Current Status and Implications of Disruptive Technology Identification Methods: Postprint

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Date: 2023-07-26T00:00:00+00:00

Abstract

[Purpose/Significance] Disruptive technologies can transform traditional production models and consumption structures, leading to tremendous changes in the industrial landscape. Identifying potential disruptive technologies helps to seize the commanding heights of science and technology, thereby gaining a first-mover advantage in technological competition.

[Method/Process] Through subject retrieval and citation backtracking, literature was collected to review the main identification methods for disruptive technologies at the current stage.

[Results/Conclusion] It is found that the choice of methods is closely related to researchers' disciplinary backgrounds. Based on researchers' main research fields, identification methods are divided into four categories: library and information science, engineering management, economic research, and the Christensen school. On this basis, a comparison of identification methods is conducted across seven dimensions, revealing three problems in existing methods: excessive reliance on expert evaluation, insufficient specificity of identification criteria, and poor effectiveness in forward-looking identification, among which insufficient specificity of identification criteria is the core issue. In view of this, subsequent research should continuously explore and improve evaluation methods for technological disruptive potential from multiple perspectives.

Full Text

Preamble

Disruptive Technology Identification Methods: Current Status and Implications

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Abstract: [Purpose/Significance] Disruptive technologies can transform traditional production models and consumption structures, causing dramatic changes in industrial landscapes. Identifying potentially disruptive technologies helps seize the commanding heights in science and technology, gaining first-mover advantages in technological competition. [Method/Process] Through subject retrieval and citation backtracking, this study collected literature to systematically review the main identification methods for disruptive technologies at the current stage. [Result/Conclusion] The selection of methods is closely related to researchers' disciplinary backgrounds. Based on their primary research fields, methods are divided into four categories: library and information science, engineering management, economic research, and the Christensen school. A seven-dimensional comparison of identification methods reveals three existing problems: over-reliance on expert evaluation, insufficient specificity of identification criteria, and poor performance in early identification, with the lack of specific criteria being the core issue. Therefore, future research should continuously explore and improve evaluation methods for technological disruptive potential from multiple perspectives.

Keywords: disruptive technology; identification method; review

1. Review of Disruptive Technology Concepts

Disruptive technology was first introduced by C. M. Christensen in his 1995 article "Disruptive Technologies: Catching the Wave," where he categorized technological innovation into sustaining innovation and disruptive innovation based on market transformation, arguing that the key difference lies in whether the innovation possesses "market-transforming potential" [5]. Subsequently, Christensen' s book *The Innovator' s Dilemma* refined disruptive technology theory, positing that many well-managed, established companies fail due to disruptive technologies. The technologies being disrupted can be termed incumbent technologies [1]. In Christensen' s view, product functionality forms the basis of competition, and the most important prerequisite for disruptive technology emergence is functional oversupply by incumbent technologies. When two or more products can satisfy the functional needs of most consumers in a market, competition shifts from functional competition to other dimensions such as reliability, convenience, and price. Because large companies' existing technological systems are often incompatible with emerging disruptive technologies, these new technologies must align with small firms, establish a foothold in low-end markets, and eventually move upmarket to complete the disruption [1].

Building on this fundamental concept, subsequent researchers have developed their inquiries along three main directions. The first direction affirms and empirically validates Christensen' s definition, as seen in studies by S. Hüsig et al. [6] and A. Stoiciu et al. [7] in local area networks and energy sectors, respectively. The second direction elaborates on technological impact, with McKinsey defining disruptive technology as having tremendous potential to transform human life, while A. Keller et al. [8] and D. Nagy et al. [9] argue from a market impact perspective that disruptive technologies change market standards and consumer expectations by providing new functionalities that incumbent technologies cannot satisfy. Wang An et al. [10] approach from the angle of industrial production impact, contending that disruptive technologies enhance production efficiency and drive transformation in production methods. The third direction focuses on technological origins, with E. Danneels [11] arguing that disruptive technologies stem from cross-disciplinary technology combinations, while A. Ganguly et al. [12] and V. Govindarajan et al. [13] propose that sources can be either combinations of existing technologies or entirely new technologies. In summary, disruptive technology can be understood as an innovation process influenced by other fields and capable of triggering massive changes in industrial structures.

