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Analysis of Uncertainties and Levels of Foreknowledge in Relation to Major Features of Emerging Technologies —The Context of Foresight Research for the Fourth Industrial Revolution

Andrzej Magruk

Faculty of Engineering Management, Bialystok University of Technology, 45A, Wiejska Street, 15-351 Bialystok, Poland; a.magruk@pb.edu.pl

Abstract: One of the key roles in the development of Industry 4.0 systems is played by "emerging technologies" as new tools with promising—though with a high level of uncertainty—capabilities. The management of such systems should be based on a comprehensive—future-oriented—research approach. Such activities are enabled by the foresight methodology. The main purpose of this publication is to attempt to answer the following research question: "What levels of foreknowledge and knowledge in the context of the development of emerging technologies—in relation to their features in Industry 4.0—should be taken into account during the analysis of uncertainties in the sense of foresight research based on different anticipated options?" In detail, the examination covered the relationship of classes of research foresight methods with regard to types of future, scopes of uncertainty, cycles of knowledge and original levels of foreknowledge in the field of the development of emerging technologies in Industry 4.0. Emerging technologies combined with the research on foreknowledge and uncertainties is an interesting research area with many theoretical and practical potential implications. The study uses the results of the analysis and criticism of the literature, mental experiments, and the intuitive method as the main research methods. This provides a basis for performing conceptual modeling.

Keywords: uncertainty; knowledge; foreknowledge; emerging technologies; futures studies; foresight methods

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1. Introduction

The evolution of the fourth industrial revolution is determined by the development and recombination of its main components, most of which should be classified as emerging technologies, i.e., internet of things, cyber physical system, modern artificial intelligence, cloud manufacturing, blockchain, quantum technologies, and others [1–9]. The full list of main components is open and today it fluctuates—depending on the country—between approximately 40 and 50 factors [3].

According to G. Veletsianos, from a general point of view, an emerging technology is "a new tool with promising potential". However, an emerging technology is generally defined according to the field in which it is analyzed [10].

Emerging technologies in the context of industrial development 4.0 are burdened by some of the greatest potential uncertainties, especially with regard to their technological evolution and market acceptance, but also by the lack of definition of their boundaries [3].

One of the most important research activities with the prospective aim of minimizing uncertainty in current decisions are futures studies, and especially foresight research [11]. Foresight is a research approach that anticipates the desired future, taking into account the complexity and uncertainty of the analyzed phenomena.

According to N. Pidgeon, we are currently confronted with the increasingly complex and, at the same time, uncertain and unpredictable nature of technological risks, as well as the need to control emerging technologies before their final application [12].

The complexity of the development of emerging technologies at an early stage of research may lead to unintended consequences, such as systemic errors [12]. The aim of avoiding such undesirable phenomena is a forward-looking, systemic analysis of the aforementioned technological development in the form of foresight research. One of the main advantages of the foresight methodology is its set of numerous research methods, which can be used in very different contexts and configurations. These combinations should be based on an appropriate mix of complementary approaches and methods, which synergistically may be able to cope with inherent uncertainties and potential disruptions [13].

One of the overriding aims of anticipation activities should be the identification, comprehension and management of uncertainty. Situations of uncertainty—in terms of foresight—are those wherein it is impossible to predict what impact the decision will have, but different outcomes for these impacts can be anticipated [14]. In this process it could be very useful to explore different types of futures (of the development of emerging technologies) in their relationship with knowledge and foreknowledge ranges.

Foresight is also defined as an ability to spot developments before they become trends, to see patterns before they fully emerge; that is why foresight is also referred to as prescience and foreknowledge of events [15,16].

In this article the term "foreknowledge" should be understood as anticipatory—based on prediction and technology assessment—knowledge [17,18] of an existing emerging technology before it happens as technology in phase of the realization and implementation.

Other similar areas of foreknowledge include system modeling and simulation, forecasting and policy evaluation [17], but these are not the subject of this publication.

From a theoretical perspective, the study of emerging technology in foresight research (especially in technology foresight) is a well-known and recommended phenomenon [19–22]. An area that has not yet been explored in depth in this context (foresight and emerging technologies) is the common surface of uncertainty and foreknowledge. So far, the literature on the subject has only included single recommendations on the use of specific approaches and research methods in the field of emerging technologies at the interface of chosen areas, i.e., uncertainty, foreknowledge, foresight, industry 4.0. W. Boon and E. Moors, for example, stress the importance of uncertainty and the need to anticipate it early in the process of technology emergence [23]. According to M. Halaweh, one of the characteristics of emerging technologies is the uncertainty associated with several forms of unknown and unpredictable values and outcomes [24]. According to R. Srinivasan, emerging technologies are science-based innovations with the potential to create a new industry or transform an existing one [25]. D. Rotolo, D. Hicks, and B. R. Martin proposed to use selected research approaches [26]: (1) to qualitatively assess the degree of uncertainty and to identify possible multiple visions of the future associated with an emerging technology; (2) for the assessment of uncertainty and for the evaluation of how prominent the impact of an emerging technology will be; (3) for retrospective analyses of the evaluation of uncertainty. According to D. Rotolo, D. Hicks and B. R. Martin, the gap in the uncertainty assessment of emerging technology is an important arena for future research [26]. Technological progress as part of scientific progress is often driven by the need to understand uncertainty. Research (which includes foresight research) reveals new uncertainties [27]. According to N. Pidgeon, different forms of uncertainty require careful analysis [12]. It should be stressed that the above proposals are not comprehensive, and do not cover all the areas mentioned above at once.

