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Analysis of US National Research Council's Persistent Forecasting System for Disruptive Technologies

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Abstract: The National Research Council's (NRC) report on *Persistent Forecasting for Disruptive Technologies* analyzes the key issues in forecasting disruptive technologies and proposes an ideal persistent forecasting system model. This paper summarizes the connotation and challenges of forecasting disruptive technologies, presents the attributes of the ideal persistent forecasting system, and analyzes the system model and its functions. Finally, the insights obtained from the research on forecasting disruptive technologies are proposed as a point of reference for relevant research work in China.

Keywords: disruptive technologies; persistent forecasting; ideal forecasting system

1 Introduction

Because of the continuous advances in theoretical research related to disruptive technologies, people have a deeper understanding of such technologies; further, accurately forecasting and identifying these technologies have become exciting topics that have attracted attention worldwide [1,2]. Many think tanks and advisory bodies at home and abroad are intensifying their research efforts to find the best way to effectively forecast disruptive technologies. After several years of research and development, key institutions, such as the National Intelligence Council, the Center for a New American Security, and McKinsey, have published forecasting and analysis reports on disruptive technologies [3−5], thereby creating a list of disruptive technologies.

The National Research Council (NRC) set up a Committee on Forecasting Future Disruptive Technologies in 2009 to provide guidance and insights for the development of a forecasting system for disruptive technologies. The Committee on Forecasting Disruptive Technologies believes that the list of disruptive technologies released by think tanks and advisory bodies mentioned above are mainly based on questionnaires and seminars, which are largely dependent on expert opinions. Such forecasting methods may generate many biases. Therefore, the Committee on Forecasting Disruptive Technologies is committed to finding a better way to forecast disruptive technologies; the method selected should be able to continuously capture the disruptive technologies that may be ignored by other forecasting methods and describe their disruptive nature in a way that other methods cannot. Through several discussions and analyses, the Committee on Forecasting Disruptive Technologies issued three reports on continuous forecasting of disruptive technologies in 2009 and 2010 [6]. In these reports, the attributes of disruptive technologies were systematically analyzed, and the problems present in the existing forecasting methods were discussed; as a result, the ideas and framework needed to construct an ideal continuous forecasting system for disruptive technologies were proposed.

This paper aims to make a systematic and in-depth analysis of the NRC report, and summarize the key problems faced in forecasting disruptive technologies and the ideal model framework for a continuous forecasting system. The aim is to provide a point of reference for the forecasting and research of disruptive technologies in China.

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2 NRC's definition of disruptive technologies forecast

2.1 Definition and attributes of disruptive technologies

The term "disruptive technologies" currently does not have an accurate or widely accepted definition. In the NRC's report, disruptive technologies are defined as the "technologies and their applications that can significantly affect the global balance of power." This definition of disruptive technologies can be understood from two perspectives. First, it does not mention a new technology but emphasizes its novel application. This is because emerging technologies rarely become disruptive technologies immediately; a certain incubation period, consisting of a series of innovative applications, is required to become a disruptive technology. Second, disruptive technologies emphasize the impact of the technology, which can cause discontinuous and non-linear changes in the life cycle of the technology, and have a disruptive impact on existing technologies, business models, the national economy, and security. This definition, thus, lists some attributes of the disruptive technologies.

From the perspective of historical development, the emergence of disruptive technologies has many attributes. First, in terms of the temporal dimension, the performance, cost, reliability, utilization rate, and so on of the technology are discontinuous; this may be related to the new application field, rather than the change in the technology itself. Second, to ascertain whether a technology can become a disruptive technology, we must consider its impact on other technologies. The sudden emergence of a technology does not ensure that it will become a disruptive technology; we must observe whether it is powerful. Third, disruptive technologies may be a combination of technologies based on interdisciplinary collaboration. For example, the Internet is based on computer, communication, and browser technologies. Finally, the emergence of disruptive technologies is closely related to the development vision of an enterprise; thus, the emphasis on innovation, forward thinking, and the willingness to cater to the development vision of the emerging market, rather than the historical one, will accelerate the onset of the inevitable disruption. Thus, it can be seen that for a technology to become disruptive, it does not need to be radical or novel from the perspective of engineering or technology. Many technologies become disruptive simply because they exceed the "tipping points" for price or performance, or greatly improve the accessibility or functionality of existing technologies. As a result, ubiquity is another important feature of disruptive technologies.

