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THE IDENTIFICATION OF WEAK SIGNALS AND WILD CARDS IN FORESIGHT METHODOLOGY: STAGES AND METHODS

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THE IDENTIFICATION OF WEAK SIGNALS AND WILD CARDS IN FORESIGHT METHODOLOGY: STAGES AND METHODS

This research explores the key stages and methods for the identification of weak signals (WS) and wild cards (WC) in foresight methodology. Theoretical approaches and practical projects in this field were studied, key characteristics and features of these concepts were identified. A review of potential data sources for the monitoring of WS and WC were also provided. The key groups of methods were formed including scanning and monitoring; data analysis; modelling, clustering, interpretation; expert procedures. The stages for identification of WS are proposed. A case study devoted to WS for the analysis of technology development of bioprinting is considered.

JEL Classification: O31, O32, O33.

Keywords: weak signals, wild cards, bioprinting, foresight, scanning, analysis

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Introduction

Recently the areas of science and technology (S&T) and innovation have been developing quickly; there have been significant achievements in information and communication technologies, energy, bio- and nanotechnologies. At the same time, growing socio-economic instability and the need to respond to global challenges require new instruments for managing S&T. There has been growth in the number of foresight studies; foresight methodology has been becoming an indispensible stage in the formation of S&T and innovation policies in many countries. In foresight there are many methods and approaches aimed at an evidential justification of forecast estimates and a decrease in uncertainty. The identification of weak signals (WS) and wild cards (WC) is one actively developing area which is now at the centre of attention of researchers and experts.

The term WS was introduced by the mathematician and economist Igor Ansoff. He considered them to be early and uncertain signs of important events applied to strategic management in organizations [Ansoff, 1989]. To analyse a WS Ansoff suggested using three filters: observation (to obtain the information), the "mentality" filter (to indicate the relevance and significance of the signal based on existing experience) and the "power" filter (to apply the acquired knowledge in the decision making process). While WS were introduced in 1975, today because of the rapid development of foresight methods and the increasing need to manage uncertainty they are experiencing a rebirth. The timely identification and interpretation of WS reveals the signs of future changes, preventing or to reducing the costs of negative events both at the company level and on a global scale.

Due to the comparative immaturity of the conceptions of WS and WC, there are no established methodological principles for their identification in the academic literature and practical projects; moreover, there are even some discrepancies in the definitions of these terms. Therefore this research identifies their key features and develops a methodological basis for their identification using a detailed literature analysis. As an example, a WS analysis of the technological development of bio-printing is considered.

1. Weak signals and wild cards: definitions and main features

1.1 Weak signals

The concept of WS is now actively developing although researchers have suggested different definitions for this term. A literature analysis identifies similarities and differences in these definitions. For example, Saritas and Smith [2011] describe them as "the early signs of possible but not confirmed changes that may later become more significant indicators of critical

forces for development, threats, business and technical innovation. They represent the first signs of paradigm shifts, or future trends, drivers or discontinuities". Lambert and Sidhom [2011] point at a great impact of WS for the future. Hiltunen [2008] and Kamppinen, Kuusi and Söderland [2002] indicate that WS are "current oddities, strange issues that are thought to be in a key position in anticipating future changes in organizational environments" or "an individual event or a group of inter-related events, which may not seem important initially, but develop into significant phenomena in shaping the future". The authors analyse WS with an emphasis on changes in the economy and provide examples of WS such as market volatility, changes in prices and consumer preferences, and the launch of new products. On the other hand, some experts assume that uncertainty is a more important feature of WS. For instance, Caraca, Cardoso and Mendonca, [2012] presents WS as "gross, unstructured, fragmented, incomplete and inadvertent environmental data that may be refined into valuable information regarding context and further be articulated into strategically actionable knowledge". Saul [2006] complements this definition and considers them "ambiguous and controversial bits of information about the competitive environment that are typically hidden among the "noise" of the prevailing sense-making paradigm and that gradually coalesce to form a pattern of intelligence that alerts sensitive leaders that it may be time to change their game".

Although many authors certainly indicate that WS often testify to future negative changes, some research also concentrate on positive effects. For example, Ansoff [1984] studies WS as "the first symptoms of strategic discontinuities, i.e. symptoms of possible change in the future, acting as warning signs or signs of new possibilities". Glossary [2014] specifies that WS can be "a novel situation/new trend created by unforeseen recurrent events".

To sum up, we could define WS as events which characterize a high degree of uncertainty and lag time, there is at the start no complete and relevant information about their consequences, but they indicate future changes and can lead to serious transformations in the current social and economic situation; sometimes WS may be harbingers of disruptive events or witnesses to new possibilities.

On the basis of these definitions (for the full list see Attachment A) key features are: the uncertainty of the consequences, incomplete information and complexity of interpretation, lag time, the ability to become a new trend or to lead to significant changes in the future.

There are also attempts in the literature to classify WS. For example, Hiltunen [2008] divides them into objective WS which can be applied in all areas and subjective which are more important for specific fields. Van Rij [2012] sorts WS depending on their origin and divides them into social which are produced by peoples (such as conferences) and physical which can be evaluated by scientific methods (such as an analysis of earthquakes or disease symptoms).

1.2 Wild cards

WC are strictly linked with WS. Accordingly to Moijanen [2003] WC are WS which "last for a short time". Cooper et al. [2011] points out the connection between WC and WS, describing WC as "unexpected events with high impact in the future that can be predicted with the help of weak signals analysis". Caraca, Cardoso and Mendonca [2012] deny this dependence considering WC surprising occurrences "for which there was no early weak signals". Accordingly to Kaivo-oja [2012] the concepts of WS and WC have the following differences: probability of WC is lower but their impact is higher. WS have a lower level of uncertainty than WC (see the Fig. 1).