The modification of uncertainty (through its identification, understanding and analysis) in a forward-looking view of such complex systems as Industry 4.0 requires comprehensive research approaches based on a rich methodological range of foresight and a thorough analysis of knowledge and foreknowledge.

The above recommendations and conclusions have led the author of this publication to formulate the main research objective, i.e., an attempt to answer the following question: "What levels of foreknowledge and knowledge in the context of the development of emerging technologies—in relation to their features in Industry 4.0—should be taken into account during the analysis of uncertainties in the sense of foresight research based on different anticipated options?"

The study uses results of analyses and criticisms of the literature, mental experiments, and the intuitive method as the main research methods. This provides a basis for conceptual modeling.

2. Literature Review

B.R. Martin describes an emerging technology as a technology the use of which will benefit many sectors of the economy and/or society [19]. A.L. Porter, J.D. Roessner, X-Y. Jin and N.C. Newman define emerging technologies in the next 15 years as those that can have a significant impact on the economy [28]. B.C. Stahl identifies emerging technologies as those that have the potential to gain social validity in the next 10 to 15 years [29]. According to N. Corrocher, F. Malerba and F. Montobbio, the development of emerging technologies refers to technical, institutional and social changes [30]. This may have unintended consequences that increase uncertainty and ambiguity. Other important characteristics of emerging technology, according to D. Rotolo, D. Hicks and B. R. Martin, include radical novelty, relatively fast growth, coherence, and prominent impact [26]. M. Halaweh, on the other hand, lists the following attributes of an emerging technology: uncertainty, network effect, costs, unobvious impact, availability. These are not yet fully investigated [24]. According to Veletsianos, an emerging technology [31]: (a) may or may not be a new technology (depending on the context, an emerging technology may appear in one context, i.e., place, domain, or application, even though it is considered to exist in another [24]); (b) can be described as an evolving organism that exists in a state of "coming to being" and experience hype cycles; (c) satisfies the "not yet" criteria of not yet being fully understood and not yet being fully researched; (d) is potentially disruptive, but its potential is mostly unfulfilled.

There is no final consensus-based definition of emerging technology due to different research perspectives, which in turn may lead to misinterpreting this term [24,26]. The only certain feature—as R. Srinivasan has shown—of an emerging technology is the high degree of uncertainty associated with it [25]. This is due to the specificity of an emerging technology, whereby its future development is not based on well-established knowledge and is therefore difficult to estimate [29,32]. Furthermore, the uncertainty of emerging technology development refers, as M. Halaweh points out, to many variables, the values of which are unknown, unpredictable or unstable. This fact has a strong connection with the specificity of the future per se, which, according to K. Cuhls [33] and others [34–36], is unknown and unpredictable; however, broad, general directions can be reasonably guessed or anticipated by foresight studies.

According to B. Martin (on the basis of M. Godet and De Jouvenel), there is always more than one possibility; therefore, foresight looks—in a systematic process—into the several alternative futures of science, technology, economy and society by using very rich and flexible research methodology. One aim of exploring these uncertain but possible future options is to identify areas of strategic research and the emerging technologies [19].

For further time horizons, especially in complex systems such as Industry 4.0, uncertainty increases and deepens, while the predictability of the development of the studied phenomena decreases. This results from, among other things, the complexity of the features, structures and behaviors of the analyzed systems, which usually go beyond the area observed and verified by the available knowledge, both subjectively and objectively.

The domain of uncertainty, which used to be mainly related to gambling and focused on the concept of risk, began to cover more and more areas of social life from the mid-1970s [37].

The definition of uncertainty focuses on different aspects, depending on the area concerned, e.g., economics, probability, social science, quantum physics, risk theory, policy analysis, systems analysis, cosmology, future studies, scenario analysis, information theory, and others [38–47].

In the context of the subject matter of this article, the importance of two definitions should be stressed. Firstly, in systems theory, uncertainty results from the inability to accurately determine all states of the elements of large dynamic systems and their relationships in the past and future [48].

Secondly, an important feature of foresight is accepting the fact of the existence of uncertainty, trying to understand it, and making it a part of thinking about the future [45]. This can be done by speculating (scenario building) on future uncertainty by anticipating alternative future states. For example, the scenario method has developed an intuitive logic based on subjective expert—logical, formal and coherent—uncertainty assessments [49].