2.2 How to define the forecasting of disruptive technologies

The concept of forecasting disruptive technologies was not specifically proposed in the NRC's report; after analyzing the common methods for forecasting general technologies used in the past and present, including judgment or direct observation method, extrapolation and trend analysis, model analysis, and scenario simulation, they concluded that no method can completely solve the present set of problems, challenges, and requirements encountered by policy makers. This is because forecasting disruptive technologies is a complex and systematic project, which requires not only the forecasting of the potential technology itself, but also the potential market opportunities, competitive threats, and problem areas that may influence technical innovation.

First, the potential changes and impacts of a new and highly disruptive technology are not appreciated or valued. Thus, forecasting disruptive technologies is important to distinguish the signs and signals of potential disruptive technologies from the numerous innovations and applications resulting from technologies and new discoveries. Second, history shows that many technologies have not achieved the expected disruptive effects because of the influence of various factors, such as cost, investment, social needs, market promotion, geography, politics, and so on. Hence, forecasting future needs, problem areas, threats, and opportunities is just as important as forecasting the specific technology that may lead to disruption.

Based on this, the forecasting of disruptive technologies can be defined as: identifying the signs and signals of potential disruptive technologies from ubiquitous technologies; making a systematic and comprehensive evaluation of the disruptive potential of the technology by comprehensively considering various influences, such as the feasibility of technology promotion, market, investment, cost, society, and population, as well as geographical, political, and cultural factors; and, finally, providing the suggestions for development or solutions required for decision making.

3 Analysis on key problems of disruptive technologies forecast

3.1 Challenges of Disruptive technologies forecast

Many think tanks and advisory bodies have successively conducted disruptive technologies forecasts and released a series of reports, such as *Game Changers: Disruptive Technologies and U.S. Defense Strategy* by the Center for a New American Security, *12 Disruptive Technologies that May Change Life, Enterprise and Global Economy by 2025* by McKinsey, and so on [3–5]. These reports mainly employ mainstream technology forecasting methods, such as questionnaire survey, expert consultation, scenario simulation, literature analysis, and so on. The application of these methods leads to the following three type of limitations in the forecasting results: (1) the forecasting focuses on the development of technology itself, but ignores the impact of related

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resources and problem areas; (2) the information sources are mainly from the western countries, such as the United States, and the participants are mainly experts, which may lead to the generation of many prejudices; and (3) all forecasting methods depend on historical data, to a certain extent, but relying solely on historical data will inevitably lead to an overemphasis on evolutionary innovation, as well as a forecasting bias.

Thus, a new forecasting method must be developed to make the forecasts of disruptive technologies useful. At the same time, the resources (finance, technology, infrastructure, and human capital) applied to the forecasting, such as the nature and type of the technology being predicted, availability of experts, willingness of the public to participate in the forecasting, the time range that must be considered during the forecasting, and how decision makers plan to use the forecast, must be taken into account to ensure that the forecast enables better decision making.

3.2 Building a forecasting system for disruptive technologies

As mentioned above, the development of a new forecasting method is essential for the useful forecasting of disruptive technologies. However, the new forecasting method should not be created from scratch; it should combine and apply the existing technology forecasting methods by systematically considering the needs and goals of forecasting disruptive technologies and improve the accuracy and practicability of the forecasts. NRC proposes to build a persistent forecasting system for disruptive technologies by systematically analyzing the nature of disruptive technologies and the challenges faced in forecasting. The system can forecast the disruptive technologies in a continuous, open, and stable manner; further, it can minimize the deviation caused by traditional forecasting methods and is defined as an "ideal persistent forecasting system," as shown in Fig. 1.

