Master Class

Global Technology Trends Monitoring: Theoretical Frameworks and Best Practices*

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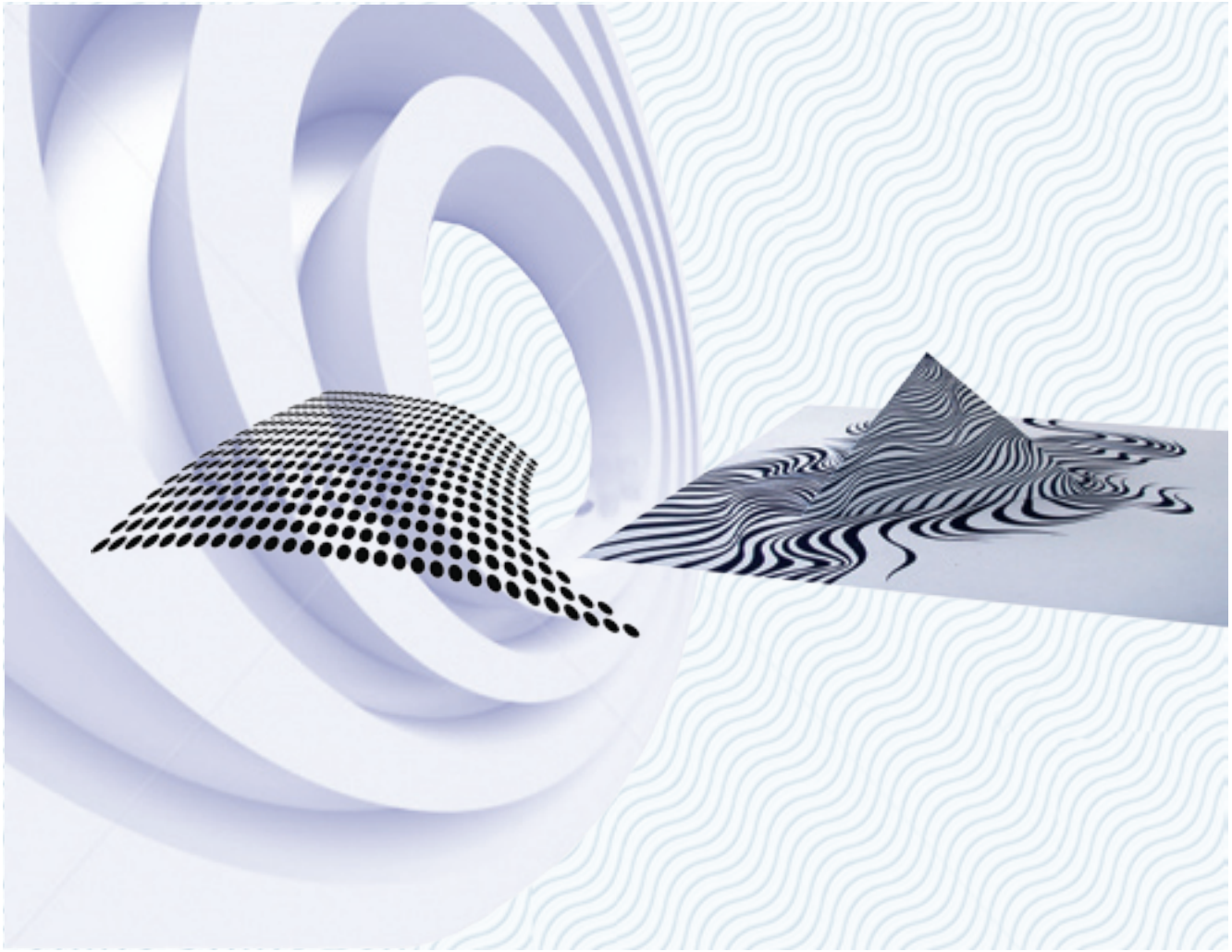

Monitoring and accurate interpretation of the data on technological trends is a key prerequisite for the gaining competitive advantages in various economic sectors. Validation of expert assessments via quantitative methods helps to reveal inexplicit signs of technological change based on the analysis of large data sets. Synthesis of qualitative and quantitative methods enables identification of global technological trends, formalization of their criteria, and creation of automated information processing tools.

The paper presents an analytical review of international practices for monitoring global technology trends, as well as the key theoretical approaches and methods, which have been developed in this field.

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Keywords

global technology trends monitoring; technology mining; Foresight; qualitative and quantitative methods; evidence-based approach; bibliometric analysis; patent analysis; text mining; information overload; information sources; automated tools

Citation: Mikova N., Sokolova A. (2014) Global Technology Trends Monitoring: Theoretical Frameworks and Best Practices. *Foresight-Russia*, vol. 8, no 4, pp. 64–83.

* Support from the Basic Research Programme of the National Research University Higher School of Economics is gratefully acknowledged.

Alongside the accelerating pace of technological progress and the shortening of the innovation cycle, we are faced with the task of identifying and systematically monitoring trends that are capable of having a significant impact on long-term social and economic development. Systematic monitoring of prospective science and technology (S&T) trends is necessary for flexible and timely strategic decision-making in response to technological changes.

Numerous studies aimed at uncovering these technological trends interpret this very term variously and make use of associated concepts. These studies differ in the emphasis they place on varying effects, the life cycle stage of the technologies, and the scale and methods used. The expected effects are the most significant characteristic of a technological trend. Thus, the unique feature of *disruptive innovations* lies in the fact that they endow technology with fundamentally new consumer properties which are capable of fully changing the structure of markets [*Christensen*, 1997]. Where *emerging technologies* are identified, intensively developing technological directions with high potential for inventions, innovations and associated significant economic and social consequences are the focus of attention [*Gokhberg et al.*, 2013]. When analysing *technology applications*, the emphasis is on interdisciplinary technological fields that could have a major impact on social and economic development and change the lives of people around the world [*Silberglitt et al.*, 2006]. Authors often include differing notions in the concept of technological trends depending on the technology's life cycle stage. For instance, emerging technologies fall under the research and development stage, while technology applications and products may already have been partially introduced on the market. Terminological preferences can be caused by the trends' scale. Thus, *mega-trends* are viewed as stable trends on a global level that determine the future development of the global economy and society [*Singh*, 2012]. Technology trends can also differ in the way they can be identified. In particular, dynamic and high-interest areas of S&T such as *research fronts* are defined as clusters of documents sorted on the basis of co-citation analysis [*Upham, Small*, 2010].

As such, choosing how best to define the notion 'trend' primarily depends on the aim and objectives of the study, its scale, and main focus. In a general sense, a *technology trend* can be defined as a topical breakthrough and actively evolving direction of technological development, capable of having a significant impact on the economy and society in the future.

Studies aimed at identifying prospective S&T trends are carried out at national, industry, and corporate levels in many countries. The results of such research are in wide demand across a broad spectrum of stakeholders (for example, government, business, research institutes, and the general public) involved in the development and practical use of long-term forecasts. For the most part, expert methods (interviews, surveys, seminars, etc.) are used to carry out such large-scale projects. At the same time, there is a growing demand for an evidence-based approach to monitoring trends, capable of verifying expert assessments and revealing implicit signs of technological changes using large volumes of data. It is no coincidence that theoretical studies increasingly focus on improving quantitative technology monitoring methods and developing automated data processing procedures.

The aim of this paper is to present an analytical review of international practices on identifying global technology trends, as well as key related theoretical approaches and methods.

Global practice in technology trends monitoring

Many projects on identifying technology trends are now being carried out by international organizations, national research centres, universities, companies and consultancy agencies. The aims of these studies vary. Technology monitoring by international organizations is necessary for supranational regulation of the S&T sphere, the development of joint programmes within country unions, and effective integration and standardization of activities in science, technology

and innovation. Governmental institutions are faced with the task of shaping the overall state of global S&T and identifying a country's competitive advantages in key areas that are important from the perspective of national security and improving military potential (a portion of such data remains secret and inaccessible to the public). Monitoring projects by universities and research centres involve regular collection and analysis of information on new S&T directions, not only for scientific purposes, but also in the interests of businesses and drafting recommendations to governments on selecting certain national or regional priorities. Major corporations and private firms carry out their own monitoring of potential S&T breakthrough areas, which helps them to adapt to changing market conditions and guarantee global competitiveness. Consultancy and audit companies engage in such initiatives to collect information needed by businesses to define strategic priorities.