At this point, the fundamental work of F.H. Knight, entitled "Risk, uncertainty and profit", from 1921 [39] should be mentioned. This book should be considered as a milestone in not only the theory of uncertainty, in its general sense, but also in relation to foresight research, although it is not directly devoted to this theory. Among the fundamental methods of dealing with uncertainty, F.H. Knight lists control of the future, and increases in power of prediction. Both methods are closely connected to the general progress of civilization, the improvement of technology, and an increase in the level of knowledge.

According to F.H. Knight, the complete elimination of uncertainty could be based on the generation of universal foreknowledge, which is paradoxically undesirable [39]. This will be explained later in the article.

The term "foreknowledge" is closely related to such concepts as anticipation, prediction, forecasting and foresight [17], but it is not synonymous with them. It is important to stress that each of these approaches, even though they relate to the future, regards a different area (Table 1).

Table 1. Terms related to the notion "foreknowledge" and their key areas for analysis in the future.

Term	Definition	Key Analysis Area
Foreknowledge	knowledge of the event before it occurs	knowledge
Anticipation	feeling about something to happen or preparing for something to happen	feeling; preparing for something
Prediction	a statement about what you think will happen in the future	statement; thought
Forecasting	activity of judging what is likely to happen in the future, based on the information you have now	activity of judging
Foresight	the ability to judge correctly what is going to happen in the future and plan your actions based on this knowledge	ability to judge and plan; actions

Source: own elaboration on the basis of Cambridge Dictionary [18].

Foreknowledge is a domain used in many other areas with different definitions and functions [17,50]. For example, it is used:

- In knowledge-for-policy—policy evaluation under various conditions, such as ex ante, in itinere and ex post [50];
- In strategic foresight—to plan or monitor the system. According to T. Kuosa, strategic foresight is about producing foreknowledge and strategic options [51];
- In system assessment—to generate knowledge about the possible future of the system, its effectiveness and its social acceptance;

- In data collection and the revolutions in data processing—these are the predictions made by Big Data [52];
- In etymology—to analyze the privilege of the God Who knows in advance what will happen [53,54];
- In Western philosophical traditions—as linked to free will [55,56].

The term "foreknowledge" essentially refers to complex systems, often considered in the context of their long-term evolution [17]. According to the author, it is therefore adequately applied to foresight analysis of the development of "emerging technologies" in the system of Industry 4.0.

3. Results

In general, relations between foresight research and uncertainty research have been identified and analyzed. In detail, this examination covered the relationship between classes of research foresight methods with regard to types of future, scopes of uncertainty, cycles of knowledge and original levels of foreknowledge in the field of the development of emerging technologies in Industry 4.0.

Based on the publications presented in the Section 2 "literature review" chapter, Table 2 presents, in a synthetic form, a set of the most important features of emerging technologies.

Table 2. The main attributes of emerging technologies.

Attributes of Emerging Technologies	Supplementary (Synonymous) Terms	References
novelty	radically new	[26]
prominent impact	significant impact on the economy; potential to gain social validity; refers to technical, institutional and social change	[26,28–30]
promising potential	relation to the process of creating, or becoming important and visible; potential applications are flexible, fluid and sometimes even contradictory	[10,26]
high degree of uncertainty	not fully investigated and researched; not based on well-established knowledge; values are unknown; possible outcomes are incomplete and ambiguous; unstable; hard to predict; difficult to estimate; unobvious impact	[24,26,29,32]
other	coherence; relatively fast growth; generating a network effect	[24,26]

For the research purposes of this publication, the following definition of an emerging technology has been created (among others, on the basis of the presented literature review), which refers to the crucial following contexts: aspect of future time, anticipation, uncertainty and Industry 4.0. Emerging technology in Industry 4.0 is a technology the development of which, from today's point of view, is uncertain and not obvious, but through complex anticipatory research, it is possible to identify its potential radical impact in selected areas, e.g., social, technological, economic, scientific.

According to D. Rotolo, D. Hicks and B. R. Martin, the knowledge of possible outcomes of emergence is incomplete and ambiguous. The potential applications of the analyzed emerging technologies are flexible, fluid, and sometimes even contradictory [26]. Therefore, in the opinion of the author, in the process of foreknowledge management, in the context of emerging technology, a key role should be attributed to the phenomenon of uncertainty, knowledge, and types of future in foresight activity.

One of the most important foresight issues in which futures are analyzed is the "cone of the future". Its most popular form can be found in the work of Voros [57], based on the article of Hancock and Bezold [58]. Having considered these publications and the article of Sardar and Sweeney [59], the authors propose to use in the research the idea of a "cone of the future and uncertainty" (Figure 1).

