that the studies at the root of cluster 1 had findings particular for less weak signals from the environment.

The second cluster represented weak signals that should lead up to the decision-making process. This cluster referred implicitly to signals that were already assessed as relevant, but not yet analyzed.

The third cluster represented weak signals that had unpredictable outcomes. This cluster referred implicitly to signals that were assessed and classified as relevant, but their development or impact was impossible to analyze and could be guesstimated at best.

The fourth cluster represented weak signals in the shape of threats and opportunities that were new to the perceiver because they had remained outside the perceiver's focus. These were the weaker signals that were newly perceived, not necessarily intrinsically novel.

The fifth cluster represented weak signals that originated from a weakness of the company itself, not from the environment.

The sixth cluster represented weak signals that consisted of seemingly random bits of information which disrupted the reference frame of the perceiver once interpreted as a pattern. These were weaker signals that were created during interpretation.

Table 4
Lowest probabilities describing the partitioning of the cluster analysis.

Partitioning				
Variable	Description	Type	p Value	df
Internal	Signal originates from within company	Origin	< .01	3
Peripheral	Signal originates from perceptual periphery	Origin	< .01	3
Random	Signal consists of random information	Info Type	< .01	3
Threat/Opportunity	Signal consists of threats and/or opportunities	Info Type	< .01	3
Novel	Signal consists of novel information	Info Type	< .01	3
Phenomena	Signal consists of environmental phenomena	Info Type	< .01	3
Dynamic	Signal consists of multiple perceptions over time	Info Type	< .01	3
Impact	Signal will have significant impact on company	Effect	< .01	3
Frame-effect	Signal disrupts frame once interpreted	Effect	< .01	3

Table 5
Variable categories describing the clusters.

Cluster Analysis Weak Signal Descriptions (N = 68)					
Cluster	Variable	Category	Proportion in cluster	p Value	Characterization
	Phenomena in environment	y	79.55	< .01	
	New to perceiver	n	69.36	< .01	
1	Threat or opportunity	n	70.18	.01	Less weak signals from the environment
	Seemingly random signals	n	67.19	.02	
	From periphery (outside focus)	n	67.19	.02	
2	Leading up to decision-making	y	100.00	< .01	Assessed signals, to be analyzed
3	Unpredictable outcome	y	100.00	< .01	Analyzed signals
	New to perceiver	y	100.00	< .01	
4	Threat or opportunity	y	63.64	< .01	Detected signals outside the focus
	From periphery (outside focus)	y	100.00	< .01	
5	From within company	y	100.00	< .01	Internal signals
	Seemingly random signals	y	100.00	< .01	
6	Disrupts frame once interpreted	y	50.00	< .01	Weak signals created during interpretation
	Set of signals (pattern)	y	40.00	< .01	

The clusters separated the descriptions, and thus the studies to which descriptions belonged. Descriptions were separated in signals that varied in source (external or internal environment), strength (less weak or weak), and process stage (detection or interpretation). The separation of clusters could be visualized with a process map (see Fig. 4).

5. Developing the definition

The clusters of keywords were easily to interpret and taken together, they described distinct aspects of the meaning of "weak". Meaning emerged from the characteristics of the information belonging to a signal, the origin, occurrence and level of weakness, and the weak signal process flow. We will discuss the aspects and summarize meaning into definition components.

5.1. Information characteristics belonging to a signal

Weakness referred to three characteristics of the information that the signal represented: novelty, strategic relevance, and unpredictability. Signals were novel to the perceiver during perception (cluster 4) or interpretation 6). Signals seemed to have an intrinsic strategic relevance. Noise only became a signal when it was interpreted as a nearly missed threat or opportunity (cluster 4), when it disrupted established strategic notions about the environment and/or the company (cluster 6), or when it was perceived as important enough to require analysis (cluster 2). The unpredictability of impact could cause weakness regardless of the initial strength of the signal (cluster 3).