Trends monitoring covers both certain sectors and the entire range of potential directions of technological development. The forecasting horizon, as a general rule, ranges from 10 to 30 years or more (the database of the German consultancy firm Z_punkt includes assessments up to 2020, while in some cases it is up to 2040–2050). These projects make active use of qualitative methods (literature review, expert surveys, interviews, developing scenarios, etc.) alongside quantitative methods (bibliometric and patent analysis, collecting and summarizing web-data, etc.). Numerous attempts have been made to automate the processing of information on technologies (a semi-automated approach) and to use online tools to publish and discuss results online.

Figure 1 shows certain types of technology trends monitoring projects carried out by different organizations.

International organizations

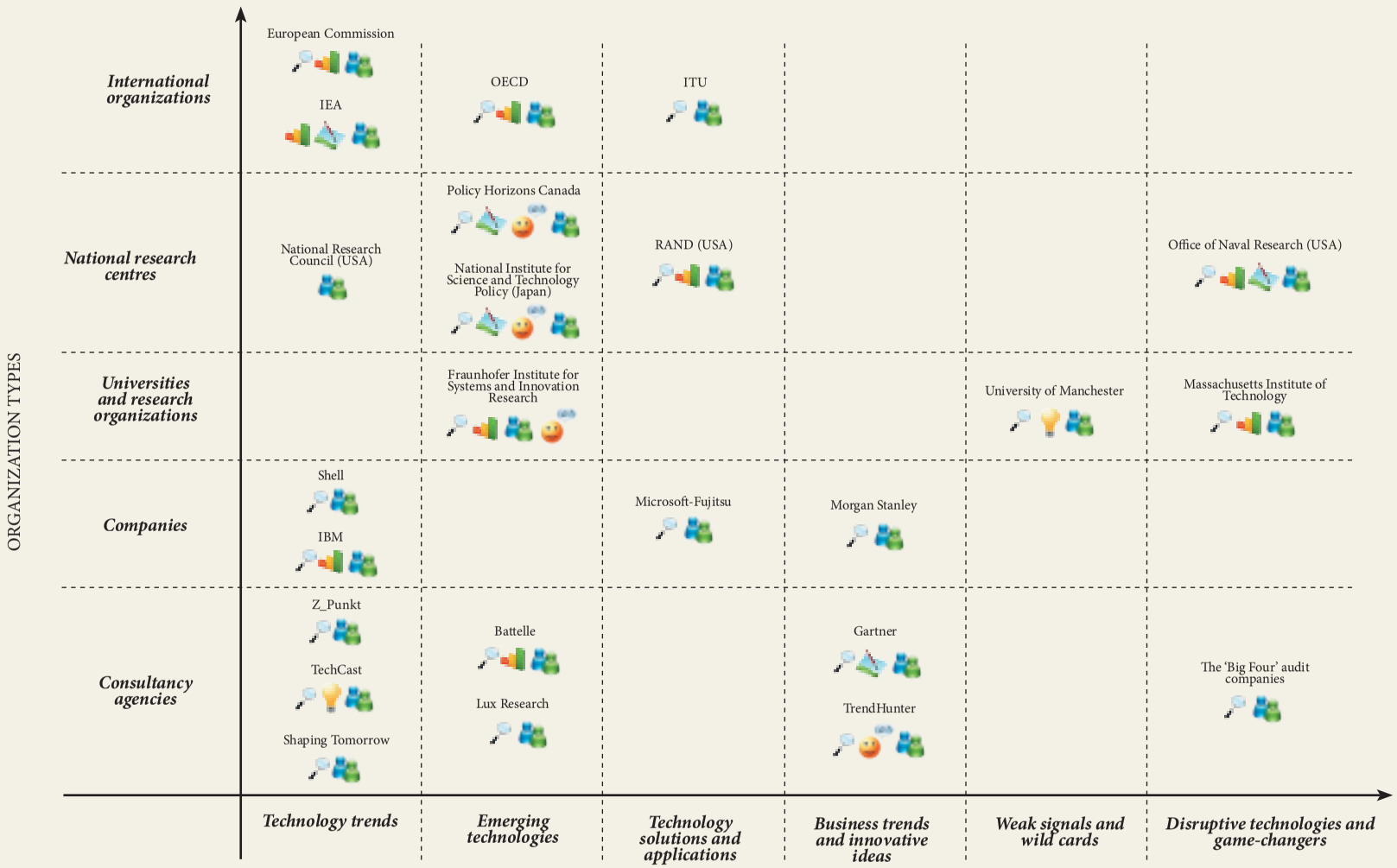
A number of international organizations carry out studies to identify prospective S&T directions and emerging technologies and to assess long-term development opportunities in certain areas. Generally, these projects result in the development of scenarios, a list of key technologies, trends and driving forces behind their development, and technological standards and policy recommendations for various countries. Examples of monitoring projects by international organizations are given in Table 1 below.

The European Commission implements various programmes to study global technology trends capable of influencing the development prospects of the economy and society and publishes summary reports with recommendations to the European Parliament on S&T policy. For example, the 'European Technology Watch' programme by the European Organization for Security [European Commission, 2009] draws together the efforts of various participants (science, business, government) with a view to furthering existing competencies and raising the potential of European countries in S&T to secure the region's leading positions in the world. This type of monitoring involves searching for potentially important technological fields and working on measures to stimulate their development in European countries.

The OECD conducts an ongoing large-scale analytical study on technology forecasting and a number of projects to monitor technology trends and drivers of growth in an extremely diverse range of fields (space, energy, bioeconomics, etc.) For instance, in 2006–2007 the OECD published a series of 'Infrastructure to 2030' reports [OECD, 2007] analysing the long-term opportunities and challenges faced by the global environment and setting out recommendations for the governments of the organization's member states. In 2014, a report revealed the key challenges and trends which could change the developmental trajectory of prospective fields such as nano-, bio-, space and information and communication technologies, and incorporated the lists of key OECD reports in these fields [OECD, 2014].

The International Telecommunication Union's (ITU) 'Technology Watch' project [ITU, 2014] looks at significant trends in information and communication technology (ICT) and proposes standards for new technological fields. The study aims to search for and study prospective S&T directions and measure

Figure 1. **Typology of organizations and technology trends monitoring projects**



Methods

- Review of information sources (international projects, media resources, reports, etc.)
- Statistical analysis (publications, patents, news, etc.)
- Analysis of 'weak signals' and 'wild cards'
- Development of scenarios and roadmaps
- Surveys of the population and community participants
- Expert procedures (surveys, seminars, interviews, etc.)

Source: compiled by the authors.

Table 1. **Examples of technology trends monitoring projects by international organizations**

Organization	Project name	Project aim	Examples of trends	Methods	Results
European Commission	European Technology Watch [European Commission, 2009]	Early identification of emerging technologies in various fields, assessing their impact on the market to stave off any security threats to EU states	Robotic assistants	Literature review (materials from joint European Commission projects – DEISA, PRACE, EGI, EMI) Collecting and summarizing expert assessments (interviews, expert panels, surveys, seminars, etc.)	Recommendations to EU state governments to guarantee security in Europe and globally
Organization for Economic Co-operation and Development	'Infrastructure to 2030: Mapping Policy for Electricity, Water and Transport' [OECD, 2007]	Identifying long-term development opportunities for infrastructure around the world, drafting recommendations to improve infrastructure for OECD member states	Intelligent transport systems	Reviewing studies by the OECD and member states of the organization Collecting and summarizing expert assessments (involving specialists from government agencies, companies, research institutes)	Report on opportunities to develop infrastructure in fields such as electricity production, water resources, rail freight transport, urban public transport, road transport List of recommendations to OECD member states to improve infrastructure in the sectors under consideration
International Telecommunication Union	'Technology Watch' [ITU, 2014]	Identifying emerging technologies to later set ICT standards in developed and developing countries	Ubiquitous sensor networks	Literature review (various ITU reports) Consultations with experts	27 reports on technology monitoring (for example, 'Trends in Video Games and Gaming', 'The Optical World', 'Standards and e-Health', etc.) TechWatch Alerts on technology development
International Energy Agency	'Energy Technology Perspectives 2012' [IEA, 2012]	Identifying technologies capable of reducing the negative effects of climate change and improving energy security	Carbon capture and storage	Statistical analysis Building roadmaps Developing scenarios Seminars with experts	Energy development scenarios and strategies up to 2050 10 technologies potentially capable of having an impact on energy development 25 energy recommendations to governments of various countries

Source: compiled by the authors.

their potential in terms of R&D standardization. The ITU reports offer an assessment of the impact of emerging technologies on the competitiveness of developed and developing economies, analyse standardization activity and trace the trajectory of ICT dynamics. As a whole, 'Technology Watch' describes the broad current and future context of global S&T development and establishes a normative framework within which to draft regulations and standards in ICT at national and international levels.