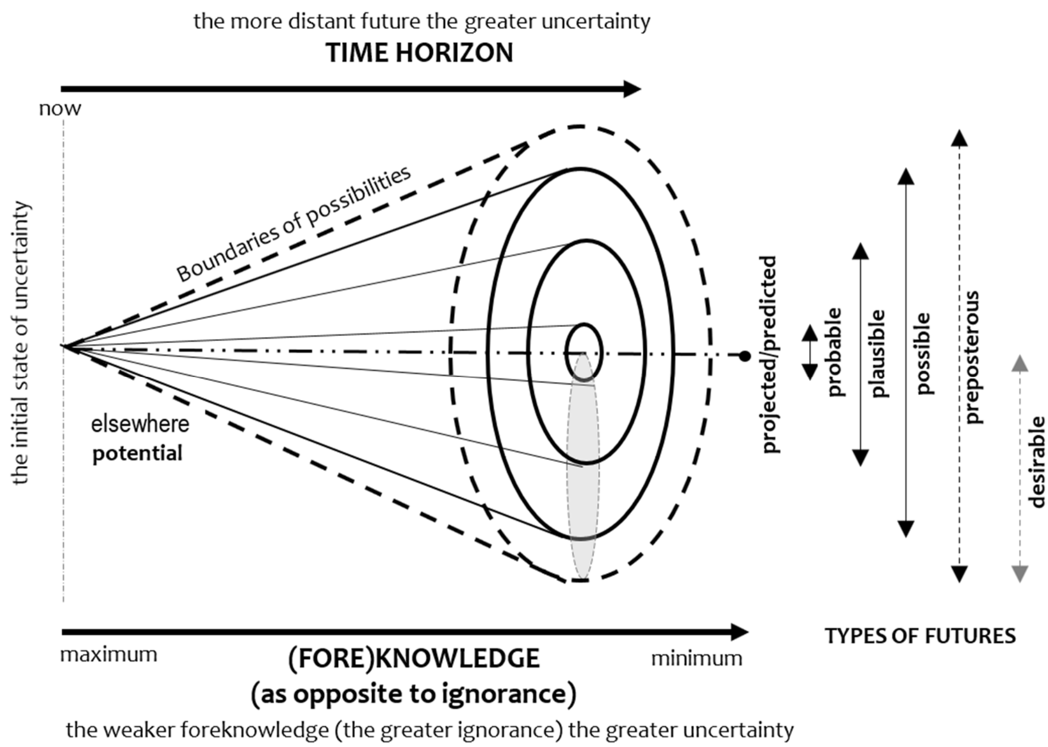

Figure 1. Cone of futures and uncertainties. Source: Author, based on [44,57,59].

The expanding cone reflects the complexity and uncertainty of the future, based on increasingly weak foreknowledge, generating different types of future. More likely, future pathways are closer to the center, and pathways that are not realistic (but are not impossible) are at the edges of the cone. The absolute future of the event under investigation is inside the cone of the future. It is a set of all events with which a person can (but does not have to) interact.

To strengthen the focus of foresight research on the modification of uncertainty in the studied area, the author has identified more than 100 methods (dividing them into 10 classes [60]) that have the potential to generate a certain level of knowledge and foreknowledge (Figure 2).

	LEVELS OF KNOWLEDGE IN RELATION TO CYCLES OF KNOWLEDGE/IGNORANCE	Tacit Knowledge	Conscious Knowledge	Conscious Ignorance	Meta-ignorance	Errors	Total Ignorance	we know what we want to achieve
	LEVELS OF FOREKNOWLEDGE	Universal/Predictive	Analytical	Normative	Visionary	Ridiculous	Abstract	Renormative
	TYPES OF FUTURE	Predicted/Projected	Probable	Plausible	Possible	Preposterous	Potential	Desirable
CLASSES OF FORESIGHT METHODS	FORESIGHT METHODS	potential to generate or identify knowledge and foreknowledge and to determine the uncertainty scope and the future type on a four-stage scale: very high potential, high potential, medium potential, low potential						
CONSULTATIVE	Voting, Polling, Survey, Interviews, Expert Panels, Essays, Conferences, Workshops, Citizen Panels, Brainstorming							A combination of methods from selected classes
CREATIVE	Wild Cards, Mindmapping, Lateral Thinking, Futures Wheel, Role Play, Business Wargaming, Synectic, Speculative Writing, Visualization, Metaphors, Assumption Reversal							
PRESCRIPTIVE	Relevance Trees, Morphological Analysis, Rich Pictures, Divergence Mapping, Coates and Jarratt, Future Mapping, Backcasting, SRI Matrix, Science Fiction Analysis, Incasting, Genius Forecasting, Futures Biographies, TRIZ, Future History, Alternative History							
MULTICRITERIAL	Key Technologies, Source Data Analysis, Migration Anal., Shift-Share Anal., DEA, Factor Anal., Correspondence Anal., Cluster Analysis, Sensitivity Analysis, AHP, Input-Output Analysis, Priorization, SMART, PRIME, MCDM							
RADAR	Scientometrics, Webometrics, Patent Analysis, Bibliometrics, Technological Substitution, S-Curve Analysis, Technology Mapping, Analogies,							
SIMULATION	Probability Trees, Trend Extrapolation, Long Wave Analysis, Indicators, Stochastic Forecast, Classification Trees, Modeling and Simulation, System Dynamics, Agent Modeling							
DIAGNOSTIC	Object Simulation, Force Field Analysis, Word Diamond, SWOT, STEEPVL, Institutional Analysis, DEGEST, Trial&Error, Requirement Analysis, Theory of Constraint, Issue Management, ANKOT							
ANALYTICAL	SOFI, Stakeholder Analysis, Cross-Impact Analysis, Trend Impact Analysis, Structural Analysis, Megatrend Analysis, Critical Influence Analysis, Technology Barometer, Cost-Benefit Analysis, Technology Scouting, Technology Watch, Sustainability Analysis, Environmental Scanning, Content Analysis, FMEA, Risk Analysis, Benchmarking							
SURVEY	Web Research, Desk Research, Technology Assessment, Social Network Analysis, Literature Review, Weak Signals, Retrospective Analysis, Macrohistory, Back-View Mirror Analysis							
STRATEGIC	Technology Roadmapping, Technology Positioning, Delphi, Scenarios, Social Impact Assessment, RPM, Technological Scanning, Technology Monitoring, Multiple Perspectives Assessment, Causal Layered Analysis, MANOA, Action Learning							
	SCOPES OF UNCERTAINTY	Zero/Surface	Statistical	Scenario	Substantial	Deep	Absolute	Combinations