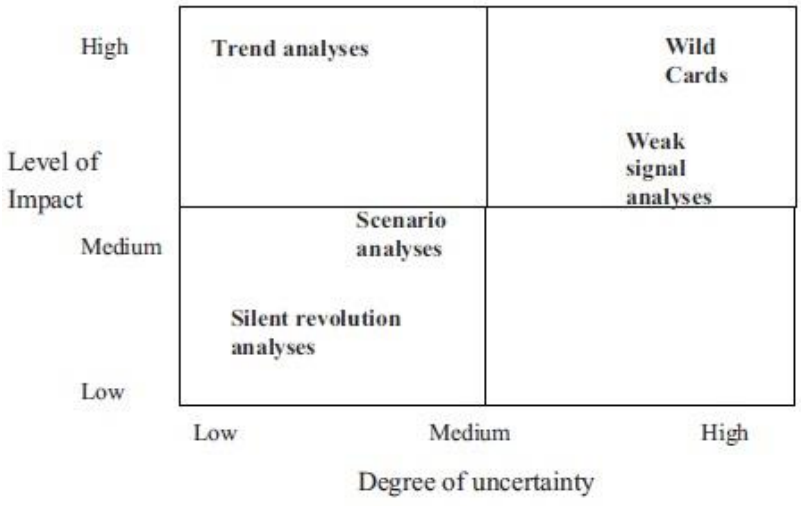

Fig. 1. The impact–uncertainty matrix and futures research methods [Kaivo-oja, 2012].

One of the main features of WC is their erratic character: Kaivo-oja et al. [2004] indicates that they are "sudden and unique incidents that can constitute turning points in the evolution of a certain trend". Petersen [2001] provides another definition of WC: "low probability, high impact events that happen quickly" This is supported by Amanatidou et al. [2012] and Saritas and Smith [2011] who emphasize the low probability of their occurrence. Kaivo-oja et al. [2004] regards them as "phenomena that will have large and immediate consequences for organizational stakeholders if they take place". Earthquakes, cyclones, tsunami, meteorite falls are frequently named as typical examples of WC. On the other hand, WC can be seen in other fields, for instance, 9/11, the fall of the Berlin Wall and the seizure of the company are proper WC that are difficult to identify.

The key features of WC are their inability to be anticipated, their low chance of occurrence and high impact on the economy and society. The literature reveals a few classifications:

1) Van Rij [2012] identifies natural and human WC depending on their origin;

2) by the character of the consequences there are positive WC (for example, the launch of innovative green product) and negative WC (terrorist attack);
3) according to the scale of the impact WC can be local (the flood in Japan) or global (meteorite fall);
4) in agreement with their development WC are divided into continuous (financial crisis) and instant (the resignation of the president);
5) Kaivo-oja et al. [2009] analyse WC based on the sphere of influence and classify them as economic (a sharp drop in the exchange rate), political (an unscheduled meeting of heads of state), social (the creation of a new civil society organization), ecological (a tsunami), or technological (a breakthrough in research);
6) Hiltunen [2006] divides WC into reversible (a stock market crash) and irreversible (the displacement of the Earth's axis).

2. The goals of Weak Signal and Wild Card identification

The concept of WS and WC can be applied in different spheres such as policy, R&D, strategic management. For example, in policy WS and WC identification is aimed at improving the effectiveness of the current policy and its appropriate adjustment. Amanatidou et al. [2012] highlight the priority of informing politicians about life changes, new threats or possibilities, establishing priority areas of policy correction, which contribute to more effective decision making. According to Dubois and Smith [2010] WS and WC are used for anticipating potential developments of European regions.

In S&T, WS and WC identification allows the analysis of possible developments in technological trends, forecasting new tendencies, disruptive innovations and emerging technologies; thereby, new possibilities, risks and the most important objectives of the research can be determined.

Many experts focus on detecting WS and WC in business, especially in strategic management because their analysis may improve a company's efficiency. The literature review indicates the main tasks which can be solved with help of WS and WC:

1) the identification of new possibilities and increasing competitiveness [Cooper et al, 2011];
2) an analysis of the consequences of current strategies and decisions that have already been taken [Calcei et al, 2013];
3) the specification of future spheres of company's activity [Ilmola, Kuusi, 2006];
4) risk analysis [Darkow, Gracht, Markmann, 2013];

5) preparation for possible negative events [Goodwin, Wright, 2010];
6) forecasting changes and the reduction of uncertainty [Halal, 2013];
7) the identification of market entrance and exit barriers [Prahalad, 1995];
8) the establishment of tendencies influencing the business environment [Yoon, 2012].

The development of the innovation potential of employees is one of the ways to improve company efficiency. Hiltunen [2007] says WS and WC identification will contribute to developing innovative thinking in employees, and enhance their motivation.

The identification is also essential in other areas such as the natural environment (to anticipate natural disasters [Harremoës, 2001]), and economics (to predict financial crises [Ojala, Uskali, 2006]).

3. Sources of Weak Signal and Wild Card identification

Choosing the relevant sources of information is one of the main issues in identifying WS and WC. The majority of researchers divide them into three categories: human, textual and online sources [Hiltunen, 2008]. The first group consists of experts such as futurists, scientists, and colleagues [Cooper et al, 2011]. Textual sources are reports, databases, academic or scientific journals, media, science fiction and so on [Cooper et al, 2011; Hiltunen, 2008]. Blogs, Internet resources and databases are examples of online sources of information.

According to Hiltunen [2008] there is a classification of sources for WS depending on the following fields:

Politics	Politicians, civil servants and citizens, media, scientists, futurists
Economics	Futurists, consultants, academic and scientific journals, colleagues, market research, university reports, study materials
Society	Futurists, civil citizens, media, academic and scientific journals, people of culture and art, television and radio
S&T	Scientists, futurists, academic, scientific and economic journals, university reports, scientific films and books, colleagues, Internet, study materials
Ecology	Scientists, university reports, colleagues, academic and scientific journals, Government reports, futurists, consultants, study materials, media
Education	Futurists, colleagues, scientists, consultants, academic, scientific and economic journals, study materials, scientific films and books

4. Methods for Weak Signal and Wild Card identification

An analysis of theoretical approaches and foreign experience shows that the methodology for WS and WC can differ, and be based on qualitative and quantitative measures depending on the goals and limitations of the research. However, it is possible to establish key groups of methods for WS and WC identification. They are presented below.

4.1. Scanning and monitoring

Almost every study, after establishing goals and objectives starts with the scanning and monitoring of the external and internal environments for WS identification. Environmental scanning (or horizon scanning) is used for this purpose; it analyses "potential opportunities, challenges, and likely future developments" for a concrete company or an area [Jackson, 2013]. According to Amanatidou et al. [2012] there are two stages of horizon scanning: exploratory and issue-centred scanning. Exploratory scanning is aimed at WS and WC identification, the detection of the search profile by key words, broad scanning, first evaluation, selection and clustering of WS. There are some steps of issue-centred scanning: the analysis and processing of current WS and WC, literature reviews, the analysis of additional sources and the identification of second WS. Pang [2010] mentions social scanning consisting of "aggregating and analysing publicly available content created by futurists and shared on blogs and other social software platforms". The majority of researchers apply scanning methods to a particular field.