National research centres

Many national research centres have been called upon by their governments to monitor prospective directions in technology development with a view to adjusting the country's domestic and foreign policy. These projects describe technology trends, emerging technologies, prospective technology applications, driving forces and alternative technology development scenarios, as well as the most promising countries in terms of S&T collaboration. Table 2 shows several monitoring projects by national research centres.

The activities of the RAND Corporation — a strategic US research centre — focus on analytical support for science and education activity and health care and helping to strengthen national security and the stability of international relations. Certain technological trends are covered in the report 'The Global Technology Revolution' [*Silberglitt et al.*, 2006]. The report presents four main S&T directions that are capable of having a radical impact on future development: bio-, nano-, information technologies and new materials. As part of the study, researchers looked at factors underlying the technology revolution and evaluated the prospects of 16 key technology applications, including hybrid vehicles, green manufacturing, targeted drug delivery, etc., and their most important effects.

Table 2. **Examples of technology trends monitoring projects by national research centres**

Organization	Project name	Project aim	Examples of trends	Methods	Results
RAND Corporation	'Global Technology Revolution 2020' [*Silberglitt et al.*, 2006]	Identifying key technology applications and analysing their impact on global social andeconomic development	Embedded sensors and computational devices in commercial goods	Literature review (core S&T publications) Assessment of R&D and investment dynamics Interviews with experts	List and description of key technology applications
National Institute for Science and Technology Policy (Japan)	'The 9th Science and Technology Foresight' [NISTEP, 2010]	Analysing science, technology and innovation trends to increase the country's competitiveness in key S&T fields	Cloud computing	Delphi surveys Developing scenarios Population surveys	12 scenarios 120 key topics List of countries for S&T collaboration with Japan 13 areas with special importance to Japan
Office of Naval Research (USA)	'Science and Technology Text Mining' [ONR, 2014]	Analysing and mapping technology directions to plan and develop political programmes	Sensor networks	Review of information sources (reports) Statistical analysis (patents, scientific publications) Web-mining Collecting and summarizing expert assessments (roadmaps)	Global map of S&T development S&T investment plan
National Research Council (USA)	'Technology Warning' [NRC, 2014]	Identifying key technologies and innovations from a military perspective, posing a potential threat to the US national security system	Supercomputing	Review of information sources (materials from the 'Joint Vision 2020' project and others) Consultations with experts	Description of key technologies in the form of reports on: 'Technology Futures', 'Technology Watch', 'Technology Warning', 'Technology Alert' and others.

Source: compiled by the authors.

The National Institute for Science and Technology Policy (NISTEP) was set up through the Japanese government to work on S&T policy, provide companies and associated organizations with analytical materials, and assist in research activity in vital technological fields. In 2010, NISTEP published 'The 9th Science and Technology Foresight' [NISTEP, 2010], which was devoted to key directions to raise the competitiveness of the country in science, technology and innovation. The NISTEP Foresight centre publishes regular reports (Science and Technology Trends) [NISTEP, 2014] focusing on trends in technological fields (life sciences, ICT, ecology and energy, nanotechnology, etc.) which, if developed, could help to solve global and national problems. These trends are studied within expert networks made up of representatives from the sciences, business and the public sector.

Since 1998, the US Office of Naval Research (ONR) has been working on its 'Science and technology text mining' programme [ONR, 2014]. The aim of this project is to identify technology trends by processing textual data obtained from S&T databases (publications, patents, etc.) and using the results when planning and developing political initiatives. The programme looks for new interdisciplinary ways to overcome current challenges and identifies the key players and experts in specific S&T fields. In view of the importance of the programme to protect the country's national security, the results are presented to the US Navy command privately. At the same time, the authors behind the research regularly publish articles in academic journals and use their work as empirical evidence to support the accuracy of analytical conclusions [*Kostoff et al.*, 2001, 2002, 2004].

The US National Intelligence Council (NIC) prepared a series of 'Global trends' reports describing the factors and directions of technological progress that are capable of changing the trajectory of global development. Thus, the technology section of the report 'Global Trends 2030: Alternative Worlds' [NIC, 2012] outlines the impact of new technologies on global development in fields such

Table 3. **Examples of technology trends monitoring projects by universities and research organizations**

Organization	Project name	Project aim	Examples of trends	Methods	Results
Manchester Institute of Innovation Research	iKNOW database [Manchester IIR, 2013]	Identifying, classifying and analysing 'weak signals' and 'wild cards'	Production of artificial organs	Review of information sources (publications, blogs, news articles, EU technology monitoring projects) Delphi surveys and interviews (panels involving scientists and research organizations) Analysing 'weak signals' and 'wild cards'	List of 'weak signals' and 'wild cards' according to the themes of the EU Seventh Framework Programme
Fraunhofer Institute for Systems and Innovation Research	'Emerging technologies' [Fraunhofer ISI, 2014]	Identifying technology trends in S&T fields and analysing the potential to introduce innovative technology applications into industry	Lithium-ion batteries	Review of information sources Monitoring R&D activity Developing scenarios Seminars with experts Population surveys	Reports on emerging technologies in various fields (bioeconomy and life sciences, health system, ICT and others)
Massachusetts Institute of Technology [MIT, 2013]	'MIT Technology Review' [MIT, 2013]	Analysing prospective technology fields selected at the Open Innovations Forum	Human brain modelling	Review of information sources (scientific reports, news articles, etc.) Statistical analysis Surveys and consultations with experts	List of key technology trends

Source: compiled by the authors.

as ICT, automation and manufacturing, resource and health technologies, and others. The document was drawn up on the basis of surveys carried out among company employees, members of academic institutes, governmental and non-governmental experts from the USA and other countries around the world. The study proposed four alternative global development scenarios, indicating the drivers, barriers and disruptive factors for them.

Universities and research organizations

Academic institutions, including non-governmental, make a significant contribution to technology trends monitoring. The emphasis here is placed on new technologies, 'weak signals' and 'wild cards'[1] that could have a major impact on global socio-economic development in future. Studies such as these are carried out with the backing of national and international grants or as part of consultancy activity using vast information databases. They tend to develop databases (of trends, emerging technologies, 'weak signals', 'wild cards', etc.) that are widely accessible. Table 3 shows certain monitoring projects of this type.

The iKNOW project by the Manchester Institute of Innovation Research [Manchester IIR, 2013] is carried out with the support of the European Commission jointly with a number of international organizations and aims to identify 'weak signals' and 'wild cards'. iKNOW operates within an expert network bringing together decision-makers, researchers and participants in scientific and innovation activity. Every member of the community has access to a specialized database and can add information on existing or new technology trends. This project serves as an effective monitoring and long-term planning tool and is based on carefully studied conceptual and methodological principles to search for, classify and analyse 'weak signals' and 'wild cards' which have proven effective when assessing the potential impact of the latter on S&T development in Europe and the rest of the world.

A specialized division operates within the Fraunhofer Institute for Systems and Innovation Research (ISI) called the Competence Center for Emerging Technologies [Fraunhofer ISI, 2014]. Employees at this centre analyse develop-

[1] 'Weak signals' are indicators of possible, but not obvious, changes in the future. 'Wild cards' are less likely, but potentially highly important events that could bring about radical negative (e.g. terrorist attacks or natural disasters) or positive (e.g. the discovery of penicillin) consequences [Manchester IIR, 2013].