Figure 2. Foresight-oriented matrix of relations among uncertainties, foreknowledge, futures and cycles of knowledge/ignorance.

By taking into account types of future (Figure 1) with a strict link to foresight methods, according to their classes—by their characteristics and features, attributes of emerging technologies (Table 1) and levels of knowledge and foreknowledge—it is possible to identify and/or modify the scope of uncertainty.

Types of future and scopes of uncertainty are based on the author's research presented in [61] and in the works of Walker, Harremoës, Rotmans, van der Sluijs, van Asselt, Janssen, Krayer von Krauss [62], Sardar and Sweeney [59] and Voros [57]. The author focuses on two borderline sources of uncertain knowledge in the future context: awareness of self, referencing a state of mind [63] (subjective component strongly emphasized, e.g., by Willett [38] and Shackle [40]), and knowledge of world, referencing an indeterminate state of affairs (objective, ontological component [63]), in the extreme assuming a lack of remedies to resolve this kind of uncertainty [64]. According to the "Ignorance matrix" and "Ignorance Map" developed at the University of Arizona, knowledge can be manifested in the following ways [65]:

- known knowns (conscious knowledge)—high level of awareness of subjective and objective knowledge;
- known unknowns (conscious ignorance)—all the things you know you do not know;
- unknown knowns (tacit knowledge)—all the things you do not know you know;
- unknown unknowns (meta-ignorance)—all the things you do not know that you do not know;
- errors (misconception about possessed knowledge)—all the things you think you know, but in fact do not.

The author of this publication proposes to add to this classification one more level of knowledge—"total ignorance". It refers to issues that cannot be imagined. In this state, uncertainty, taking the absolute form, is non-reducible and very difficult to modify. The awareness of the existence of "total ignorance" is important [61] because, despite the fact that we cannot imagine a future, it does not mean that it cannot happen [57]. The following are the levels of foreknowledge in relation to the main attributes of emerging technologies:

- universal;
- analytical;
- normative;
- visionary;
- ridiculous;
- abstract;
- renormative.

Universal foreknowledge results from the complete elimination of uncertainty, which, paradoxically, is an undesirable phenomenon. According to F.H. Knight, common knowledge would preclude any entrepreneurial activity. The role of the entrepreneur should be to expand knowledge (by the learning process), especially through foresight activities, with simultaneous awareness of their limitations [39]. This postulate, despite the passage of a century since its appearance, is still relevant, and in the context of Industry 4.0, very adequate due to the dynamics, complexity and systemic nature of the occurring phenomena within it.

Analytical foreknowledge should be treated as prior knowledge—developed on the basis of regularities observed in the past, and thus helping to make decisions [17].

Normative foreknowledge has a strong connection with scenario uncertainty and possible futures, and therefore it should (i.e., foreknowledge) relate to alternative thinking, using, among other things, a heuristic apparatus. According to Leibniz's "philosophy of possible worlds", the world can always look different (on the basis of "possible world-story"), even taking into account the whole history of the past, present and future of the world. Every event or object (in the case of this article, the main object is "an emerging technology") that can be identified as being in this particular story brings with it all the relevant and necessary properties to the world story discussion [66].

The main attribute of visionary foreknowledge is fuzziness—based on a wide and infinite range of alternatives and many possible ways of development. This type of foreknowledge, despite its high level of vagueness, can generate mental images that can lead to action, such as entrepreneurialism [17].

Ridiculous foreknowledge is an undesirable state resulting from deep uncertainty regarding, and the preposterous future of, the analyzed phenomena. One way to avoid the formulation of ridiculous foreknowledge, believed to be the truth we deeply believe in, is to apply the principle of retrocausation (also known in quantum physics as the "backward-in-time effect" [67]). Retrocausation is the complex (and nearly impossible) event of making the past what it was. The correct (based, e.g., on sound research methodology) formulation of a future event (in this case, foreknowledge of the future of an emerging technology) can make the present event (knowledge of the potential of an emerging technology) what it is or should be [66]. A research approach that can be used in this case is the scenario method, based on the concept of "memories of the future" developed by D. H. Ingvar. According to Ingvar, "concepts about the future (also in multi-alternative terms) can be remembered, often in great detail, just like memories of past events" [68]. Other closely related concepts of this approach include episodic future thinking and prospective memory [69], as well as episodic foresight [70,71].