From clustering, we were tempted to conclude that novelty, strategic relevance, and unpredictability were synonyms for weakness. Logically though, this did not hold. For instance, in the 1980s, the invention of the Internet may have been a strong signal to its inventors and early adopters, but it was simultaneously weak (novel) to the general public. From 1995 onward, its strategic relevance could become apparent when browsers like Internet Explorer became the norm, but video rental companies like Blockbuster did not see it. So, a signal that isn't novel, but does have strategic importance, can only be perceived as weak by those who sense that it may become a threat or opportunity. Furthermore, the Internet's impact became evident even later, when Internet driven business models like Netflix (founded in 1997) emerged (Harraf, Soltwisch, & Talbott, 2016; Schulte, 2013). Therefore, novelty, strategic relevance, and impact unpredictability on their own did not solely predict weakness.

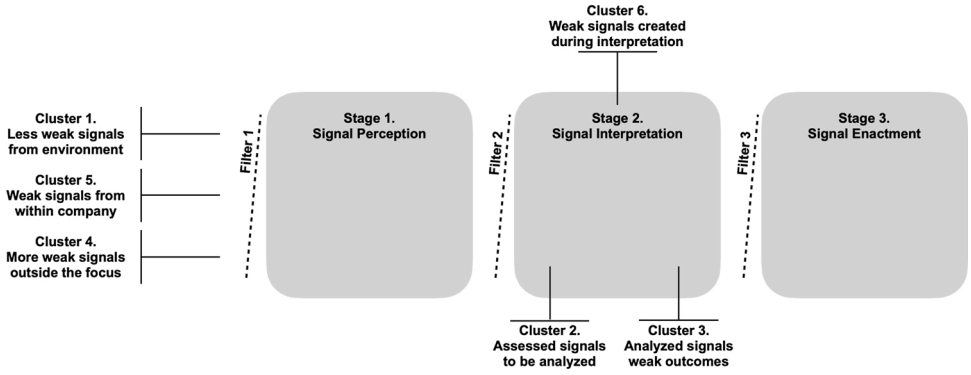


Fig. 4. Clusters mapped onto the process.

During the COVID-19 pandemic lockdowns, the Internet gained immense importance as brick-and-mortar business shifted to online, and e-commerce shifted to online third-party marketplaces (Fredriksson, 2021). This sudden large increase in Internet usage was novel, strategically relevant, and unforeseen at the same time, even though the Internet itself is now well-known, used all over the globe, and its strategic relevance obvious.

Novelty, strategic relevance and impact unpredictability alone or as a group are not sufficient to predict weakness, but without them signals weakness does not occur. When information is not novel, or in other words, the information is already known, then the signal it emits is strong. When information is not strategically relevant, it gets discarded and does not become a signal. When signal impact is obvious, the signal is strong enough to take action upon. More likely, these characteristics are important conditions for weakness to occur, but they are not the essence of weakness.

Novelty, strategic relevance and impact unpredictability are central to the emergence of new information which, over time, turns a weak signal strong. At first, a signal is so novel that it can only be sensed. There is only the conviction that a disruption will possibly occur; it cannot be put into words. At the second level, the source of disruption is identified, followed by understandings of the nature, gravity and timing of impact (Ansoff, 1979). Signals gain strength as more about it becomes known and thus a signal becomes easier and easier to interpret. In reverse, the weaker the signal, the more difficult to interpret and recognize, because less is known to its perceiver. Thus, the essence of weakness is the lack of knowledge of the perceiver about a signal.

When a perceiver has no knowledge about a signal, it is completely novel and difficult to place (Ilmola & Kuusi, 2006). It is seen as odd (Hiltunen, 2008), ridiculous (Kuosa, 2010), atypical (El Akrouchi et al., 2015), or redundant (Cevolini, 2016). Such signals would disrupt the existing knowledge of the perceiver (Maitlis & Christianson, 2014) and hinder the adjustment of knowledge to accommodate the signal (Cevolini, 2016). In other words, such a signal is different from the existing knowledge and does not easily fit into the existing body of knowledge. In cluster analysis, the difference between clusters is measured in distance: the larger the distance, the more different the clusters are. This implied that future research may be able to measure weakness in terms of distance: the weaker the signal, the larger the distance to the perceivers reference frame.