Table 4. **Examples of technology trends monitoring projects by large companies**

Organization	Project name	Project aim	Examples of trends	Methods	Results
Shell	'Shell Energy Scenarios to 2050' [Shell, 2009]	Analysing factors affecting the business environment, development of global energy scenarios	Biofuels	Review of information sources Interviews with experts	Trends in the energy industry Alternative global energy scenarios
IBM	'Next Five in Five' [IBM, 2014]	Identifying technologies that have potential to change people's lives in future	Personalised medicine based on DNA technologies	Collecting and analysing information on cutting-edge technologies developed at IBM laboratories Analysing markets and social trends	Regular reports describing five promising innovations over the next five years in fields such as education, retail trade, healthcare, security, urban development
Microsoft-Fujitsu	'Insights Quarterly' [Microsoft-Fujitsu, 2011]	Identifying the most important challenges and technological solutions in ICT	Tablet computing	Review of information sources Surveys of ICT company representatives	Quarterly reports on challenges and technology trends in ICT
Morgan Stanley	'Morgan Stanley Blue Papers' [Morgan Stanley, 2014]	Analysing technological changes that could have a significant impact on the development of the global economy and business	Mobile commerce	Review of information sources Consultations with experts (analysts, economists, strategic management specialists)	Reports on technology trends

Source: compiled by the authors.

ments in fields such as bioeconomy and life sciences, health system, data processing and communications, etc. Using a wide range of data, they study the developmental trajectories of emerging technologies and their impact on one another and they carry out assessments of the economic, ecological and social effects of S&T progress. The institute involves economists, politicians and representatives of various scientific industries in its interdisciplinary projects, and its final recommendations are used in decision making on science, technology and innovation policy.

The 'Technology Review' project [MIT, 2013] by the Massachusetts Institute of Technology (MIT) aims to identify prospective trends, business models and innovative solutions, as well as the directions of global development. In the report on the project for 2013, information was presented on biomedicine and pharma, medical devices and digital health, the digital economy and mobile world, the new global energy map, advanced manufacturing, nanotechnology and new materials, 'smart' cities, and the mass market. These fields had a short description, a list of key trends and game changers, leading countries and forecast assessments of the future development of the technologies. In addition, the report contained an analysis of mega-trends relevant to a wide range of sectors (nanotechnology and new materials, the power of the consumer, the automation of work, hyper-connectivity). As part of its 'Technology Review' project, the Massachusetts Institute of Technology publishes annual reports on 'Ten Breakthrough Technologies' [MIT, 2014] that are giving renewed momentum to many S&T fields.

Companies

Large private companies carry out technology trends monitoring projects in the core sectors of their activity and associated fields. Such studies allow them to detect innovation breakthrough areas at an early stage, thereby enabling them to improve the flexibility of their business and their market competitiveness. These projects result in alternative scenarios and lists of trends (innovative solutions) in the technological fields selected for study. Table 4 gives some examples of monitoring projects implemented by companies.

The goal of IBM's 'Next Five in Five' monitoring project [IBM, 2014] lies in analysing key marketing and social trends that are capable of changing people's

lives, as well as the new prospective technologies underlying these trends, over the next five years. In 2013, innovative trends were identified in five key fields: education, retail trade, healthcare, security and urban development. IBM uses the results when drafting strategic priorities and publishes them on its website for use by any interested parties. There is demand for this type of data from private firms, investors, research collectives, the media, etc.

A global alliance was signed between Microsoft and Fujitsu with a view to search for and apply innovative approaches to guaranteeing reliable long-term relationships with clients, involving consultancy services, business hardware, and software solutions. In 2011, the alliance launched the 'Insights Quarterly' research project aimed at identifying challenges and trends in ICT and searching for technological solutions that companies can rely on amid restrictions on budgets and high administrative risks. The 'Key ICT Trends and Priorities' report [Microsoft-Fujitsu, 2011] gives a short review of technological trends in fields such as tablet computing, cloud computing, business intelligence and communications and also gives assessments of the significance of and trust in these technologies from the perspective of representatives of leading ICT companies.

Consultancy agencies

Consultancy companies offer an extremely broad range of technology monitoring services, although they are often highly specialized in nature and adapted to the needs of specific clients. Consultancy services tend to focus on business trends and emerging and breakthrough technologies in fields that are most attractive to their clients (Table 5).

The consultancy company Z_Punkt provides services to work on the development strategies of its client companies, including identifying technology trends in the corresponding fields. The 'Z_Punkt Trend Radar 2020' database [Z_Punkt, 2014] covers technological development directions such as ICT, materials, life sciences, nanotechnology, robotics and artificial intelligence, transport and mobility, medicine, the environment, energy and others. It allows users to carry out a complex analysis of significant medium- and long-term social, cultural, economic, technological, political, and ecological events. The database includes approximately 240 trends with detailed descriptions of their time horizon, global development level, potential impact, etc.

Gartner carries out regular studies on the ICT market, offering consultancy services to developers, investors and software suppliers. An important strand of Gartner's studies is its forecasts of technology trends capable of affecting prospective market dynamics. The aim of the 'Top 10 Strategic Technology Trends' project [Gartner, 2014] is to search for and analyse strategic technologies that could have significant impacts for businesses in the coming three years. The potential of the technologies, investment demand and the risks caused by late implementation are all factors that affect their impact. Both existing and new directions in ICT that open up unique opportunities or have high disruptive potential for companies over the next few years are all considered strategic.

Deloitte's expert network brings together roughly 200,000 financial, audit and risk management specialists from around the world. Deloitte publishes annual reports on technology trends that will have the greatest impact on the activities of ICT companies in the future. After a round-up of a wide range of potential technologies, the analysis moves on to private surveys of clients, suppliers, researchers and analysts. In the final report, technology trends are classified into two categories: disruptors (causing stable positive changes in the ICT sector) and enablers (their development gives rise to new practices in the field). In particular, the 'Tech Trends 2012: Elevate IT for digital business' report [Deloitte, 2012] describes five disruptive trends ('Social Business', 'Gamification', 'Enterprise Mobility Unleashed', 'User Empowerment' and 'Hyper-hybrid Cloud') and five enabling trends ('Big Data Goes to Work', 'Geospatial Visualization', 'Digital Identities', 'Measured Innovation' and 'Outside-in Architecture').

Trend Hunter is the largest global trends monitoring community covering various fields (fashion, technology, culture, design, social media, business, ecology, and others) [Trend Hunter, 2014]. The TrendHunter.com global network brings

Table 5. **Examples of technology trends monitoring projects by consultancy companies**

Organization	Project name	Project aim	Examples of trends	Methods	Results
Battelle	*Battelle.org* [Battelle, 2014]	Identifying innovations and technology trends in various S&T fields	Membrane technology	Review of information sources (reports, standards) Statistical analysis Collecting and summarizing expert assessments Laboratory experiments	Emerging technologies in various fields (industry, energy and environment, healthcare, national security, pharmaceutical and medical devices, and others)
Z-Punkt	*TrendRadar* database [Z_Punkt, 2014]	Identifying and describing key technology trends in the medium and long term	Social networks and collective intelligence	Review of information sources Web-data collection and analysis Interviews with experts	Database of technology trends in fields such as ICT, materials, life sciences, nanotechnology, robotics and artificial intelligence, transport and mobility, medicine, environment, energy, nutrition
Lux Research	*Luxresearchinc.com* [Lux Research, 2014]	Identifying and describing emerging technologies for clients to select key technology directions to finance	Metamaterials	Review of information sources (marketing surveys, company profiles, publications, etc.) Interviews with company managers, clients, partners and external experts in more than 20 countries	Database of discoveries and technology trends in various fields (advanced materials, agro innovation, alternative fuels, bioelectronics, water, and others)
Gartner	'Top 10 Strategic Technology Trends' [Gartner, 2014]	Identifying technology trends capable of affecting the activities of ICT companies in the next three years	Smart cars	Review of information sources Web-mining Developing scenarios Expert surveys	Ten strategic technology trends in ICT
Deloitte	'Tech Trends' [Deloitte, 2012]	Identifying disruptive technologies, as well as technologies that contribute to S&T development in ICT	Gamification	Review of information sources Collecting and summarizing expert assessments by science and industry representatives Crowdsourcing of ideas* (global expert network)	Annual reports on technology trends: five disruptors and five enablers
TechCast	*Techcastglobal.org* [TechCast, 2014]	Analysing topical technology trends for use in business planning and developing company policy	The Internet of Things	Review of information sources (S&T literature, web-data,the media, etc.) Interviews with experts	Summary map of technologies, published annually 60 emerging technologies and 30 'wild cards' in various fields Technology forecasts by direction (energy and environment, information technology, digital economy, manufacturing and robotics, medicine and biogenetics, transportation, space, and others)
Shaping Tomorrow	*Shapingtomorrow.com* [Shaping Tomorrow, 2014]	Monitoring key trends, events and news in science and technology	Augmented reality	Review of information sources (news feeds, materials from analytical centres, international reports, etc.) Collecting and summarizing expert assessments (in the form of interviews, expert panels, surveys, seminars, etc.)	Reports on trends in various fields Trend alerts Information bulletins
Trend Hunter	*TrendHunter.com* [Trend Hunter, 2014]	Collecting information on innovations and cutting-edge technologies for start-up businesses and large-scale companies	Wearable fitness trackers	Crowdsourcing and polling among community members Collecting and summarizing expert assessments	250,000 microtrends 2,000 technology clusters Summary reports on trends