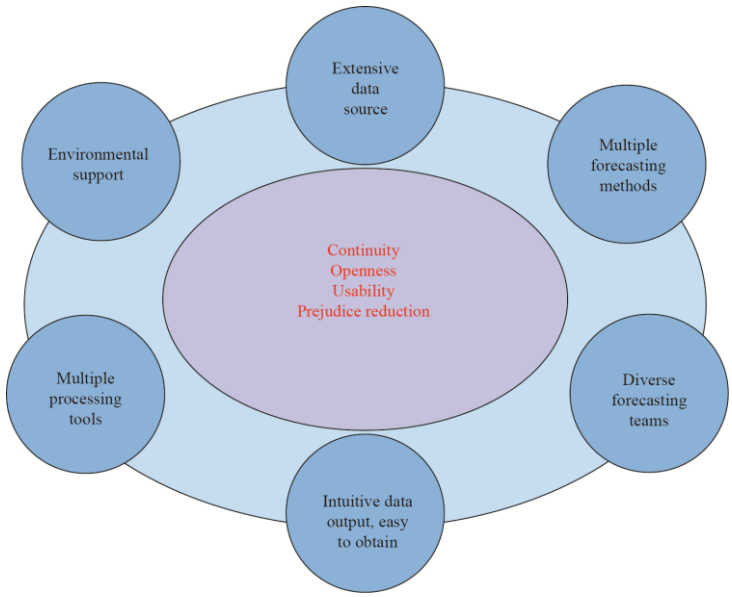

Fig. 1. Properties of the ideal persistent forecasting system for disruptive technologies.

The most important criteria to be considered in an ideal persistent forecasting system is its sustainability; the purpose is to continuously update the forecast based on new data, signals, and inputs from participants. Further, it needs to consistently provide the latest forecasting conclusions for decision makers or customers. Because no single team has the manpower, capital, or intellectual resources to imagine each possible disruption scenario, capture each signal, or obtain all key data, persistent forecasting system must be as open and friendly as possible. This will allow the building of a trust- and incentive-based mechanism to attract various groups to participate in a persistent and extensive manner. However, extensive public participation requires the system to be as simple and intuitive as possible—to support persistent access and ensure global availability.

In addition, the key to ensure that the forecasting results of the system are useful is to minimize the deviation caused by the limitations of the data source and forecasting methods used. The only solution is to collect information from a wide range of experts, with specialized knowledge, from different countries, languages, cultural backgrounds, age groups, technology fields, and educational backgrounds; further, the public, especially young researchers, technical experts, entrepreneurs, and scientists must be consulted because they are the group that is most likely to create, and be affected by, the disruptive technologies of the future. The forecasting and evaluation of disruptive technologies requires the combination of various qualitative, quantitative, and new forecasting methods and tools to present the forecasting results in a visually appealing and intuitive way; further, there is a need to constantly improve and update the system through regular feedback and reviews so that it is persistent and effective for a long time.

4 Persistent forecasting system model of disruptive technologies

After analyzing the properties and key problems of the ideal persistent forecasting system, the NRC proposed the framework model of an ideal forecasting system, as shown in Fig. 2. This model defines six important functions that should be included in the persistent forecasting system: (1) provide a mechanism that defines forecast requirements; (2) provide a wide range of data collection tools; (3) provide preprocessing tools for unstructured data; (4) track, monitor, and process early warnings and weak signals of disruption; (5) provide data analysis and visualization tools for the participation of decision makers, stakeholders, and the public; (6) establish a feedback mechanism that allows the iterative development of the system. See Table 1 for specific functions.

As can be seen from Table 1, the ideal persistent forecasting system model defines the functions of the forecasting system, besides providing the system's functional process and its implementation methods. The NRC proposed several possible system design schemes in the subsequent sections of the report and pointed out that no scheme could meet all the requirements of a persistent system. Therefore, the forecasting system must be a learning system that needs long-term evaluation and continuous optimization. By contrast, the system puts special emphasis on the collection of various information sources and the joint application of existing forecasting methods. As a result, the screening of a wide range of information sources and the selection and evaluation of existing forecasting methods are the key factors to realize the system's functionality.