Abstract foreknowledge has a strong connection with impossible events, but its description is never coherently affirmed by any story. Even if there are possible events or real things in this type of description, according to the theory of R. Stalnaker, there is still no way to know them [66].

Renormative foreknowledge has a strong connection to the creation of a desired future (often with multiple alternatives), characteristic of foresight research, in which knowledge is the product of the application of an appropriate set of methods, resulting from the research objective.

As regards the process of modifying the phenomenon of uncertainty in foresight research in the field of emerging technology, the author of this publication proposes to carry out the following two stages first: 1) the determination of the available or possessed levels of knowledge and foreknowledge in relation to the studied area using selected foresight methods; and 2) the identification and analysis of the scope of uncertainty and types of future in relation to possessed knowledge and foreknowledge (Figure 3).

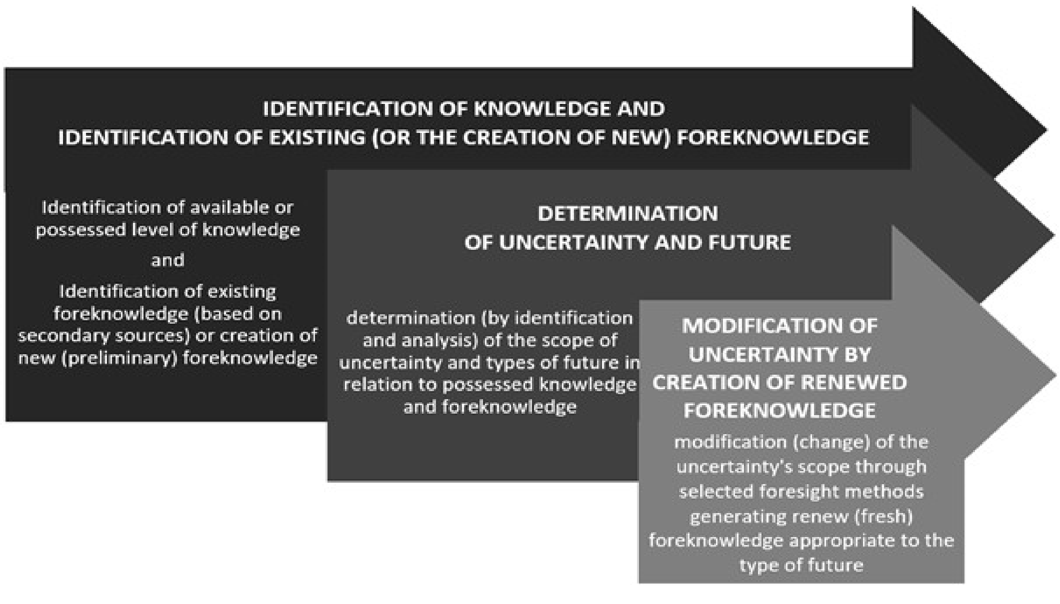

Figure 3. Simplified uncertainty management process in relation to levels of knowledge, levels of foreknowledge and types of future using selected foresight methods.

An emerging technology of Industry 4.0, which will be studied on the basis of the uncertainty management process (Figure 3), is quantum technology.

Quantum technologies offer a potentially significant advantage over existing technologies. Quantum sensors, networks, communication and calculations are of great interest [72].

The speed of calculations based on quantum technology is incomparable to that of the traditional method (based on a binary system), so it is worth taking them into account in the context of the complex and dynamically developing fourth industrial revolution.

According to S. Ghose, business leaders should consider developing a strategy that takes into account the uncertain future, covering three main areas: (1) quantum safety planning, (2) identifying the use of quantum computers, and (3) thinking about responsible design [73].

Monitoring the state of complex production systems can be one of the paradigms for the development of sensors and measurement sciences for Industry 4.0 [74]. A major role in this process is played by quantum sensors, which measure physical quantities with the highest relative and absolute accuracy, in order to improve, e.g., navigation systems [75].

Exemplar relationships between uncertainty, knowledge and foreknowledge regarding quantum technologies—as an emerging technology in the context of Industry 4.0—are presented in Table 3. These relationships are based on the data shown in Figure 2 and Figure 3. More complete descriptions of the scopes of uncertainty and types of future (sixth column—"identification of the scopes of uncertainty and types of future") can be found in the publication [61].

Table 3. Relations among uncertainties, knowledge, foreknowledge and futures in the context of an exemplary emerging technology.