Hence, weak was defined as being “distant to the perceiver’s reference frame”.

Distance covered novelty and unpredictability in the sense of unforeseen, but not strategic relevance. Strategic relevance kept signals in the process, and thus should be part of the definition.

5.2. Origin, occurrence and level of weakness

Three places of origin appeared from clustering: the environment (cluster 1), within the company (cluster 5), or from interpretation (cluster 6). This paper was focused on signals from the environment, so the meaning from cluster 1 and 6 was retained for the definition.

Weakness occurred at two process stages. At the perception stage, when novel (distant) signals were perceived (cluster 4), and at the interpretation stage, when new random bits of information were combined into new signals (cluster 6), or when the impact of a strong signal appeared unpredictable or unexpected (cluster 3). Weakness in the perception stage was covered by the idea of distance. Weakness in the interpretation stage was covered as one of the places of origin.

At least four levels of weakness surfaced from clustering. The first or weakest level referred to signals that were completely outside the focus of the perceivers and therefore in their eyes new (cluster 4). The second, slightly less weak level referred to the signals that were heard of, but had not been interpreted yet (clusters 1 and 5). Then came level three, the signals in the interpretive stage that were assessed as relevant, but not yet fully analyzed (cluster 2). Finally, at level four, came the signals that had been perceived, assessed, and even analyzed, but still led to uncertain outcomes (cluster 3).

This implied that signals could also become weaker after passing the second perceptual filter, not just stronger. Increasing weakness was the case when seemingly unconnected signals were combined into a new pattern, which possessed higher weakness than the signals it originated from. For instance, managers familiar with the platform economy could view the developing platforms as a less weak signal, until they combined it with the platform usage of former customers. The definition should name both stages so that possible changes in weakness levels or the occurrence of weakness during interpretation could surface in research. Hence, “either detected in the environment or created during interpretation” was included in the definition.

This part of definition fits the existing idea of a signal as a three part model, in which the phenomenon, its representamen in information, and its interpretant together form the signal (Carbonell et al., 2015; Hiltunen, 2008). Signal weakness in terms of the phenomenon would refer to its origin: the real world. Signal weakness in terms of the representamen would refer to its first occurrence in information. Signal weakness in terms of the interpretant would refer to its level of dissimilarity to the information already known by the interpretant.

5.3. Weak signal process flow

Literature had divided the weak signal process in a model containing filters and stages. Some studies separated the interpretation stage in assessment and analysis. When separated, the first step entailed the prioritization of information in terms of relevance, urgency, or actionability. The second step involved the analysis of the meaning of the information for the company (King, 1984; Schwenk, 1984). This separation was mirrored by two clusters: the assessment of the relevance or strategic importance of a perceived signal (cluster 2) and the analysis of assessed signals (clusters 3 and 6).

The separation of the interpretation stage into assessment and analysis may have an interesting implication for the weak signal flow. It has been argued that signal discards occurred at the perceptual filters in between the stages (Ansoff, 1975; Ilmola & Kuusi,

2006), but it is quite imaginable that signals can be discarded within a stage: when a perceived signal is assessed as not relevant, urgent, or actionable enough.

Although the disaggregation of the interpretation stage may lead to interesting findings in weakness levels, this aspect seemed more suitable to guide operationalizations instead of the definition of a signal. Hence, the disaggregation itself was not included in the definition.

5.4. The new definition

While discussing the characteristics of the information belonging to a signal, the origin, occurrence and level of weakness, and the weak signal process flow, we were able to pinpoint notions that are important in a definition of weak signal. We found that noise can become a signal when a piece of information is perceived. Signals are perceived in information from the environment or in the combination of bits of signals during interpretation. Signals will only remain in the process if they are perceived as strategically relevant. Signals are weak when they are distant to the perceiver's reference frame. Distance also incorporates a measure of the levels of weakness. Taken together, these notions make the new definition:

A weak signal is

> ***A perception of strategic phenomena detected in the environment or created during interpretation that are distant to the perceiver's frame of reference***

The definition reflected the collective wisdom of the 68 studies on whose descriptions it was based.