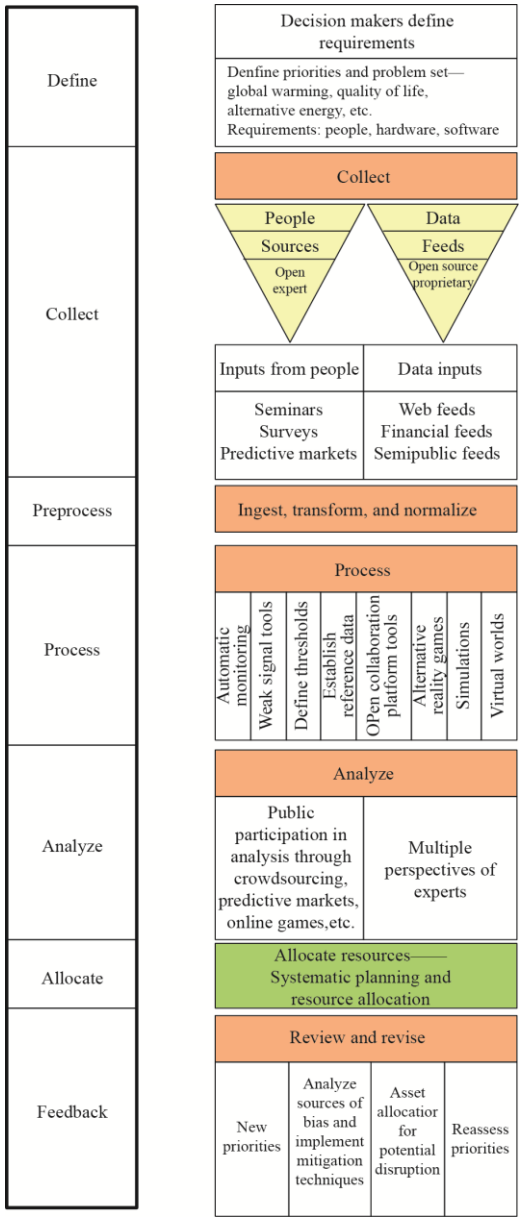

Fig. 2. Framework model of the ideal persistent forecasting system for disruptive technologies.

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Table 1. Ideal persistent forecasting system functions.

System function	Function description
Requirement definition	A requirement definition mechanism is established to collect a wide range of questions from the perspective of stakeholders, including the groups affected by technology, the time frame, relevant fields, and influence of technology, thus, to define the users and forecasting tasks.
Information collection	One needs to: collect information from different cultures and languages, as well as various information sources; improve the accessibility of information or consider the adoption of multiple types of alternative data; evaluate the reliability of information sources; and overcome the cognitive bias caused by the traditional method of collecting all the relevant data within a fixed period before forecasting.
Data preprocessing	The data from multiple sources are standardized to form a unified format for data processing and analysis later.
Information processing	Various scientific and technological discoveries, natural and social trends, abnormal behaviors, or enabling technologies are tracked by monitoring relevant websites, blogs, publications, and so on. Disruption thresholds are set through trend analysis, causal modeling, and roadmap. Signals are extracted using a data analysis tool or manually detected by experts or other participants; these signals are judged and comprehensively processed by a combination of computers and human wisdom.
Information analysis	An interactive and easy-to-read overview of complex data structures using visual analysis and intuitive user interface design. The visual system shall have the following properties: (1) ability to process mass data; (2) ability to change the time range; (3) global display; (4) macro and user-defined alarms; (5) possibility of search and real-time filtering; and (6) support user communities.
Allocation and management	Once a potentially disruptive technology is identified, key decision makers will assess the possibility of disruption, the impacts it may have, the factors that may accelerate or hinder disruption, and the incidence relation existing in the events that may cause disruption. Decision makers need to allocate resources, based on the information available, to counter the impact of disruption when it occurs; the system needs to update information regularly and create evaluation reports.

5 Conclusions

The report titled *Persistent Forecasting of Disruptive Technologies* that was published by NRC proposed the framework model and design scheme of an ideal persistent forecasting system for disruptive technologies; further, it systematically analyzed the key problems and existing challenges. Although there has been no follow-up report on the construction of an ideal forecasting system till now, it continues to provide a good point of reference for the research on the forecasting for disruptive technologies.

By analyzing the persistent forecasting system for disruptive technologies, the author proposes the following two points. First, disruptive technologies forecasts are usually made to distinguish the signs of disruptive technologies from those of ubiquitous technologies and evaluate their disruptive influence. Therefore, the forecasting of disruptive technologies needs to comprehensively consider various factors, such as potential market opportunities, competitive threats, and relevant issues that may promote technological innovation. Second, forecasting of disruptive technologies aids decision making. To minimize the forecasting deviation and guarantee the availability of forecasts, the best solution is to build an open persistent forecasting system. However, the construction of a system is a long-term and complex task that requires the participation of researchers and experts from various industries all over the world, as well as more systematic and comprehensive in-depth research.

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