4.2. Modelling, clustering and interpretation

This group of methods is also needed for WS and WC identification as it helps create the required model for analysis, and the forming and interpreting of groups of similar signals. For example, Hiltunen and Kuusi [2007] used the semiotic Peirce model for the identification of potential WS (especially in the methodology of future-oriented signification process) (see the Fig. 2).

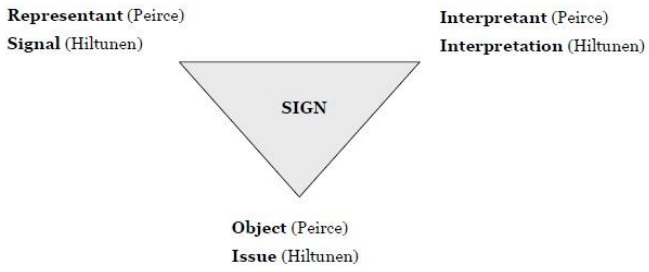

Fig. 2. Semiotic three-dimensional Peirce's model in Hiltunen's interpretation [Hiltunen, Kuusi, 2007].

The figure shows that the model consists of three elements: object (issue), representant, a sign emerging in response to the object (signal), and interpretant (interpretation). For WS the

model describes the following: when, for example, a person reads news about a sharp increase in the dollar exchange rate (object), he analyses its impact on different spheres (representant) and then evaluates potential consequences for his own life (individual interpretation).

Jackson [2013] applied a *Futures Wheel* aimed at the "graphical visualization of direct and indirect future consequences of a change or development**"** for modelling and analysing the impact of trends. There are many different software and tools for clustering data. For example, in Tabatabaei [2011] it is shown that CLUTO software is effective in clustering data and how it can be used for WS identification. Some authors [Poel, Thorleuchter, 2012] have used a semantic clustering approach to group documents with similar meaning for the further detection of WS. This method is based on getting WS from information provided in different forms, styles and contexts. In general, modelling and clustering methods are connected with scanning approaches because they contribute to creating a more relevant sample of documents for WS analysis.

4.3. Expert procedures

These methods are the most common among foresight technologies as they are universal and can be applied in different spheres. Expert interviews, workshops, and Delphi are frequently used for WS and WC identification. Many scientists have emphasized the significance of brainstorming and described it as one of the main methods for WS and WC detection. Saritas and Smith [2011] study future-oriented technology analysis (FTA), which consists of conducting a survey in a conference format about WS, WC, and drivers. It is essential to conduct survey polls and focus groups with experts in order to collect basic information about WS and WC and then to validate and interpret this information during the final stages of the analysis.

4.4. Data analysis

The last group of methods for identification of WS and WC consists of technologies aimed at data analysis. In addition to scanning Yoon [2012] has used web mining comprising an intellectual analysis of web content. A Strategic Early Warning System (SEWS) is applied for strategic risk evaluation as indicated in Rossel [2011]. This approach obtains information, analyses it, and develops appropriate strategies according to the context. A few researchers exploit deductive or inductive data analysis to detect WS [Cooper et al, 2011]. The sense making process is based on data analysis, as described in Ilmola and Kuusi [2006], and this method creates "a socially constructed mental model about the business environment" to anticipate unexpected changes and the model of the formation of organizational cognition in a turbulent environment.

A brief analysis of the methods for WS and WC identification shows that they can be applied both separately and in combination. However, the combination of methods from different groups is more effective: without data analysis and scanning a strategy of WS detection cannot be realized, clustering helps getting more reliable documents and latent information about potential signals. Expert opinions allow researchers to form a complete picture of the situation while they are applied throughout all stages of analysis.

5. Stages of weak signals identification

A detailed analysis of the literature containing theoretical approaches and practical examples makes it possible to establish key steps in WS identification which form the basis for methodology development[3]. These steps consist of:

1. The determination of the goals, main tasks and the scale of the research
2. Environmental scanning
    2.1. The creation of information and the analytical base
    2.2. Filtering and sorting information
3. The identification and clustering of WS
    3.1. The clustering of documents
    3.2. Detecting potential WS
    3.3. The validation of WS
4. Conclusions and recommendations

Next, each stage will be analysed in detail.

1. The determination of the goals, main tasks and the scale of the research

This preparatory stage involves the formulation of the objectives and the goals of the study and defines the scale of the research. This step assumes the development of hypotheses, a detailed methodology of the project and expert selection.

2. Environmental scanning

2.1. The creation of information and the analytical base

Environmental scanning is the first substantial step comprising the formation of the analytical base with all the relevant information about the subject area along with the external environment influencing its development. There are many different methods at this stage, however, invited experts play the most important role because they take part in surveys or collect

[3] In this and the next chapters we concentrate mostly on key stages for WS identification, however the proposed stages could be applicable to some extend for WC identification also.

the information using internal and external analysis [Miles, Saritas, 2012]. With the help of key words, special software and applications (for example, DEVONagent [Tabatabaei, 2011], advanced programming interfaces (APIs) [Poel, Thorleuchter, 2012]) and manual browsing of the internet and media experts obtain appropriate information. Web mining, social scanning, expert panels, interviews, and FTA, can be applied for this purpose. This step can also contain the development of an electronic platform with a network of experts, which includes results of the studies, articles, conference materials in various areas [Bae et al, 2013]. For companies, WS identification is often accomplished through expert analysis of the external and internal organizational environment [Battistella, De Toni, 2011].

2.2. Filtering and sorting information

At the next stage the information should be processed and filtered. To do this experts and analysts select relevant documents by means of quantitative (knowledge matrix) and qualitative (brainstorming) methods [Bae et al, 2013]. However, the majority of researchers use specialized programs, applications and methods for data processing such as sorting and deleting repeating information by DEVONthink [Tabatabaei, 2011], stop-words removal, and tokenization. Elimination of irrelevant and repeated information [Poel, Thorleuchter, 2012] is a mandatory step which can be done with the help of automated filtering algorithms [Poel et al, 2014]. Some experts apply bibliometric and semantic analysis as well as statistical methods to filter data more effectively [Miles, Saritas, 2012].