* In crowdsourcing, a solution to a problem is sourced from a large distributed group of community members, which helps to reduce spending on searching for and processing information.

Source: compiled by the authors.

together more than 150,000 participants and serves as an important source of information on technologies and innovative ideas for start-up enterprises and large companies. Within this network, a methodology has been developed making it possible to codify information on emerging technologies, added by service users and to exchange opinions on their relevance using polls on the site. At present, the Trend Hunter database has thousands of reports on trends, technology clusters and new innovative ideas which private companies can use when developing their marketing and product strategies.

Quantitative approaches to technology trends monitoring

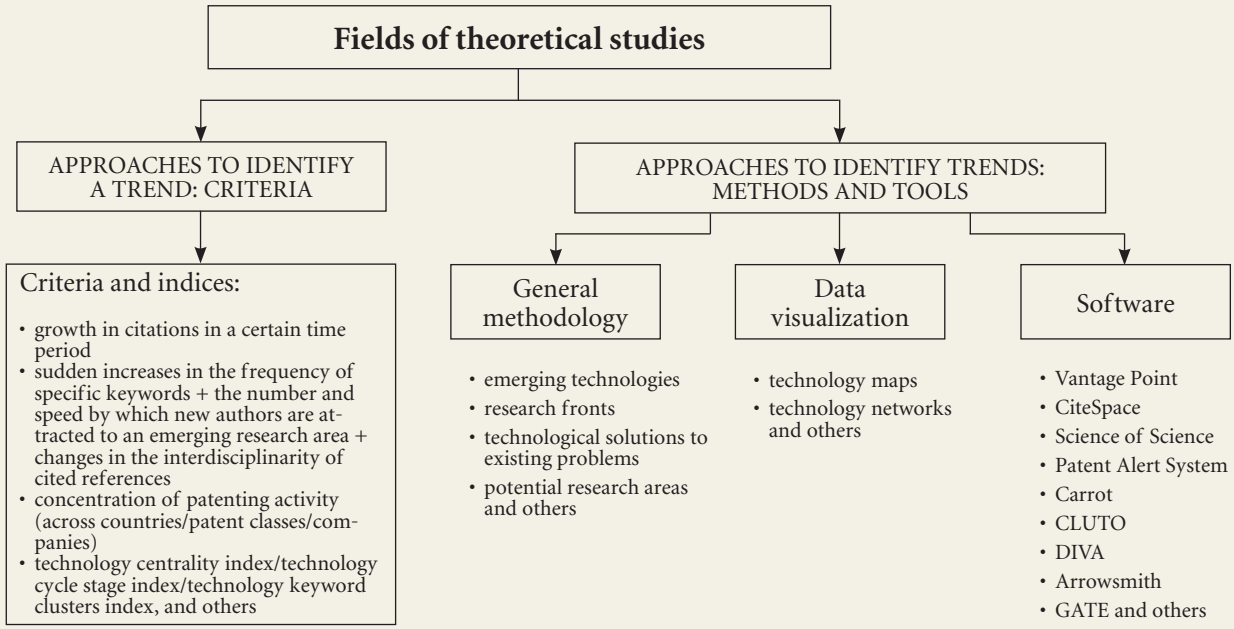
Contemporary approaches to technology monitoring propose a synthesis of qualitative and quantitative methods with the latter taking on an ever-growing role. Amid the current information overload, researchers are developing new toolkits to detect 'hidden' knowledge using effective processing and interpreting methods for data collected from a broad spectrum of sources.

The main theoretical studies devoted to identifying and revealing technology trends are shown in diagram form in Figure 2 below.

Several studies are devoted to classifying trends and developing criteria to identify them. Trends are grouped according to various parameters: growth in the number of highly cited publications on the topic [*Upham, Small*, 2010], keywords use statistics [*Guo et al.*, 2011], etc. One study [*Upham, Small*, 2010] analysed the change in the number of publications in research fronts[2] over a specified period of time, identifying the following types of research fronts:

- **Emerging** — fronts in the current dataset that contain no papers from the previous dataset;
- **Growing** — those that have more papers in the current period than the sum of all their contributing fronts in the previous period of analysis;
- **Stable** — those for which the sum of all contributing fronts yields the same number of papers;
- **Shrinking** — those that are smaller than the sum of all their contributing fronts in the previous time period;

Figure 2. **Main fields of theoretical studies on technology monitoring**



Source: compiled by the authors.

[2] Research fronts represent the most dynamic areas of S&T and the areas that attract the most scientific interest.

- **Exiting** — fronts that existed in the previous period of analysis but have no papers in any front in the current period analysed.

The authors of the study [*Guo et al.*, 2011] propose a mixed model to describe and forecast emerging technologies involving three key indicators:

- Sudden increases in the frequency of specific words indicating the emergence of new directions in scientific research;
- The number and speed by which new authors are attracted to an emerging research area;
- Changes in the interdisciplinarity of cited references.

The authors note a correlation between these three factors: first, authors show up in emerging fields, then the number of interdisciplinary publications and citation levels starts to grow, which in turn gives rise to a spike in keywords use statistics [*Ibid.*]. Besides, various technology trends indices are being developed. In particular, one study [*Cobo et al.*, 2011] proposes using parameters such as centrality and density[3] to divide scientific subjects into the following types: highly developed and isolated; emerging or declining; motor; basic and transversal. Another study [*Corrocher et al.*, 2003] analyses emerging technology trends on the basis of concentration of patenting activity across countries, International Patent Classification (IPC) classes and companies.[4] The suggestion is that the newer the technology, the narrower the range of countries and companies that have access to it, and information on technology in the early stages of development is only provided for key patent classes.

Monitoring stages

The most important research task is developing the overall methodology to monitor technology trends. Methodologies can include methods to identify emerging technologies [*Porter, Cunningham*, 2005], technological solutions to existing problems [*Kostoff et al.*, 2008; *Kim et al.*, 2009], research fronts [*Upham, Small,* 2010], potential research fields [*Lee et al.*, 2009] and other trend types. On the whole, irrespective of the chosen focus and the tools used, the monitoring can be broken down into five main stages (Table 6).

Porter and Cunningham [2005] introduce the notion of *tech mining* to refer to the step-by-step process of technology monitoring. At the stage of setting the objectives, the aim of the study is set and relevant data sources are selected. At the second stage, certain queries are formulated and data are collected from the selected sources. The next step — data processing — involves a basic (refining and filtering) and advanced (in-depth) analysis of the information gathered. The monitoring closes with the stage where the results are presented, interpreted and summarized.