Disruptive technology identification primarily addresses the challenge of screening technologies with disruptive potential from a range of options. It differs from typical technology foresight, which often focuses on technology' s own development and evolution, whereas disruptive technology identification emphasizes whether a technology can transform industries. More specifically, successful disruptive technologies often disrupt established technological trajectories within industries, leading to their decline—a level of destructive impact rarely seen in previous technology foresight efforts, which constitutes a significant aspect of disruptive technology identification' s importance.

2. Research Approach and Literature Collection

The following analysis proceeds in five steps: First, collect literature on disruptive technology identification through subject retrieval and citation backtracking. Second, systematically review existing methods and classify them into four categories based on researchers' disciplinary backgrounds. Third, compare the advantages and disadvantages of each method across multiple dimensions and discuss their current status and future trends. Fourth, summarize the overall research status of identification methods and analyze major problems. Fifth, propose reasonable suggestions based on these problems.

To comprehensively collect relevant literature, this study employed both subject retrieval and citation backtracking across different databases. For Chinese literature, CNKI, Wanfang Data, and the National Engineering Technology Library were used; for English literature, the Web of Science Core Collection was searched. The retrieval process involved three steps: 1) Initial subject retrieval: Chinese database search strategy used (disruptive technology OR destructive technology OR breakthrough technology OR disruptive innovation OR destructive innovation OR breakthrough innovation). For English databases, the unambiguous term (("disruptive innov" *) OR (" disruptive technol*")) was used, with the time frame limited to 1995-present (retrieval date: September 5, 2018). 2) Manual screening: Approximately 700 Chinese and 2,000 English bibliographic records were retrieved, but many were irrelevant. After reading titles and abstracts, over 300 literature pieces related to disruptive innovation and over 40 related to identification methods were selected. Full texts were then obtained through the National Engineering Technology Library, SpringerLink, Elsevier, and EBSCO. 3) Citation backtracking: Each paper was read, and references were traced to identify additional relevant literature without limiting backtracking depth until no new relevant literature could be found. Ultimately, 54 papers related to disruptive technology identification were obtained. Based on this literature, this study reviews the main identification methods and discusses future development directions.

3. Current Status of Identification Methods

3.1 Overview of Identification Research

Despite high research interest in disruptive innovation, direct studies on disruptive technology identification remain limited. This study collected 54 domestic and international papers. Following the 1997 publication of *The Innovator' s Dilemma*, disruptive innovation gained widespread attention, and researchers gradually shifted focus to identification methods after 2000. Research can be divided into three stages: 1) Before 2015, annual literature volume remained at 1-4 papers; 2) After 2015, literature increased sharply, peaking in 2016-2017, primarily due to Chinese scholars publishing extensively during those years; 3) Fewer papers appeared in 2018-2019, possibly because recent research has not yet been indexed. See Figure 1 [Figure 1: see original paper].

3.2 Classification by Disciplinary Background

Currently, no widely accepted identification method exists, and researchers' method selection often depends on their disciplinary backgrounds. Library and information science researchers typically employ patentometrics supplemented by bibliometrics and content analysis; engineering management researchers often use technology roadmapping and TRIZ theory to study technology evolution; economic researchers tend to select market analysis indicators such as corporate investment and market share. Additionally, many researchers, based on Christensen' s theory, attempt to build specialized identification methods. Although these researchers also come from the aforementioned three backgrounds, their theoretical foundation differs, leading to methods based on Christensen' s theory. This study classifies these scholars as the "Christensen school." Currently, this field lacks unified theory, with limited citation among researchers and fragmented efforts. Overall, disruptive technology identification research remains in its infancy, without a broadly convincing method, and researchers are often constrained by their knowledge backgrounds with limited cross-disciplinary method adoption. Based on researcher backgrounds, four main methodological categories are identified and discussed below.

3.2.1 Library and Information Science Methods In 2004, R. N. Kostoff et al. [14] first linked literature to disruptive technology, assessing technology status based on core components, key experts, institutional affiliations, and collaboration patterns, then synthesizing expert opinions to identify potential disruptive technologies. However, few scholars connected literature to identification for some time. After 2009, S. Kassicieh et al. [15] proposed that disruptive technologies originate from scientific research and developed identification methods based on scientific and patent literature. B. Buchanan et al. [16] proposed a science-intensive identification framework capable of analyzing existing or future disruptive technologies and detecting potential disruptive technologies in specific fields. I. Bloodworth et al. [17] further constructed two evaluation indicators—technological frontiers and performance breakthroughs—based on scientific and patent data to identify disruptive technologies. While these methods used scientific literature, they did not fully incorporate library and information science methods, with expert evaluation remaining dominant.