3. Identification and clustering of weak signals

3.1. Clustering of documents

Clustering is an essential step in WS identification. By means of different instruments experts create groups of clusters [Amanatidou et al, 2012] which are sorted by the criteria of relevance and the uncertainty of the information. For this purpose all data should be in a unified format, for example, a matrix or Doc2mat file with its further loading in CLUTO software [Tabatabaei, 2011]. Some researchers use semantic clustering based on LSI and WS maximization to indicate similar groups of data [Poel et al, 2014]. Vejlgaard's Diamond Shaped Trend Model, statistical methods, programs and applications for clustering and processing the information (UCINET, PAJEK), bibliometric and semantic analysis, Futures Wheel, morphological search and analysis are potential methods for clustering and grouping information. The final stage of clustering consists of the analysis of the clusters along with detected WS and trends in accordance with STEEPV analysis (Social, Technological, Economic, Environmental/Ecological, Political and Value-based issues) [Saritas, Smith, 2011].

3.2. Detecting potential weak signals

In order to provide more effective data processing and the identification of potential WS, experts analyse selected documents and clusters using statistical methods (Spearman's correlation, Wilcoxon test) [Tabatabaei, 2011]. They detect trends and development scenarios with the help of Hiltunen's model or Delphi and investigate the company's development, their products and vision [Battistella, De Toni, 2011]. In some cases a special team creates indicators of effectiveness of the development scenarios with further risk analysis and monitoring [Gilad, 2003].

3.3. Validation of weak signals

Experts and analysts brainstorm to work out the criteria of WS identification such as the probability of occurrence and level of impact, and evaluate their significance by means of text mining, conferences and consultations [Amanatidou et al, 2012]. Results of these surveys are actively used during the validation of WS.

4. Conclusion and recommendations

The final step of WS identification is the development of subsequent actions and recommendations concerning the detected WS. For this purpose using different instruments, experts participating in the previous steps define the potential effect of WS on the further development of the subject area, confirm or refute established hypotheses, create scenarios, define risks and possibilities. This stage results in recommendations to adjust the strategy of the development of a subject area, to take management decisions and to create proposals to amend the science, technology and innovation policy.

6. Case study: bioprinting

To demonstrate how the analysis of WS works, in this section a case study devoted to development of bioprinting is considered. The technology of bioprinting (3D-printing of organs) has become popular since bioengineer Thomas Boland (Clemson University) received his first patent to print cells [The Economist, 8 March, 2014]. Initially, the invention of a 3D printer and its successful implementation of the creation of different volumetric details led to the development of bioprinting field: it became clear that this technology would have a huge range of applications in medicine. The most active companies in this sphere are from USA (Organovo, founded in 2007), Japan (CyFuse, founded in 2010) and Switzerland (RegenHu, established in 2007). Bioprinting is also developing in Russia, where the first bioprinter appeared in 2014 in the laboratory 3D Bioprinting Solutions [Novgorodskaya, 6 November, 2014]. The same year Skolkovo organized the first International Conference on 3D Bioprinting [Mungalov, 21 October, 2014]. Experiments in printing various animal organs (blood vessels, bladder, liver,

kidneys) are being carried out in these countries. To analyse the possible directions of development of bioprinting in the future, the analysis of WS following the stages described in the previous section is provided.

1. *The determination of the goals, the main tasks and the scale of the research*

The study evaluates the areas of development of 3D bioprinting analyses the risks and barriers, the terms of technological breakthroughs and the potential size of the market. Potential experts and actors are medical scientists, investors, and healthcare representatives of universities, media and government.

2. *Environmental scanning*

The information base of the project consists of scientific articles in the medical field, reports on experiments in printing organs and their implantation into the body (only animals), conference reports on relevant issues, web search results by keywords (such as bioprinting, organ printing, genetics, 3D printer), news about investments in prospective projects and companies (Skolkovo, private investors), the analysis of companies engaged in the creation of 3D bioprinters, and reports of university laboratories.

While sorting the information it should be filtered, all irrelevant and unreliable information has to be deleted with help of different approaches: stop-words removal, statistical methods, programs for data processing.

3. *Identification of weak signals*

After the information was processed it should be clustered in accordance with different criteria. In this study, potential WS were classified regarding timeline and STEEPV. As an example, WS received by analysis of media sources are presented at the tables below.

Technological signals:

2013	• Organovo anticipated that due to bioprinting the lifespan and size of tissue samples will be increased [Liat, 24 Apr., 2013] • Michael McAlpine (Princeton University) predicted the replacement of human organs with synthetic ones (electronic) [Telegraph, 2013]
2014	• 3D Bioprinting Solutions will print hair on the human head by bioprinter [Novgorodskaya, 6 Nov., 2014] • Ibrahim Ozbolat (Organovo) said that mini-organs printed with bioprinters will maintain their function [The Economist, 8 March, 2014] • James Yoo (Wake Forest Institute for Regenerative Medicine) has anticipated the creation of biomask—a three-dimensional facial imprint [Mungalov, 21 Oct., 2014]
2015	• Lawrence Bonassar (Cornell University) predicts the development of "living prosthetics" using bioprinting [Szczerba, 24 June, 2015] • L'Oreal together with Organovo is engaged in creating human skin for product testing [Rhodes, 28 May, 2015]
2019	• Takanori Takebe from Yokohama City said that he will generate and transplant artificially grown human liver by 2019 [Gnedinskaya, 15 Apr., 2015]
2027	• Italian design firm MHOX plans to create a human eye on a 3D bioprinter by

	2027 [Gnedinskaya, 15 Apr., 2015]
2030	• Yusef Khesuani ("3D Bioprinting Solutions") said that there will be the first transplant of artificially grown body parts in 2030 [Gnedinskaya, 15 Apr., 2015] • William Warren has predicted that in 2030 it will possible to print tissue with enough vascular and scaffold support to replace organs [Mearian, 21 May, 2015]

Economic signals:

2014	• Vladimir Mironov ("3D Bioprinting Solutions") estimated a price reduction for bioprinters in the near future [Novgorodskaya, 6 Nov., 2014]
2018	• Gartner says that by 2018 the bioprinting industry will lose approximately $100 billion because of problems with intellectual property [Cooney, 7 Oct., 2013] • Visiongain predicted that the 3D printing market for healthcare will reach $4 billion [Gartner, 17 Jan., 2014]
2021	• Vladimir Mironov said that the first 3D printed organ will appear on the market in 2021 considering the high costs and extremely complex regulations for bioprinted organs [Mironov, 2011]
2025	• Lux Research claimed the market for 3D printing is expected to grow to $8.4bn by 2025 but 3D bioprinting's contribution will be negligible by that stage [Nanalyze, 14 Feb., 2014]