Table 6. **Main stages of technology trends monitoring**

No.	Stage	Content
1	Setting objectives	Establishing the research objectives, selecting the subject area and methodology
2	Data collection	Selecting data sources for analysis and the search strategy determined by the research objectives; collecting materials
3	Data processing	Selecting the units of analysis (documents, keywords, authors, etc.) and methods (text mining, clusterization, network analysis, citation analysis, etc.)
4	Drafting a preliminary list of trends	Defining candidate trends (integrating the results from the data processing)
5	Validation and interpretation	Validation of candidate trends (ensuring that the candidate trends meet the criteria of a trend)

Source: compiled by the authors.

[3] 'Centrality' describes the strength of the external links between the scientific subjects under consideration and other subjects. 'Density' defines the strength of the internal links between keywords describing a particular scientific subject.

[4] The basis of the patenting activity concentration across countries lies in the hypothesis that the development of innovative products and applications takes place in a limited number of countries, the number of which gradually grows after standardization of the technologies. The analogous concentration across patent classes stems from the hypothesis that in the early stages of development, emerging technologies are concentrated in certain IPC classes, and then information on these technologies spreads to other patent classes. The concentration across companies is based on the hypothesis that the development of emerging technologies is initially carried out by a narrow, albeit expanding over time, group of companies.

The methodology of creating patent maps [*Lee et al.*, 2009] to identify new prospective research fields is also packed into the presented technology monitoring outline. Based on the objectives, a collection of patents is formed, and the data processing stage involves the creation of a patent map to identify and describe candidate trends. The final stage of the monitoring is devoted to analysing, validating and interpreting the results obtained.

Differences in the technology monitoring process are caused not only by the objectives set, but also the sources of data and methods of analysis used. Figure 3 shows the possible choices at each stage of technology trends monitoring.

As Figure 3 shows, the monitoring process is dependent on the chosen trend type (emerging technologies, research fronts, technological solutions, potential research fields, etc.), the sources of information (databases of publications, patents, news, etc.), the data extraction methods (broad thematic inquiry such as 'nanotechnology', list of keywords or a certain feature), the units of analysis (a certain document, structured or unstructured data), and the methods used to process and validate the trends identified (quantitative, qualitative or mixed).

Data sources

The selection of database is one of the most important stages of technology monitoring. The majority of authors give preference to bibliometric sources (either general e.g. Web of Science or Scopus; or specialized e.g. Medline, etc.) to monitor research fronts and emerging technologies or patent databases (e.g. the United States Patent and Trademark Office (USPTO), European Patent Office (EPO), Japan Patent Office (JPO) to search for information on technology solutions and applications in a particular subject area. Other data sources for technology monitoring might include: the news [*Daim et al.*, 2006], business resources (in particular, the LexisNexis database) [*Porter, Cunningham*, 2005], and reports on activity by venture capital funds, start-ups, etc. [*Cozzens et al.*, 2010]), conference materials [*Porter, Cunningham*, 2005] and others.

Collecting information from the sources selected is a separate task, solved by drawing up a list of keywords delineating the scope of the study. The specific tools used in the search include: one or more keywords combinations describing the subject field, a list of keywords selected on the basis of expert opinions [*Lee et al.*, 2009; *Morris et al.*, 2002] or from key documents [*Kim et al.*, 2008], or combinations of these approaches [*Kim et al.*, 2008; *Porter, Cunningham*, 2005]. An alternative search strategy is to draw up a list of publications or patents based on a specific feature: articles from specialized journals [*Cobo et al.*, 2011; *Guo et al.*, 2011; *Kajikawa et al.*, 2008; *Kostoff et al.*, 2008], the most cited publications [*Upham, Small*, 2010], patents from corresponding IPC classes [*Corrocher et al.*, 2003; *Lee et al.*, 2011], patents in certain countries [*Tseng et al.*, 2007] etc.

The data obtained forms collections[5] (of scientific publications, patents, etc.) which are then processed using certain qualitative or quantitative methods.

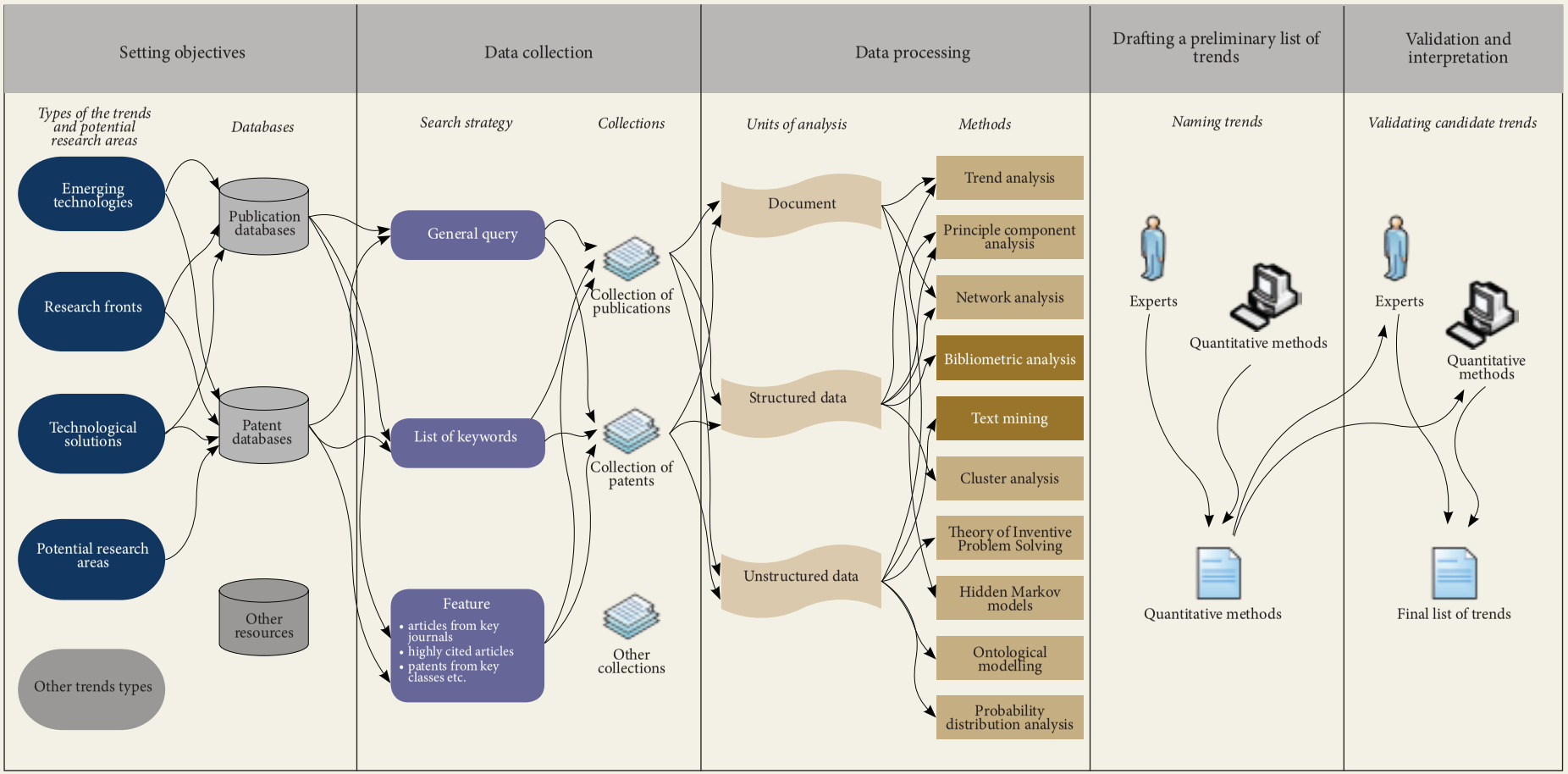
Data processing methods

Data collections may be processed in one of three ways. The first involves taking a certain document as the unit of analysis and examining their quantitative dynamics within a set time interval [*Campbell*, 1983; *Daim et al.*, 2006; *Dereli, Durmusoglu*, 2009; *Lee et al.*, 2011] to assess publication activity in a specific subject area — a sufficiently narrow and potentially breakthrough direction. The second way is working with structured data from each text: the classification code determining which subject area the document falls under, keywords chosen by the author, citation statistics, etc. The third method uses unstructured information, i.e. analysing a full text after preliminary processing — removing duplicate documents, excluding stop words without individual meaning (prepositions, conjunctions, pronouns, etc.), stemming[6], etc.