After 2011, common library and information science methods gradually appeared in identification research. Regarding citations, Chen Ao et al. [18] selected highly cited patents for study, while Zhang Jinzhu et al. [19] used patent citations to represent knowledge breakthroughs. Luan Chunjuan et al. [20] emphasized innovation degree and technological impact, using patent application activity, citation counts, and technological novelty as identification indicators. A. Momeni et al. [21] combined patent development paths (forward citations), clustering analysis, and topic modeling for identification, though their core assumption—that disruptive technologies should be based on highly cited patents—lacks proven necessity. Su Jingqin et al. [22] explored the relationship between disruptive technologies and patent evolution trajectories, using smartphones as a case study to argue that early patent evolution should follow J L curves in terms of patent volume, citations, and citation rates, though such trajectories often indicate completed technology accumulation, leaving actual identification effectiveness to be validated.

In topic research, F. Dotsik et al. [23] used keyword network co-occurrence to analyze temporal changes in business articles and scientific literature themes. Zhao Ge et al. [24] attempted to identify disruptive technologies through topic heat differences across papers, patents, and news. Bai Guangzu et al. [25] and Liu Qiuyan et al. [26] identified topic mutation degrees in scientific papers and patents, combined with expert selection. Huang Lucheng et al. [27] employed similar methods from different perspectives. Additionally, combining patent data with analytical models represents an important approach, such as Huang Lucheng et al. [28] incorporating species invasion models into patent analysis, and Y. Cheng et al. [29] analyzing disruptive technology outbreaks using the SIRS epidemic model.

In summary, library and information science identification methods have evolved through three stages (see Figure 2 [Figure 2: see original paper]): In 2004, scientific literature was first linked to identification; in 2009, non-patent literature was incorporated, and citation analysis and topic clustering were formally introduced; after 2012, researchers recognized that potential new entrants in research fields often have disruptive potential, shifting focus to potential topic identification methods, with text mining, semantic analysis, and data models becoming research hotspots, showing diversified trends. Today, while library and information science researchers have achieved results in topic identification, how potential topics transform into disruptive technologies remains unclear, with most studies avoiding this issue by substituting expert evaluation. Thus, evaluating the disruptive capability of potential topics will be a key challenge.

3.2.2 Engineering Management Methods Technology roadmapping, as an important tool for technology foresight, has been frequently applied to disruptive technology identification. B. A. Vojak et al. [30] used roadmapping as a decision-support tool, though standalone roadmapping works better for sustaining innovation. Many scholars have attempted improvements: S. T. Walsh et al. [31] modified the roadmapping process, while Lu Guangsong and Lu Ping incorporated stakeholder factors [32]. Scenario planning is another important method: S. A. Drew et al. [33] identified disruptive technologies through application scenarios; P. J. Schoemaker et al. [34] positioned technology markets using scenario planning; E. Danneels et al. [11] combined scenario planning with roadmapping; and R. N. Kostoff et al. [35] integrated text mining with roadmapping and scenario planning to identify potential application scenarios and key technological components.

Beyond roadmapping and scenario planning, the Theory of Inventive Problem Solving (TRIZ) has been applied. Sun Jianguang et al. [36] described the alignment between non-mainstream technologies and TRIZ evolution models, while Xu Zehao et al. [37] analyzed disruptive technology cultivation using TRIZ maturity indicators. Subsequently, Xu Zehao et al. [38] combined TRIZ with Strategic Niche Management (SNM) theory to further develop analysis methods.

In summary, engineering management methods lack the clear timeline of library and information science approaches, focusing primarily on technology evolution through three categories: technology roadmapping, scenario planning, and TRIZ theory (see Figure 3 [Figure 3: see original paper]). These approaches rely more heavily on expert evaluation than other fields, with all three methods requiring close expert participation. While engineering management researchers are closely connected to technology development—some being frontline developers themselves—they prioritize reliability and practicality, often adopting established methods rather than creating new ones specifically for disruptive technology identification. This focus on reliability, though correct in practice, makes identification schemes overly stable with few theoretical breakthroughs. Future work should address how to better integrate identification with engineering practice.