6. Discussion of the method

To capture the definition of the substance that makes a weak signal weak, a literature review of four research disciplines was performed. The search resulted in a collection of 152 papers, of which 68 papers gave a specific description of weak signals. The variety of attributes in the descriptions made it abundantly clear that weakness was not an obvious construct. Therefore, the reasoned choice for an existing definition or the simple combination of a few common attributes one often finds in papers on weak signals simply did not do the construct justice. A more complex analysis was required: not too simple that significant meaning was excluded, and just complex enough to capture only the necessary. In other words, a competent definition.

The analysis of the definitions consisted of three steps to find the simplest method to arrive at a competent definition. Together, the three steps exhausted the available options. The steps built on one another; each step slightly more complex than the previous one. Per step, a reasoned definition was created from the most important part of the data. Then, the remaining data was checked for meaning with a falsification question. If important meaning was left out of the definition, the next step in the analysis was taken. The steps, criteria and falsification questions are included in the decision diagram pictured in Fig. 5 and explained in more detail in the following paragraph (see Fig. 5).

In the first step descriptions were turned into a series of keywords, which were then tabulated into a frequency table (see Fig. 5, step 1). A provisional definition was formed from the keywords with the highest frequency, but this omitted important attributes from the

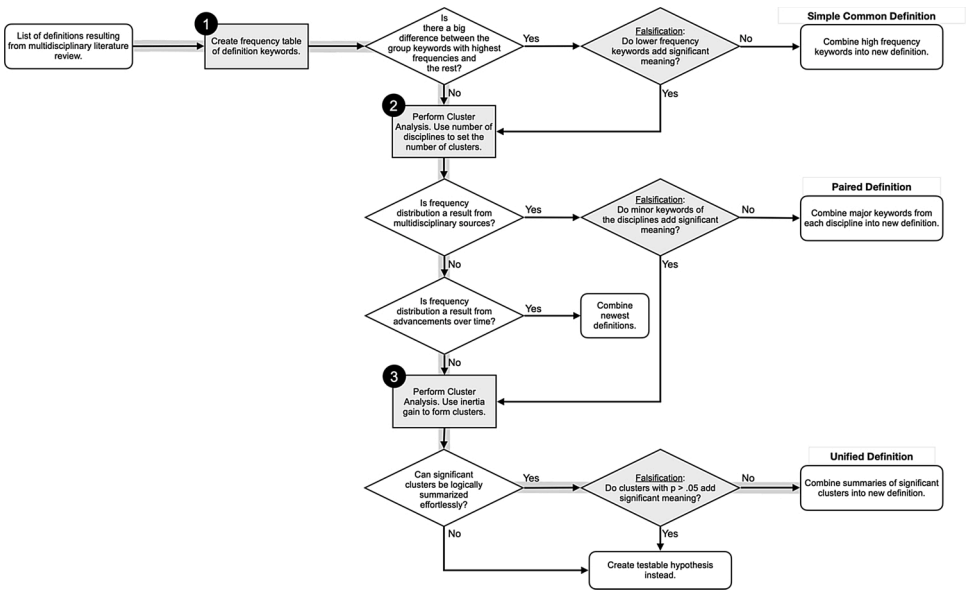


Fig. 5. Steps in the reviewed definitions analysis decision diagram; the arrows for the path followed for the unified weak signal definition are highlighted in grey.

keywords with lower frequencies. Therefore, a simple combination of the most common keywords was inadequate.

In the second step, a cluster analysis was performed on the frequency table (see Fig. 5, step 2). The cluster analysis was done to let two possible effects of the literature review set-up emerge. Firstly, by limiting the number of clusters to the number of reviewed disciplines, the analysis would show if the variation in keywords was an effect of the multidisciplinary character of the review. If so, the definition could combine the highest-ranking keywords per discipline. However, cluster analysis showed that this was not the case. Secondly, by including the year of publication, the analysis would show if variation in keywords was an effect of advanced insight over time. If that was the case, a mere combination of the newest definitions would be in order. However, a temporal effect was not found.