[5] A collection is an array of structured or unstructured data obtained from a specific source (database of publications, patents, news, dissertations, etc.).

[6] Many words have the same lexical root but perform various syntactical functions, for instance *computation* and *computing* [*Wang et al.*, 2010]. During stemming, researchers look for the common lexical root of similar-sounding words for further normalization of a text.

Figure 3. **Stages of technology trends monitoring**



Source: compiled by the authors.

The selection of the unit of analysis predetermines the methods that will be used during the technology monitoring. The main methods used to process the data under consideration involve citation analysis and text mining, which in many studies are combined with supporting methods such as network analysis, clusterization, trend analysis and others. Figure 4 shows the methods used to identify technology trends. It goes without saying that their scope and the diverse ways in which they can be combined are not covered exhaustively in this diagram and can be supplemented by other methods, the use of which depends on the objectives set, the types of technology trends identified, and other factors.

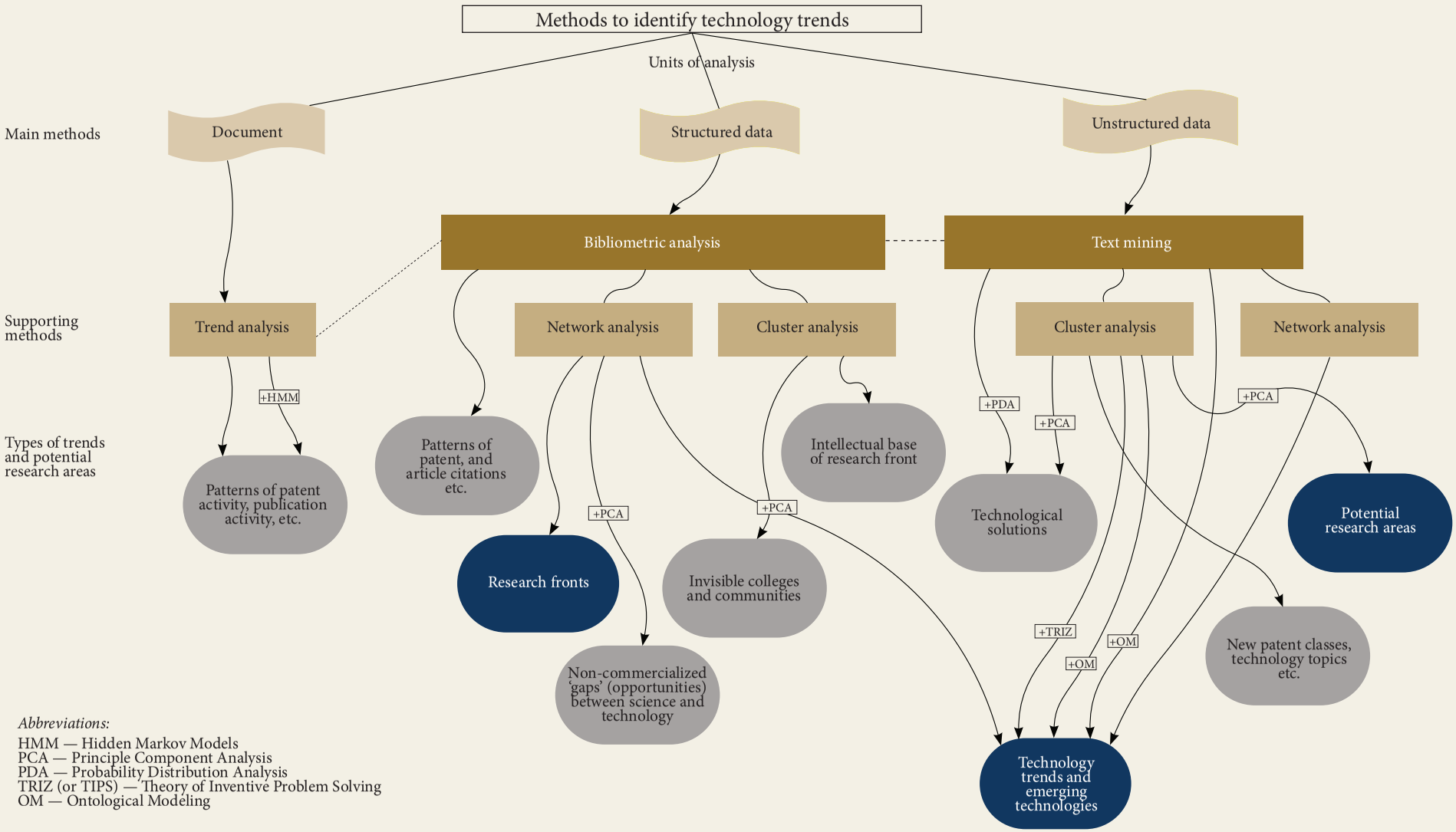
Citation analysis as a bibliometric method is widely used to process structured data. The citation level of documents (publications, patents, etc.) can point to the emergence of research fields (fronts), opening up new directions for technological development [*Igami, Saka*, 2007; *Kim et al.*, 2008; *Morris et al.*, 2002; *Upham, Small*, 2010; *Chen*, 2006; *Shibata et al.*, 2008; *Kajikawa et al.*, 2008; *Noma*, 1984]. In addition to citations when monitoring technology trends, structured data from bibliometric descriptions of documents can also be analysed: keywords [*Kim et al.*, 2008; *Cobo et al.*, 2011; *Guo et al.*, 2011], the name of the organization, author, title, and abstract [*Morris et al.*, 2002], and classification category [*Spasser*, 1997], among others.

One of the most widespread methods used to work with unstructured information is *text mining*.[7] Use of this method requires the structure of the document to be taken into account [*Tseng et al.*, 2007] so that word combinations selected from the most relevant segments of the text can serve as data for clustering. Therefore, sentences or paragraphs in a text that include keywords, parts of headings or associated words selected by experts (for instance, *goal, important, needed, problem*, etc.) can have maximum weight. Some methods propose an analysis of keyphrase distribution throughout a text. Some authors work on the basis that keywords repeated throughout the entire document with a certain regularity can contain information on the nature of a technological problem in the subject field and can be used to search for solutions using linguistic analysis [*Kim et al.*, 2009]. The focus of the analysis might be the most [*Lee et al.*, 2009; *Corrocher et al.*, 2003] or least frequent but potentially significant word combinations [*Wang et al.*, 2010; *Li et al.*, 2009] to identify emerging technologies and promising research areas. Some works offer a mechanism to create automated annotations of documents [*Trappey et al.*, 2006]. For example, text mining of a patent generates a short abstract containing the most frequent keywords and parts of headings, phrases specific to the subject field, etc. In the future, this lexical material could serve to improve the speed and efficiency of patent analysis.

As mentioned above, text mining is based on large volumes of data. Many theoretical studies have been devoted to creating and using automated software to process data, including linguistic and statistical analysis and visualization tools [for example: *Chen*, 2006; *Guo et al.*, 2011; *Dereli, Durmusoglu*, 2009; *Morris et al.*, 2002; *Palomino et al.*, 2013; *Porter, Cunningham*, 2005]. The faster information processing time significantly speeds up the sorting and filtering of data, analysis of trends and statistics, and the process of visualizing results. During analysis, both online (*Carrot, PAS* and others) and offline software tools (Vantage Point [*Porter, Cunningham*, 2005], CiteSpace [*Chen*, 2006], DIVA [*Morris et al.*, 2002], Sci [*Guo et al.*, 2011], TextAnalyst [*Wang et al.*, 2010], Arrowsmith [*Smalheiser*, 2001], PackMOLE [*Fattori et al.*, 2003] and others) may be used. Many of the above tools have been developed by the authors themselves. Such applications, as a general rule, use information from electronic databases (publications, patents, news, etc.) and have a special user interface to make queries, filter and visualize the results. Some programmes — Vantage Point, CiteSpace, DIVA — offer powerful data processing and visualization tools in the form of tables, graphs, maps, clusters, etc.; others allow users to receive special alerts on changes in the developmental trajectory of technologies (for example, PAS notifies users of

[7] The aim of text mining is to extract hidden, previously unknown meaning from a large volume of unstructured data (annotations and full-texts of documents, web content, etc.) As a complex approach, text mining is a combination of statistical and computational linguistic methods of data processing. It simplifies the technology data collection process by indexing the keywords encountered in the text of the documents and makes it easier to deal with these indexes afterwards [*Yoon, Park*, 2004].