3.2.3 Economic Research Methods Viewing disruptive technology from a market perspective represents an important research direction. D. Nagy et al. [9] proposed an evaluation system including technical standards, functionality, and proprietary rights, arguing that identification must assess whether new functionalities can generate new standards and proprietary rights and compare technologies against corporate value chains and existing technologies. A. Ganguly et al. [12] developed indicators through literature review and expert consultation, including target market comparison, incumbent technology maturity, adoption rates, and expected utility comparison. J. D. Linton et al. [39] used the Bass model to independently analyze new technology development across multiple markets. G. M. Schmidt et al. [40] constructed identification indicators from price and market segmentation perspectives, building an erosion model to analyze diffusion patterns and identify disruptors and disrupted parties. Song Jianyuan et al. [41] constructed dynamic models for enterprise, industry, and national disruptive technologies from different perspectives. Li Cunbin et al. [42] built indicators from technology input, diffusion, and support dimensions. L. M. Sainio et al. [43] developed an evaluation system from customer benefits, core strategy, strategic resources, and value network dimensions. A. Keller et al. [8] proposed a three-stage identification framework: foothold stage, mainstream market entry stage, and incumbent failure stage, with different indicators for each stage. Zhang Guangyu et al. [44] divided development into five stages: technology selection, market selection, market establishment, market expansion, and paradigm formation, evaluating evolution using the strategic niche concept. F. P. Adams et al. [45] explored assessment methods for disruptive technologies in the energy sector, while Chen Jin et al. [46] used fuzzy evaluation to build composite qualitative-quantitative indicator systems.

Unlike other methods, market analysis approaches focus not on technological changes but on capturing signals from market performance. By directly facing markets, they can measure disruption from industry, government, consumer, product, and capital perspectives (see Figure 4 [Figure 4: see original paper]). While seemingly comprehensive, these indicators lack direct connection to disruptive technology features, with most being commonly used for other technology evaluations. Whether recombination of existing indicators can meet identification needs remains unproven. Moreover, these methods tend to emphasize mathematical models, prioritizing quantitative indicators or those with mature quantification schemes, whereas disruptive technology characteristics are primarily described qualitatively without a usable system for quantification. This field faces the same challenge as library and information science: how to evaluate disruptive capability when a potential technology is identified, a question that remains unanswered despite early research efforts.

3.2.4 Christensen School Methods Disruptive innovation theory originates from Christensen, and many researchers continue exploring based on his theory rather than their own disciplinary backgrounds. This study classifies them as the "Christensen school." Lin Chunpei et al. [47] built an identification framework based on disruptive technology characteristic standards and performance supply-demand trajectories to predict timing and trends. S. Hüsig et al. [6] designed questionnaires covering disruptive technology features based on performance requirements. J. Paap et al. [48] linked performance supply-demand to technology maturity. R. Vecchiato et al. [49] applied user cognitive management to prediction. R. Adner et al. [50] simulated user evaluation processes to analyze chain reactions from performance changes. A. Sood et al. [51] built a technology risk model using risk coefficients for prediction. C. Chen et al. [52] argued that technology performance follows S-curves closely related to traditional lifecycle patterns, enabling identification through performance S-curves. Ji Dan et al. [53] constructed indicators from broader technology, product, market, and competition perspectives. L. O. Gavião et al. [54] proposed a multi-criteria decision model combining complex matrices and probability combinations. V. Govindarajan et al. [55] evaluated disruptive technology from reliability and validity perspectives. J. F. Guo et al. [56] assessed from dominance, maturity, and diffusion capability angles.

Christensen school methods remain unsystematic and exploratory, with researchers rarely reaching consensus. Since *The Innovator' s Dilemma*, even Christensen himself has not proposed widely accepted views. The field shows diverse approaches (see Figure 5 [Figure 5: see original paper]), exploring directions including risk, functionality, performance, demand, lifecycle, and technology trajectories, but without systematic theory. Based on disruptive innovation theory, these methods discuss features extensively, yet these features remain at the descriptive level without conversion to operational methods. Typically, identified features are listed and presented to domain experts for direct matching—a "simple and crude" approach that suffers from inconsistent expert interpretation. The field lacks systematic methods to truly connect expert knowledge with disruptive technology features. Future work may enable non-experts to evaluate disruptive potential through more thorough feature discussion, but currently, the priority remains converting features into concrete, operational methods.