Social signals:

2013	• Ibrahim Ozbolat (Organovo) said that bioprinting can help "surgeons practice before entering an operating room" [Leckart, 6 Aug., 2013]
2014	• Ostrovskiy ("3D Bioprinting Solutions" CEO) said that bioprinting technologies will solve the problem of donor organs shortage whole over the world [Invitro, 11 Dec., 2014] • Australian and German universities announced an educational program BIOFAB (Biofabrication Training for Future Manufacturing) [Sher, 10 Feb., 2014]
2015	• Susan Dodds (University of Tasmania) claimed that personalized medicine will have problems with discrimination risk because of high costs of bioprinted organs [Dodds, 11 Feb., 2015]

Political signals:

2014	• The meeting of the presidium of the Presidential Council of economic modernization and innovative development of Russian Federation insisted on the need for legislative regulation of biotechnologies (documents are under development). [Invitro, 11 Dec., 2014]
2016	• Gartner said that bioprinting will cause "a global debate about regulating the technology or banning it for both human and nonhuman use". [Cooney, 7 Oct., 2013]

Ecological signals:

2015	• Researchers from Chalmers University of Technology (Sweden) estimated that bioprinters will use renewable commodities to produce organs [Chalmers University of technology, 17 June, 2015]

Value signals:

2016	• Gartner predicts that there will be great arguments concerning ethical problems with bioprinting as well as intellectual property issues. [Cooney, 7 Oct., 2013]

4. Conclusion and recommendations

Based on the study of the analysis of WS for the development of bioprinting some conclusions can be drawn. Firstly, many signals indicate a further rapid development of bioprinting. MIT has already called bioprinting a key technology that will form the basis for regenerative medicine [MIT, 2014]. Australian and German universities have launched educational program BIOFAB (Biofabrication Training for Future Manufacturing) [Sher, 10 Feb., 2014]. Undoubtedly, the number of conferences and forums as well as companies participating in bioprinting will increase. Secondly, some signals specify potential risks and barriers to the development of these technologies. Among them ethical risks are the most essential and barriers primarily will relate to issues of intellectual property protection, legislative regulation and the difficulties of solving technological tasks (for example, Brian Derby from the University of Manchester predicted that creating the necessary blood flow and vascular structure is one of the fundamental problems of bioprinting because the organism has to accept the new organs) [The Economist, 8 March, 2014]. Thirdly, many WS concern the terms and types of the future technological revolution of bioprinting. It is estimated that in 2019 it will be possible to print and transplant a human liver [Gnedinskaya, 15 Apr., 2015], skin to treat deep burns in 2020 [Wake Forest School of Medicine, 4 Jan., 2015], a heart from human cells in 2023 [Liat, 21 Nov., 2013], a synthetic human eye in 2027 [Ossola, 21 Apr., 2015] and tissue with enough vascular and scaffold support to replace organs in 2030 [Mearian, 21 May, 2015].

Conclusion

In this paper the instruments of WS and WC in foresight methodology were analysed. The research revealed that the key features of WS are uncertainty of consequences, incomplete information, lag time, the ability to become a source of new trend and to lead to serious changes in the future. WC can be characterized by their complexity or impossibility of early prediction, low probability and, if implemented, high influence on economic and society. A comparative analysis showed a significant correlation between these two concepts. WS are often preceded by WC and concede to them concerning the power of impact and consequences. Many experts and researchers agree that the timely identification of WS and WC would help avoid such accidents as wars, crises and global catastrophes.

The research proposes the following stages for identification of WS: a determination of the goals, main tasks and scale of the research; environmental scanning; the identification and clustering of WS; conclusions and recommendations. For each stage methods that could be applied are suggested. These steps form the basis for the methodology of WS identification,

which can be specified and complemented depending on the specific objectives of the study. To illustrate this process an identification of WS for the development of bioprinting was considered as a case study.

Finally, the identification of WS and WC is a crucial tool in many areas in which future uncertainty needs to be reduced for more effective decision making. On a national level they can lead to the formation and adjustment of the S&T and innovation policy, the creation of a long-term vision and the advanced identification of threats and risks. Furthermore, WS may help indicate tipping points of current tendencies (also disruptive) and detect prospective areas of innovative development. As for the corporate level, the analysis of WS and WC is an effective and widespread method in this sphere. By means of this technology companies form flexible strategies for their development, adapt the organization to environmental changes, develop the innovation potential of their workers, evaluate risks and manage different projects.

References

1. Aho, S., Kaivo-oja, J., Myllylä,Y., Sajeva, M. (2011). iKnow Delphi 2.0. National Survey. Country Report Finland. iKnow Project.

2. Ansoff, I. (1989), *Strategic management* [Strategicheskoe upravlenie], Economics, Moscow.

3. Ansoff, H.I. (1984). Implanting Strategic Management, Prentice-Hall International, London.

4. Amanatidou, E., Butter, M., Carabias, V., Könnölä, T., Leis, M., Saritas, O., van Rij, V. (2012). On concepts and methods in horizon scanning: lessons from initiating policy dialogues on emerging issues. *Science and Public Policy*, *39* (2), 208-221.

5. Bae, K., Choi, H., Choi, S., Hong, S., Kang, H., Kim, S., Kim, Y., Koo, Y., Park, J., Park, Y. (2013). NEST: a quantitative model for detecting emerging trends using a global monitoring expert network and Bayesian network. *Futures*, *52*, 59-73.

6. Battistella, C., De Toni, A. (2011) A methodology of technological foresight: a proposal and field study. *Technological Forecasting & Social Change*, *78*, 1029–1048.

7. BIPE Conseil Institute for Future Studies & Institute for the Future, Wild Cards: A Multinational Perspective, Institute for the Future, Palo Alto, CA, 1992.

8. Calcei, D., Delatour, G., Laclemence, P., Mazri, C. (2013) Blind managers, systems complexity and weak signals, Proceedings of 22nd International Business Research Conference, Madrid, Spain.

9. Caraca, J., Cardoso, G., Mendonca, S. (2012). The strategic strength of weak signal analysis. *Futures*, *44*, 218-228.