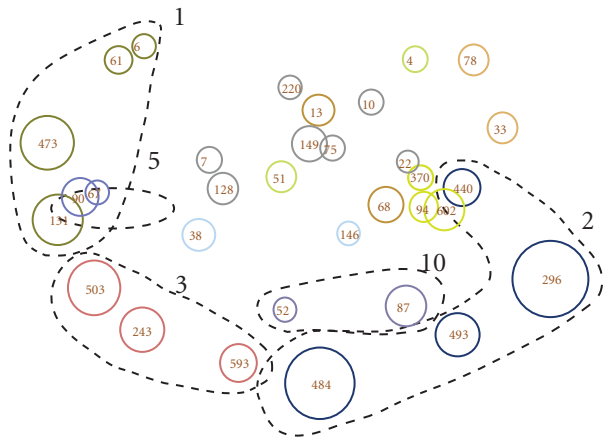
Figure 4. **Methods to identify technology trends**



Abbreviations:
HMM — Hidden Markov Models
PCA — Principle Component Analysis
PDA — Probability Distribution Analysis
TRIZ (or TIPS) — Theory of Inventive Problem Solving
OM — Ontological Modeling

Source: compiled by the authors.

Figure 5. **Example of a cluster map**



Source: [*Tseng et al.*, 2007].

a marked increase in patent activity; and DIVA help users to generate integrated reports).

Specialized tools to group and visualize data on technology development play an important role in the processing of structured or unstructured information [*Porter, Cunningham*, 2005; *Kim et al.*, 2008; *Yoon, Park*, 2004]. *Clusterization* or *network analysis* are often used for this purpose.

In the framework of technology monitoring, a *clusterization* is used to separate the prepared data (documents, keywords, thematic areas, growth curves, etc.) into groups with similar characteristics reflecting the development of the most important technological directions in the subject field. Some of the most widespread clustering methods include the k-means [*Kim et al.*, 2008; *Trappey et al.*, 2006], hierarchical [*Kostoff et al.*, 2008; *Lee et al.*, 2011; *Spasser*, 1997] and topological [*Shibata et al.*, 2008, 2010; *Kajikawa et al.*, 2008] clusterization, and the k-nearest neighbours method [*Tseng et al.*, 2007], among others. Figure 5 shows an example of data visualization in the form of a cluster map serving as evidence of developing technological directions (clusters of a similar theme are highlighted in the same colour).

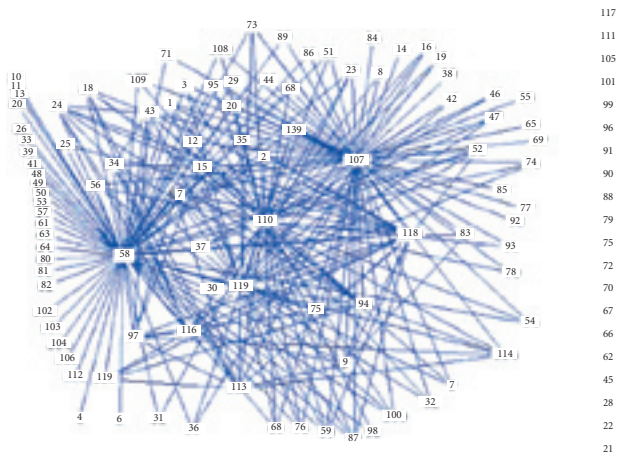
In recent years, *network analysis* has generated serious interest, allowing researchers to identify, analyse and visualize the links at the heart of various processes. This quantitative method, based on graph theory, simplifies the analysis of the links between elements (nodes) of an emerging network. Documents, authors, thematic fields, countries, keywords, etc. can constitute nodes, as sources of information on emerging technology trends. When applied to technology monitoring tasks, network analysis is actively used to forge links between documents and create citation networks [*Small*, 2006; *Shibata et al.*, 2008; *Shibata et al.*, 2010; *Kajikawa et al.*, 2008] and networks of semantically related keywords [*Yoon, Park*, 2004; *Kim et al.*, 2008]. Figure 6 gives an example of a constructed patent network based on semantic links between documents.

Depending on the aims of the technology monitoring, basic processing methods for structured (bibliometric analysis) and unstructured (text mining) data can be combined, and they can be supplemented by supporting methods (Figure 4). The latter include network analysis, clusterization, trend analysis, principle component analysis,[8] probability distribution method,[9] ontological model-

[8] The principle component analysis is most often used to supplement text mining, for example, to identify key factors (components) on a keywords map [*Porter, Cunningham*, 2005; *Lee et al.*, 2009]. It can be used in combination with citation analysis when forming citation networks [*Kajikawa et al.*, 2008; *Shibata et al.*, 2008; *Chen*, 2006], for which documents that do not have either incoming or outgoing citation links are removed from the network.

[9] An analysis of probability distributions can be used to identify keywords combinations that are encountered in documents with equal frequency i.e. they describe a certain important problem that various authors are working on in that particular technology field [*Kim et al.*, 2009].

Figure 6. **Example of a patent network**



Source: [*Yoon, Park,* 2004].

ling,[10] the theory of inventive problem solving[11] (TRIZ or TIPS), and others. Varying combinations of these methods make it possible to identify different types of trends (emerging technologies, research fronts, invisible colleges, potential research areas, citation patterns, etc.) and expand the range of information sources, relying not only on databases of scientific publications and patents but also on additional sources such as the news, information business resources, conference materials, etc.

Conclusion

Our review in this paper of the theory and practice of global technology trends monitoring shows that in a large number of studies carried out in this field different definitions and variations on this notion are used, with an emphasis on the most important effects of developing trends, life cycle stage, the scale of the trends and ways to identify them. However, the majority of authors predominantly show an interest in identifying, at the earliest possible stage, prospective technological fields with significant social and economic impacts and high potential for commercialization.

Theoretical studies and applied projects on technology trends monitoring are carried out at extremely diverse levels — global, national, industry and corporate. Interest in the results of these studies comes from international organizations, government bodies, business, research institutes and other structures involved in the process of developing and using long-term forecasts and shaping policy based on their recommendations.

Theoretical studies are focused on developing a substantiated methodology to identify emerging technologies (they also define the necessary criteria for this) and developing automated methods and software to process large volumes of data and visualize the results obtained, a critically important stage of the entire process.

Technology trends monitoring involves several stages (setting objectives, data collection, data processing, drafting a preliminary list of trends, interpreting results). The precise nature of these steps depends on the research objectives and the chosen trend type, sources of information, search strategy, units of analysis and methods used for further processing and validation. Alongside traditional sources of data for technology monitoring — scientific publications and patents — researchers often turn to news, business resources, conference materials, etc. The main methods tend to be text mining and bibliometric analysis at the

[10] In this approach, an ontological model of a trend is established, which is then used to analyse segments of a text containing external signs of the existence of a trend.

[11] TRIZ (or TIPS) can be used in combination with text mining to identify the maturity (or life cycle stage) of a given technology examined by comparing its characteristics with universal evolutionary patterns.

data processing stage and cluster and network analysis at the data structuring and visualization stage. In the majority of cases, they are combined with other supporting methods (principle component analysis, trend analysis, ontological modelling, etc.).

The combination of technology monitoring theories and practices aims to introduce a wider use of quantitative methods and automated procedures during large-scale applied projects, which, at present, are predominantly carried out on the basis of expert knowledge. The complexity of this task is caused by the highly resource-intensive nature of automated approaches when spread across the entire spectrum of technological fields. The expansion and increasing sophistication of analytical toolkits will make it possible to diversify the range of information sources used and, ultimately, increase the evidence base and effectiveness of technology trends monitoring. F

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