3.3 Summary of Current Status

DARPA has used literature review to assess current and future military needs [57]. The UK government and U.S. Department of Defense have employed horizon scanning to analyze global technology policies [58]. These unconventional, government-led identification methods lack specific operational procedures and are excluded from the aforementioned classification. The four categories each have distinct characteristics: Library and information science focuses on discovering latent technologies within fields, then relies on experts to judge disruptiveness; engineering management emphasizes organizing domain experts to predict complete industry trends, with disruptive technology as one piece of the puzzle; economic research tends to construct mathematical models to derive disruption probabilities mathematically; the Christensen school continuously explores around Christensen' s theory with diverse approaches. Each method has advantages and disadvantages, with none being absolutely viable or unviable, yet none fundamentally solves the identification problem. The root issue remains the lack of evaluation criteria for disruptive technologies. Conceptually, four main evaluation approaches exist: 1) assessing whether incumbent technologies are mature or declining; 2) evaluating the technology' s own development potential; 3) assessing alignment with future societal trends; and 4) evaluating sustained resource investment. However, most current methods or indicators are migrated from other fields, requiring substantial work to become concrete methods (see Table 1).

4. Current Status and Trends of Identification Methods

4.1 Current Status of Identification Methods

Reviewing the four categories, this study compares their main advantages and disadvantages across six dimensions: personnel background, qualitative/quantitative approach, data sources, specificity, identification basis, and effectiveness (see Table 2).

Current identification methods primarily originate from three sources: library and information science, engineering management, and economic research. Library and information science excels at discovering latent topics; engineering management specializes in organizing domain experts; economic research is adept at building indicators and mathematical models. The Christensen school continues experimenting without consensus, with relatively weak theoretical foundations but the highest potential for breakthroughs in early-stage features. Identification standards derive mainly from expert wisdom and disruptive technology features, but these features have not been reconciled with methodological implementation, leaving expert evaluation as the de facto standard. Consequently, current methods show signs of "forcing" expert evaluation. However, these shortcomings are typical for emerging fields and point to future research directions (see Figure 6 [Figure 6: see original paper]).

4.2 Main Problems with Current Methods

4.2.1 Over-reliance on Expert Evaluation Despite methodological differences across disciplines, most methods require some expert involvement—whether for topic screening (library and information science), scoring (economic research and Christensen school), or full participation (engineering management). Currently, no method can completely eliminate expert evaluation. This dependency is difficult to overcome because disruptive technologies are variable and unpredictable, and mature methods are lacking, making expert evaluation a necessary supplement. However, researchers must recognize that many studies begin by stating "traditional expert evaluation struggles to identify disruptive technologies." Moreover, disruptive technologies' earliest characteristic is their difficulty in gaining mainstream market acceptance, often leading to experts' rejection of their new functionalities or performance. Academician Xu Kuangdi noted that disruptive technologies are easily "voted down" by experts [59]. B. T. Murat and N. Ramzi used patentometrics and bibliometrics to validate Delphi method results, finding that among 20 technology fields prioritized by experts, at least a quarter had minimal scientific papers or patents, while another quarter showed no significant growth [60]. This demonstrates that expert judgment may be biased. Researchers should not merely adopt traditional expert evaluation but should establish a disruptive technology-specific theoretical system to help experts avoid blind spots.

4.2.2 Lack of Specificity in Identification Criteria In economic and engineering management methods, identification criteria often adapt existing indicators rather than designing distinctive ones for disruptive technology. Library and information science still focuses on discovering latent technologies without directly addressing identification, while the Christensen school analyzes features that cannot be converted into usable indicators. This creates a unique dilemma: researchers with implementable methods (library/information, economics, engineering) cannot directly map them to disruptive technology features, while those analyzing features (Christensen school) cannot convert them into operational methods. In practice, all four categories resort to expert evaluation to bridge this gap, which explains why expert evaluation remains indispensable. However, experts are valuable resources that should not be consumed arbitrarily. Researchers should convert disruptive technology features, especially early-stage ones, into identification methods to reduce expert evaluation' s dominance.