10. Cellulose from wood can be printed in 3-D. (2015, June 17). Chalmers University of technology, Retrieved from http://www.rdmag.com/news/2015/06/cellulose-wood-can-be-printed-3-d

11. Coffman, B. (2011). Weak Signal Research. *Journal of Transition Management*. MG Taylor Corporation.

12. Cooney, M. (2013, Oct. 7). Gartner: Top 10 future strategic IT predictions. *Network World*, Retrieved from http://www.networkworld.com/article/2225521/malware-cybercrime/gartner--top-10-future-strategic-it-predictions.html

13. Cooper, A., Kravcik, M., Pawlowski, J., Pirkkalainen, H., Unterfrauner, E., Voigt, C. (2011). Report on Weak Signals Collection, European Commission Seventh Framework Project.

14. Cornish, E. (2008). The wild cards in our future. Futurist, 37, 18-22.

15. CyFuse, Retrieved from http://www.cyfusebio.com/en/corporate.html

16. Darkow, I., Gracht, H., Markmann, C. (2013). A delphi-based risk analysis - identifying and assessing future challenges for supply chain security in a multi-stakeholder environment. *Technological Forecasting and Social Change, 80* (9), 1815-1833.

17. Dodds, S. (2015, Feb. 11). 3D printing raises ethical issues in medicine. *ABC Science*, Retrieved from http://www.abc.net.au/science/articles/2015/02/11/4161675.htm

18. Dubois, A., Smith, C. J. (2010). The 'Wild Cards' of European futures: planning for discontinuities? *Futures, 42*, 846-855.

19. Gilad, B. (2003). *Early Warning: Using Competitive Intelligence to Anticipate Market Shifts, Control Risk, and Create Powerful Strategies*. AMACOM.

20. Glossary of Terms commonly used in Future Studies (2014), Forward Thinking Problem, The Global Forum on Agricultural Research.

21. Gnedinskaya, A. (2015, Apr. 15). 3D bioprinting: how to print a man of the future (3D bioprinting: kak napechatat cheloveka iz buduchego). *MK*, Retrieved from http://www.mk.ru/science/2015/04/15/3dbioprinting-kak-napechatat-cheloveka-budushhego.html

22. Godet, M., Coates, J.F. Degenhardt, C. (1994). From anticipation to action: a handbook of strategic prospective. UNESCO Publishing.

23. Goodwin, P., Wright, G. (2010). The limits of forecasting methods in anticipating rare events. *Technological Forecasting & Social Change, 77*, 355–368.

24. Halal, W. (2013). Forecasting the technology revolution: results and learnings from the TechCast Project. *Technological Forecasting & Social Change, 80*, 1635–1643.

25. Harris, S.D., Zeisler S. (2002). Weak signals: Detecting the next big thing. The Futurist, 36 (6), 21-28.

26. Harremoës, P. (2001). Late lessons from early warnings: the precautionary principle 1896-2000, Environmental Issue Report no 22. Office for Official Publications of the European Communities, Luxembourg.

27. Hiltunen, E., Kotro, T., Lindh-Knuutila, T. (2009). How to analyze various consumer data in the future. *Future of the Consumer Society*.

28. Hiltunen, E., Kuusi, O. (2007). The signification process of the future sign, Finland Futures Research Centre FFRC eBook.

29. Hiltunen, E. (2008). Good sources of weak signals: a global study of where futurists look for weak signals. Journal of Futures Studies, 2 (4), 21-44.

30. Hiltunen, E., Kotro, T., Lindh-Knuutila, T. (2009) How to analyze various consumer data in the future. Future of the Consumer Society.

31. Hiltunen, E. (2008). The Future Sign and Its Three Dimensions. *Futures, 40* (3), 247-260.

32. Hiltunen, E. (2007). The Futures Window – A medium for presenting visual weak signals to trigger employees' futures thinking in organizations. Helsinki School of Economics.

33. Hiltunen, E. (2006). Was it a wild card or just our blindness to gradual change? *Journal of Future Studies, 11* (2), 61-74.

34. Hiltunen, E. (2007). Weak Signals, Presentation given at the Finland Futures Research Centre, Available at: http://www.slideshare.net/whatidiscover/weaksignals

35. Ilmola, L., Kuusi, O. (2006). Filters of weak signals hinder foresight: monitoring weak signals efficiently in corporate decision making. *Futures, 38*, 908–924.

36. Investing in 3D Bioprinting (2014, Feb. 14). *Nanalyze*, Retrieved from http://www.nanalyze.com/2014/02/investing-in-3d-bioprinting/

37. Jackson, M. (2013). *Practical Foresight Guide*. Shaping Tomorrow.

38. Kaivo-oja, J. (2012). Weak signals analysis, knowledge management theory and systemic socio-cultural transitions. *Futures, 44*, 206–217.

39. Kaivo-oja, J., Mendonca, S., Pina e Cunha, M., Ruff, F. (2004). Wild cards, weak signals and organizational improvisation. *Futures, 36* (2), 201-218.

40. Kaivo-oja, J., Mendonca, S., Pina e Cunha, M., Ruff, F. (2009). Venturing into wilderness. Preparing for Wild cards in the Civil Aircraft and Asset-Management industries. *Long Range Planning, 42* (1), 23-41.

41. Kamppinen, M.,O.Kuusi, and S. Söderlund. 2002. Tulevaisuudentutkimus, Perusteet ja sovellukset (in Finnish). Helsinki: Suomalaisen Kirjallisuuden Seura.

42. Lambert, P., Sidhom, S. (2011). Information design for «Weak Signal» detection and processing in economic intelligence: A case study on health resources. *Journal of Intelligence Studies in Business*, 1, 40-48.

43. Leckart, S. (2013, Aug. 6). How 3-D printing body parts will revolutionize medicine. *Popular Science*, Retrieved from http://www.popsci.com/science/article/2013-07/how-3-d-printing-body-parts-will-revolutionize-medicine

44. Liat, C. (2013, Apr. 24). Bioengineers 3D print tiny functioning human liver. *Wired*, Retrieved from http://www.wired.co.uk/news/archive/2013-04/24/3d-printed-liver

45. Liat, C. (2013, Nov. 21). Bioengineer: the heart is one of the easiest organs to bioprint, we'll do it in a decade. *Wired*, Retrieved from http://www.wired.co.uk/news/archive/2013-11/21/3d-printed-whole-heart

46. Mearian, L. (2015, May 21). Organs may someday be printed inside people, Retrieved from http://www.computerworld.com/article/2925123/3d-printing/organs-may-someday-be-printed-inside-people.html

47. Miles, I., Saritas, O. (2012). Scan-4-Light: a searchlight function horizon scanning and trend monitoring project. *Foresight, 14* (6), 489-510.