Identification of Knowledge and Foreknowledge					**Identification of the Scopes of Uncertainty and Types of Future**
Case	**Foresight Methods**	**Description of Quantum Technology as the Output of Foresight Methods**	**Determination of the Level of Knowledge**	**Determination of Existing Foreknowledge or the Creation of New Foreknowledge**	
1	expert panels	This is a hypothetical situation. The level of knowledge "don't know that you know" is possible as a result of, e.g., an expert disclosing his or her hidden knowledge.	tacit knowledge	universal	"zero" scope of uncertainty is a very rare state in which certainty is total (100%); predicted future is based on total determinism
2	desk research technology monitoring	Quantum technologies are expected to eventually penetrate many of the systems and sectors on which humans rely today, for example, in the fields of communication, medicine and life sciences, metrology, robotics and artificial intelligence, simulation technologies and cyber security [76].	conscious knowledge	analytical	statistical uncertainty is based on well-described functional relationships; probable future expresses what we know with great confidence about the future

3	technology assessment	According to Dr. Shohini Ghos, it is possible to create a quantum internet, based on the teleportation of information. Such a network has not yet been created despite the on-going work on such possibilities [73,77–79].	conscious ignorance	normative	scenario uncertainty refers to a range of discrete possible outcomes with their likelihood; plausible future indicates what could happen
4	weak signals	Artificial life approach (creation of artificial organisms) in the emulation of the open-ended nature of biological ecosystems in the context of Artificial General Intelligence [80,81].	meta ignorance	visionary	the substantial uncertainty is due to the common complexity, chaos, and contradictions of analyzed pieces of information; uncertainty is related to a complex problem—we are aware that we do not have enough knowledge, but we can still grasp it to some extent; possible future is based on some future knowledge we do not yet possess but which we might possess someday
5	genius forecasting	The Orch-OR theory of Penrose and Hameroff, according to which consciousness is due to quantum effects [82]. The theory is based on sparse evidence, and goes beyond the limits of scientific credibility [83]. It also contradicts the hard problem of consciousness, namely the existence of "qualia" (individual manifestations of subjective experience), which, according to Owen Flanagan, is insoluble [84].	errors	ridiculous	deep uncertainty results from the unawareness of the direction, dimension and impact of change, and because our worldview or epistemology is totally inadequate; a preposterous future is not expected or anticipated; its horizon is populated with seemingly infinite alternative futures
6	alternative history	Hypothetical examples: the emergence	total ignorance	abstract	absolute uncertainty is non-reducible and

	scenarios	of stronger, non-quantum data encryption; breaking the laws of quantum physics		is due to inherent (ontological) variability; a potential future is undetermined and "open", not inevitable or "fixed"

Case 1—an "unknown known" is knowledge that a person (e.g., expert) holds, but which he or she withholds. He or she does this either on purpose, to gain some personal benefit, or unconsciously, without realizing the value of his or her knowledge [85]. The possibility of gaining certain "tacit knowledge" as only one missing element in the formulation of universal foreknowledge (full deterministic future knowledge) could cause the range of uncertainty to reach zero, and its modification to become pointless. However, this is a purely hypothetical situation.

Case 2—the awareness of knowledge is high. The knowledge covers all explicit or formal knowledge [65]. The level of possessed knowledge is related to awareness about current trends and megatrends [61]. Although megatrends are certainties, they always contain elements of uncertainty. Uncertainty can be minimized through learning, research, appreciating the viewpoints of others, and asking the right questions. It is also advisable to generate renewed, normative foreknowledge (e.g., by using such methods as scenarios or alternative history)—especially regarding the knowledge "know that you don't know"—to update, supplement or confirm existing knowledge.

Case 3—conscious ignorance involves knowledge avenues briefly explored but found to be futile [65]. The knowledge covers all personal knowledge gaps in need of being addressed [65]. Scenario uncertainty and the plausible future make it difficult to gain conscious knowledge, hence a possible solution could be updating and supplementing the existing future assumptions. In parallel with the process of formulating normative foreknowledge as related to alterative thinking using a heuristic apparatus, it is advisable to generate renewed analytical foreknowledge appropriate to a probable future, in order to update and supplement the existing assumptions. It is possible to gain knowledge at the "know that you know" level thanks to the results of such methods as STEEPVL, mind mapping and technology monitoring. The purpose of such a methodological procedure is to analyze the uncertainty range at an easier statistical level.

Case 4—meta-ignorance refers to the lack of knowledge about the investigated system and suitably efficient means to become aware of relevant "unknown unknowns" to confront them [65]. Here, we do not know all the possible outcomes of an action [86]. If the used methods, characteristic of the "possible future", make you realize that there exist areas of your research named "you don't know that you don't know", it is advisable to generate renewed foreknowledge—analytical and/or normative—e.g., by means of a set of selected methods (characteristic of a given type of future), preferably coming from different classes. This hypothetically makes it possible to gain knowledge at the level of "we know what we know" and/or "we know that we don't know", which would cause the scope of uncertainty to be examined at the "statistical" and/or "scenario" level.