4.2.3 Insufficient Early or Advanced Identification Research The stage-specific features of disruptive technologies, particularly early-stage characteristics, are crucial for identification. Currently, only the Christensen school focuses on early features, but these cannot be standardized. Other fields recognize the importance but handle it differently: library and information science researchers equate early features with latent topics, leaving subsequent evaluation to experts; engineering management relies on experts' predictive capabilities, making early-stage attention dependent on individual experts; economic research requires market signals that often lag behind technological changes, making early warning difficult. Except for library and information science' s ability to mine latent topics, other fields struggle to detect early potential technologies, relying on individual insight rather than systematic methods. Even library and information science only achieves latent topic discovery, avoiding the question of how potential topics transform into disruptive technologies. This returns to the previous problems: how can researchers, especially early-stage features, convert them into identification methods to reduce subjective expert influence? This is an urgent issue requiring resolution.

4.3 Future Trends in Disruptive Technology Identification Methods

In 2009, the U.S. National Academy of Sciences proposed establishing a "persistent forecasting system for disruptive technologies" to the National Research Council [61]. Although it remains unclear whether this system was built, the proposal' s perspective—that disruptive technologies are extremely complex and unpredictable, requiring multi-domain collaboration rather than isolated efforts—offers valuable insight. Examining relationships across research domains reveals that identification is essentially divided into two sequential parts (see Figure 7 [Figure 7: see original paper]):

The first part is latent technology topic discovery—currently the focus of library and information science. Leveraging their accumulated experience in emerging technology identification, these scholars have shifted their research focus to "discovering new entrants in a field," giving them unique advantages. However, by avoiding direct evaluation of disruptive potential, they must repeatedly emphasize differences from emerging technology identification. In practice, their methods show no qualitative distinction from emerging technology identification. Integrating existing methods with disruptive technology features will become a primary research task.

The second part is technology disruptive capability evaluation—the core challenge of identification that remains without consensus. The foreseeable trend requires building connections between disruptive technology features and identification methods. Future research will likely continue its diverse discussions but must ultimately return to technology evolution patterns. Current main approaches include: 1) evaluating whether incumbent technologies are "declining" ; 2) assessing the technology' s own development potential; 3) evaluating alignment with societal needs; and 4) assessing resource investment. While no consensus exists on specific methods, converting these approaches into operational methods remains a long journey. At present, none can eliminate expert dependency.

In the short term, existing systems cannot strictly map early features to methods and cannot escape expert evaluation dependency. However, identification cannot rely entirely on experts or traditional methods like roadmapping and scenario planning designed for sustaining innovation. Therefore, a practical, comprehensive expert evaluation system specifically for disruptive technology identification should be established. This process requires converting early features into feasible standards that constrain expert evaluation. Researchers should analyze previously overlooked disruptive technologies, extract their common features, and identify factors that experts might miss to help them avoid blind spots.

In the long term, disruptive technology identification must gradually reduce the weight of expert subjectivity. This requires converting early features into concrete identification methods through collaboration among researchers from different disciplines, leveraging their respective strengths while continuously refining disruptive innovation theory. Perhaps identification will not be a single method but an entire methodological system. Within this system, evaluating disruptive potential—specifically, establishing criteria to assess a technology' s threat to an industry—remains the core component. Regardless of its special nature, disruptive innovation is ultimately a special case of technological innovation patterns. By grasping its technological patterns and stage-specific contradictions, this problem will eventually be solved and consensus reached. The solution may involve one or a combination of the four aforementioned approaches, or perhaps entirely new directions. These approaches are already abstracted conclusions close to methodological requirements; the next step is converting them into operational methods that gain widespread acceptance.

5. Conclusion and Discussion

This study systematically reviews existing disruptive technology identification methods, classifying them into four categories: library and information science, engineering management, economic research, and the Christensen school. Through seven-dimensional comparison, three problems are identified: overreliance on expert evaluation, insufficient specificity of identification criteria, and inadequate early-stage identification capability, with the lack of specific criteria being the most pressing. This directly hinders early-feature identification, forcing dependence on expert wisdom. While current methods cannot completely eliminate expert evaluation, rules based on disruptive technology features should be designed to prevent experts from "killing"disruptive technologies. However, expert evaluation principles only address short-term needs. Long-term maturity requires establishing consensus-based identification methods through criteria setting, demanding collaborative efforts across all four research domains.

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Note: Figure translations are in progress. See original paper for figures.