48. Mironov, V. (2011) The future of medicine: are custom-printed organs on the horizon? *Futurist*, Retrieved from http://www.wfs.org/content/future-medicine-are-custom-printed-organs-horizon

49. MIT Technology Review www.technologyreview.com

50. Moijanen, M. (2003). Heikot signaalit tulevaisuuden tutkimuksessa (Weak signals in futures studies), *Futura*, 4, 38–60.

51. Moscow became a center of the world bioprinting (2014, Dec. 11) (Moskva stala centrum mirovogo bioprintinga). Invitro, Retrieved from https://www.invitro.ru/doctors/science/2014/12/28431/

52. Mungalov, D. (2014, Oct. 21). Skolkovo helds the bioprinting conference (V Skolkovo prohodit konferencia po bioprintingu), Retrieved from http://sk.ru/news/b/news/archive/2014/10/21/v-skolkovo-prohodit-konferenciya-po-bioprintingu.aspx

53. Novgorodskaya, T. (2014, Nov. 6). 3D bioprinters will argue with nature (3D biopriteri posporyat s prirodoi). *S&TRF*, Retrieved from http://strf.ru/material.aspx?CatalogId=222&d_no=88725#.VWYf5NLtmko

54. Ojala, J., Uskali, T. (2006). Any weak signals? The New York Times and the stock market crashes of 1929, 1987 and 2000, XIV International Economic History Congress, Helsinki.

55. Ossola, A. (2015, Apr. 21). Replace your eyeballs with synthetic ones. *Popular Science*, Retrieved from http://www.popsci.com/biotech-startup-wants-replace-your-eyeballs-synthetic-ones

56. Pang, A. (2010). Social scanning: improving futures through web 2.0; or, finally a use for twitter. Futures, 42 (10), 1222-1230.

57. Petersen, J. (2009). How «wild cards» may reshape our future. Futurist, 43, 19-20.

58. Petersen, J. L. (2001). Anticipating global futures. The Arlington Institute, Power Point Presentation.

59. Poel, D., Scheja, T., Thorleuchter, D. (2014). Semantic weak signal tracing. *Expert Systems with Applications*, *41*, 5009–5016.

60. Poel, D., Thorleuchter, D. (2012). Weak signal identification with semantic web mining. *Expert Systems with Applications*, *40* (12), 4978-4985.

61. Prahalad, C.K. (1995). Weak signals versus strong paradigms. *Journal of Marketing Research, XXXII*.

62. Printing a bit of me (2014, March 8). *The Economist*, Retrieved from http://www.economist.com/news/technology-quarterly/21598322-bioprinting-building-living-tissue-3d-printer-becoming-new-business

63. Printing skin cells on burn wounds. (2015, Jan. 4). Wake Forest School of Medicine, Retrieved from http://www.wakehealth.edu/Research/WFIRM/Research/Military-Applications/Printing-Skin-Cells-On-Burn-Wounds.htm

64. regenHU, Retrieved from http://www.ctistartup.ch/en/startups/overview-startups/361-regenhu/

65. Rhodes, M. (2015, May 28). Inside L'Oreal's plan to 3d-print human skin. *Wired*, Retrieved from http://www.wired.com/2015/05/inside-loreals-plan-3-d-print-human-skin/

66. Rossel, P. (2011). Beyond the obvious: examining ways of consolidating early detection schemes. *Technological Forecasting and Social Change*, *78* (3), 375-385.

67. Saritas, O., Smith, J. E. (2011). The Big Picture – trends, drivers, wild cards, discontinuities and weak signals. *Futures, 43*, 292–312.

68. Saul, P. (2006). Seeing the future in weak signals. *Journal of Futures Studies*, *10* (3), 93-102.

69. Scientists 'print' 3D bionic ear (2013, July 3). *Telegraph*, Retrieved from http://www.telegraph.co.uk/news/science/10158886/Scientists-print-3D-bionic-ear.html

70. Sher, D. (2014, Feb. 10). 3D bioprinting inching closer to reality in new utrecht biofabrication facility, Retrieved from http://3dprintingindustry.com/2014/02/10/3d-bioprinting-inching-closer-reality-new-utrecht-biofabrication-facility/

71. Szczerba, R.J. (2015, June 24). New bionic ear can even pick up your favorite radio station. *Forbes*, Retrieved from http://www.forbes.com/sites/robertszczerba/2015/06/24/listen-up-new-bionic-ear-can-even-pick-up-your-favorite-radio-station/

72. Tabatabaei, N. (2011). Detecting weak signals by internet-based environmental scanning, A thesis presented to the University of Waterloo in fulfillment of the thesis requirement for the degree of Master of Applied Science in Management Sciences.

73. The 3D printing market for healthcare will reach $4043 m in 2018, predicts new study. (2014, Jan. 17). *Gartner*, Retrieved from https://www.visiongain.com/Press_Release/553/The-3D-Printing-market-for-Healthcare-will-reach-4043m-in-2018-predicts-new-study

74. Van Rij, V. (2012). New emerging issues and wild cards as future shakers and shapers. *Foresight Russia*, *6* (1), 60-73.

75. Yoon, J. (2012). Detecting weak signals for long-term business opportunities using text mining of web news. *Expert Systems with Applications*, *39* (16), 12543-12550.

Attachments

Attachment A. Definitions of weak signals

Source	Definition of weak signals
Aho, S., Kaivo-oja, J., Myllylä,Y., Sajeva, M. (2011). iKnow Delphi 2.0. National Survey. Country Report Finland. iKnow Project.	"Unclear observables warning us about the probability of future events".
Ansoff, H.I. (1984). Implanting Strategic Management, Prentice-Hall International, London.	"Early indications about mpending impactful events.....all that is known (of them) is that some Threats and Opportunities will undoubtedly arise, but their shape and nature and source are not yet known".
Ansoff, H.I. (1984). Implanting Strategic Management, Prentice-Hall International, London.	"First symptoms of strategic discontinuities, i.e. symptoms of possible change in the future, acting as warning signs or signs of new possibilities".
Caraca, J., Cardoso, G., Mendonca, S. (2012). The strategic strength of weak signal analysis. *Futures*, *44*, 218-228.	"Gross, unstructured, fragmented, incomplete and inadvertent environmental data that may be refined into valuable information regarding context and further be articulated into strategically actionable knowledge".
Coffman, B. (2011). Weak Signal Research. *Journal of Transition Management*. MG Taylor Corporation	"An idea or trend that will affect how we do business, what business we do, and the environment in which we will work".
Godet, M., Coates, J.F. Degenhardt, C. (1994). From anticipation to action: a handbook of strategic prospective. *UNESCO Publishing.*	"Hardly perceivable at present but constitutes a strong trend in the future".