Case 5—errors involve wrong assumptions, outdated, or obsolete information [65]. It is advisable to generate renewed—analytical—foreknowledge based on probable future—to revise (e.g., by means of trend impact analysis or technological scanning) whether the future analyzed so far can be called preposterous, ultimately generating completely erroneous assumptions based on ridiculous foreknowledge. If the generated foreknowledge allows us to realize that we have hitherto made a thought error and now we are certain that "we know what we know", then uncertainty should be examined at the statistical level.

Case 6—modifying uncertainty is very difficult (or even impossible), but with sufficient resources (time, people, etc.), the use of "potential future" methods can have a positive, although not yet known, effect.

For research focused on areas of high uncertainty as well as unestablished, unstable, difficult to predict knowledge, it is advisable to use complex research approaches. During the construction of the research foresight methodology (to create a desirable future), it is recommended to use methods from different classes, with reference to a few contexts of the study [60]. The aforementioned hypothetical case of this study was based on an appropriate mix of nine complementary methods from four classes. By analyzing knowledge, foreknowledge and the future in many forms, types and many aspects, there emerges the possibility of obtaining the actual comprehensiveness and synergy of foresight research, realizing the full spectrum of uncertainty research. The research approach analyzed above supports the thesis that thinking about the future should be a conglomerate of diverse skills [70].

4. Discussion and Conclusions

Despite the fact that an emergence phenomenon relates to the process of creating, or becoming important and visible, it should be remembered that the most important area of emerging technology analysis should be the future of its development, which, from the point of view of its radical novelty, is characterized by a high degree of uncertainty. Uncertainty is one of the key starting points for many different studies focusing on the role of technological development expectations [26].

One of the characteristics of contemporary technological and economic development is the increasing importance of uncertainty [65].

Uncertainty also arises in the process of forming emerging technologies. This is due to the non-linear and multifactorial development of such technologies, and because, from today's point of view, work on them is still in progress.

Emerging technologies (with their specificity, types and original features, combined with the study of foreknowledge, uncertainty and the future) relate to two spheres: (1) the scientific sphere (in the field of future management in the sense of research methodology. Until now, uncertainty in the study of the future has been treated as the background of this research rather than its main object. The proposed approach in this article makes it possible to treat uncertainty as the main research object, which in today's "era of uncertainty" is a very desirable research phenomenon) and (2) the organizational entrepreneurship sphere—according to which the fourth industrial revolution is a nascent area. In the author's opinion, the systemic research approach presented in the article can become a valuable scientific basis for formulating its paradigms.

The main subject of this study is uncertainty and foreknowledge in the future's relation to emerging technologies of the fourth industrial revolution. Uncertainty is one of the most important features of forward-looking development in many areas of social, technological and economic life.

These are entirely new and complex phenomena, requiring deep research. Many of the contemporary uncertainties associated with the development of modern emerging technologies and Industry 4.0 are systemic in nature. Managing such systems necessitates the use of complex research approaches, especially in a forward-looking context. One of the more comprehensive approaches enabling such activities is foresight, with its associated research methodology.

According to the author, the complex analysis of the relations of foresight's methods to types of future, cycles of knowledge and levels of foreknowledge makes it possible to study uncertainty (in many scopes) in the context of its modification (identification, comprehension and analysis) via its transposition to another level of foreknowledge. This seems to be a very valuable skill in such complex structures as the broadly defined Industry 4.0.

Foresight methodology, thanks to its flexibility, enables but also demands its own constant modification and improvement. Referring to the objective formulated at the beginning of the article, in the context of the development of emerging technologies, with regard to their relation to Industry 4.0 in terms of analyzing the scopes of uncertainties (zero/surface, statistical, scenario, substantial, deep, absolute), foresight research (by exploring the following types of futures: predicted/projected, probable, plausible, possible, preposterous, potential, desirable) should take into account universal, analytical, normative, visionary, ridiculous, abstract and renormative foreknowledge, and tacit knowledge, conscious knowledge, conscious ignorance, meta-ignorance, errors and total ignorance knowledge.

For research purposes, the author created a definition of emerging technology that simultaneously refers to the aspects of time, anticipation and uncertainty, and the fourth industrial revolution. An additional research contribution of the author is the assignment of levels to the previous definitions of foreknowledge and their connection with the scopes of uncertainty and types of the future

A sample list of other important emerging technologies in the context of Industry 4.0, in addition to quantum technology, that are worthy of more extensive research are [87,88]: 3D-printed soil for vertical agriculture; biodegradable batteries; RFID implants for personal data storage; fully plastic transistors; lifelong avatar assistants; recording an entire human life from birth to death; brain–computer interfaces to widely supplement keyboards; dream imaging and recording via fMRI; quantum technologies (i.e., computing).

According to the author, the formulation of new theories, laws, principles, theorems, hypotheses and axioms in the systems analysis of the hybrid area of Industry 4.0, consisting of emerging technology, foresight, uncertainty and foreknowledge, seems to be a necessary research activity. Thanks to this comprehensive approach, it is possible to obtain a different added value than when analyzing each of the areas separately.

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