In the third step, a second cluster analysis was done (see Fig. 5, step 3). This time, inertia gain was used to define the clusters. Fortunately, the resulting significant clusters could easily be summarized and captured the phenomenon sufficiently.

The three-step analysis is an original approach born out of necessity. It was only developed because the weak signal construct that emerged from the review was so very unclear. Our approach and definition were created in an effort to understand and bring order to the aspects and disciplines related to weak signals. As such, both serve as a starting point for a more precise way of defining and studying weak signals of various levels of weakness.

For example, any of the reviewed definitions would categorize new information about an emerging and seemingly significant trend in the environment as a weak signal, but our new definition would add precision by stating its distance to the perceiver's prior frame. If the trend was unsimilar to any information in its perceiver's prior frame, the signal would be very weak. If the trend surfaced as the result of a new combination from information already in the prior frame, it would be weak, but not very. If the trend was highly similar to information in the prior frame, it would be strong.

With possible effects of a multidisciplinary review method over a 50+ year time-span out of the way, we contribute construct ambiguity to its age. In terms of theory building, 50+ years is short. Like other nascent research disciplines such as decision-making under uncertainty or behavioural economics, weak signal analysis is still busy defining its constructs and developing its methods. Emerging disciplines like these would benefit from the three step approach for their definitions, to avoid leaving out essential characteristics that would not surface in simple keyword combinations.

7. Implications and future research

The scientific implications of the new definition are threefold. Firstly, cluster analysis summarized the keywords into six clusters that explained the variance, while retaining most of their meaning. The keywords from the reviewed descriptions are traceable to a cluster. The new definition was built on the clusters and so formed a framework to which the descriptions can connect. Shared keywords can help to validate findings, and also to separate findings that are only seemingly connected. This way, weak signal research can be organized in a meaningful framework of validating studies.

Secondly, the new definition allows for the proper attribution of results in weak signals studies. Hitherto, in empirical work the level of perceived weakness was only rarely explicitly determined. Instead, weak signals were retrieved from the sample or outside experts, and may or may not have been weak in the eyes of the study participants. Measuring perceived frame distance requires that researchers make sure that their stimuli are indeed perceived as weak by the sample of study participants. This avoids the attribution of strong signal findings to the weak signal process.

Measuring signal weakness by merely asking participants about its novelty is likely to lead to biased answers as managers are prone to avoid being seen as ignorant, especially when it is their job to know, and ignorance has strategic costs. By framing novelty as distance, bias may be reduced, and other ways of measuring open up. Research into psychological distance has had robust results with mapping relative distances between information and their interpreter's knowledge in spatial ways, or ratings their overlap (Chen & Li, 2018). Validation of such methods in weak signal research would make a good next step.

Thirdly, viewing weakness in terms of distance can extend weak signal research from foresight into decision-making. When weakness is the distance dimension of information in and outside the frame of reference, then both can be expressed in numbers such as available facts. The smaller the distance, the denser (higher number of facts) and the more concrete the information is likely to be. The larger the distance, the less dense, and the more abstract the information is likely to be.

These possible relationships turn distance into a strategic dimension. When there is more concrete information, interpretation is easier and likely to lead to opportunistic decision-making. When information is more abstract, it is harder to make it actionable, and decision-making is likely to be postponed or to be more conservative. Thus, distance can reverse decision-making from opportunistic to conservative and back, which means that distance can be used as a parameter in the evaluation of decision alternatives (Fiedler, 2007).

This also has exciting managerial implications because it points to distance as a means to objectify the perception of weak signals as well as reducing risk aversion caused by anxiety about uncertainty and change. As such, distance supports the collaboration in diverse teams because it can connect viewpoints otherwise negatively perceived as, for instance, risky, untrue, or subversive. And so, top-managers should include perceived frame distance as a criterion for focused search (larger distance) and for decision-making (smaller distance), as well as frame viewpoints during interpretation in terms of relative distance.

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