Harris, S.D., Zeisler S. (2002). Weak signals: Detecting the next big thing. *The Futurist*, *36* (6), 21-28.	"Small events, ignored or dismissed by standard future-seeking approaches".
Hiltunen, E. (2008). The Future Sign and Its Three Dimensions. *Futures*, *40* (3), 247-260.	"Current oddities, strange issues that are thought to be in key position in anticipating future changes in organizational environments".
Hiltunen, E. (2007). The Futures Window – A medium for presenting visual weak signals to trigger employees' futures thinking in organizations. Helsinki School of Economics.	"First signs or symptoms of a big change, even megatrends".
Hiltunen, E. (2006). Was it a wild card or just our blindness to gradual change? *Journal of Future Studies*, *11* (2), 61-74.	"Currently existing small and seemingly insignificant issues that can tell us about the changes in the future".
Hiltunen, E. (2007). Weak Signals, Presentation given at the Finland Futures Research Centre, Available at: http://www.slideshare.net/whatidiscover/weaksignals	"Warnings (external or internal), events and developments that are still too incomplete to permit an accurate estimation of their impact and/or to determine their complete responses".
Hiltunen, E., Kotro, T., Lindh-Knuutila, T. (2009) How to analyze various consumer data in the future. Future of the Consumer Society.	"Early information of possible forthcoming changes".
Kaivo-oja, J., Mendonca, S., Pina e Cunha, M., Ruff, F. (2004). Wild cards, weak signals and organizational improvisation. Futures, 36 (2), 201-218.	"Unstructured information with low content value".

Kaivo-oja, J., Mendonca, S., Pina e Cunha, M., Ruff, F. (2004). Wild cards, weak signals and organizational improvisation. *Futures*, *36* (2), 201-218.	"Information on potential change of a system toward an unknown direction".
Rossel, P. (2009). Weak signals as a flexible framing space for enhanced management and decision-making. *Technology Analysis and Strategic Management*, *21* (3), 307-320.	"A series of perceptions of issues, events or processes that might constitute an indication of further developments, possibly impacting our lives in the future".
Saul, P. (2006). Seeing the future in weak signals. *Journal of Futures Studies*, *10* (3), 93-102.	"Ambiguous and controversial bits of information about the competitive environment that are typically hidden among the "noise" of the prevailing sense-making paradigm and that gradually coalesce to form a pattern of intelligence that alerts sensitive leaders that it may be time to change their game".
Yoon, J. (2012). Detecting weak signals for long-term business opportunities using text mining of web news. *Expert Systems with Applications*, *39* (16), 12543-12550.	"Imprecise and early indicators of impending important events or trends, which are considered key to formulating new potential business items".

Attachment B. Definitions of wild cards

Source	**Definition of wild cards**
Aho, S., Kaivo-oja, J., Myllylä,Y., Sajeva, M. (2011). iKnow Delphi 2.0. National Survey. Country Report Finland. iKnow Project.	"Situations/events with perceived low probability of occurrence but potentially high impact if they were to occur".
BIPE Conseil Institute for Future Studies & Institute for the Future, Wild Cards: A Multinational Perspective, Institute for the Future, Palo Alto, CA, 1992.	"A future development or event with a relatively low probably of occurrence but a likely high impact on the conduct of business".

Caraca, J., Cardoso, G., Mendonca, S. (2012). The strategic strength of weak signal analysis. *Futures*, *44*, 218-228.	"Events for which there was no early weak signals".
Cooper, A., Kravcik, M., Pawlowski, J., Pirkkalainen, H., Unterfrauner, E., Voigt, C. (2011). Report on Weak Signals Collection, European Commission Seventh Framework Project.	"Surprising events with high impact in the future which can be predicted with the help of weak signal analysis".
Cornish, E. (2008). The wild cards in our future. *Futurist, 37*, 18-22.	"Startling events that have important consequences for almost everyone".
Hiltunen, E. (2006). Was it a wild card or just our blindness to gradual change? *Journal of Future Studies*, *11* (2), 61-74.	"Surprising events with huge consequences".
Jackson, M. (2013). *Practical Foresight Guide*. Shaping Tomorrow.	"High-impact events that seem too incredible, or are considered too unlikely, to happen".
Kaivo-oja, J., Mendonca, S., Pina e Cunha, M., Ruff, F. (2009). Venturing into wilderness. Preparing for Wild cards in the Civil Aircraft and Asset-Management industries. *Long Range Planning*, *42* (1), 23-41.	"Trend-breaking/trend-creating events that are very hard or even impossible to anticipate, but that should nonetheless be expected in complex and fast-evolving environments".
Kaivo-oja, J., Mendonca, S., Pina e Cunha, M., Ruff, F. (2004). Wild cards, weak signals and organizational improvisation. *Futures*, *36* (2), 201-218.	"Phenomena that will have large and immediate consequences for organizational stakeholders if they take place".
Kaivo-oja, J., Mendonca, S., Pina e Cunha, M., Ruff, F. (2004). Wild cards, weak signals and organizational improvisation. *Futures*, *36* (2), 201-218.	"Sudden and unique incidents that can constitute turning points in the evolution of a certain trend".
Petersen, J. (2009). How «wild cards» may reshape our future. *Futurist, 43*, 19-20.	"The possibility that this changing perception could accelerate forward, facilitated by a still under the radar spiritual movement that mirrors the trends in other sectors but is

	growing much faster and is potentially much more powerful".
Van Rij, V. (2012). New emerging issues and wild cards as future shakers and shapers. *Foresight Russia, 6* (1), 60-73.	"Events that suddenly occur and change the world in a quite drastic way, while new emerging issues tend to do this is in a more gradual way".

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