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NEWEST TRENDS IN INTERDISCIPLINARY RISK-BASED RESEARCH AND GOVERNANCE OF CRITICAL AND STRATEGIC INFRASTRUCTURES

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Abstract

This paper is a condensed version of the keynote lecture presented at the opening of the fifth Eurasian conference on Risk in Baku, Azerbaijan, October 17 2023. It is mostly based on results of the content analysis of 1500+ peer reviewed papers related to reliability, resilience, risk and safety of infrastructure systems published over the last 25 years, provided by renowned international specialists in these topics.

Keywords: interdisciplinary risk-based research, trends, smart systems, interdependent biosociotechnical critical infrastructures, management, governance

I. Introduction

The increase in the epistemic (fundamentally intrinsic) and aleatory uncertainty of the modern world, increasing role of the human factor (both individual and collective) in the occurrence of accidents and disasters created an imperative for all levels decision makers (DMs) to take into account the global technological trends that simultaneously help mitigating existing risks and generate new risks. The concept of high convergent technologies became a conscious response to the challenges presented to science by the part of modern society that was concerned by the uncontrolled development of technology.

In 2002, M. Rocko and V. Bainbridge, in their report to the US National Science Foundation (NSF), proposed the concept and first used the term NBIC convergence, built on the principle of a synergistic combination of the four fastest growing scientific-technological areas with great economic potential: N – nano- (science and technology), B – bio- (technology and medicine), I – information technologies, including advanced computing and communications, C – cognitive sciences (including neuroscience) [1–4].

Currently, there are several converging technologies in use around the world. For example, the NSF supports three such concepts:

- NBIC (Nanotechnology, Biotechnology, Information technology + Cognitive science); some scientists believe that the future of natural sciences belongs to NBIC
- GRAIN (Genetics, Robotics, Artificial Intelligence + Nanotechnology)
- BANG (Bits, Atoma, Neurons, Genes).

The European Union is funding the concept of convergent technologies for the European Knowledge Society [5]. The Canadian government is funding the Canadian Biosystems Foresight

Pilot Project. In Russia, the Kurchatov Institute supports the concept of NBICS (NBIC + Social Sciences) [6–9].

II. Convergent technologies and sciences for creating smart safe infrastructures

To solve regional problems of risk and safety of critical and strategic infrastructures (in general, of all artificial nature), in 2016 the MABICS-convergent technology was proposed, as related to applied and engineering sciences [10, 11]. MABICS stands for: Stochastic ***M***echanics, ***A***rtificial Intelligence, ***B***iotechnology and biomimicry, ***I***nformation Theory, ***C***ognitive and ***S***ocial Sciences. MABICS technologies are initially human-centric (Fig.1). When choosing a combination of convergent sciences, for creating smart infrastructures the author proceeded from the need to:

- Harmonize the coexistence of the oppressed first and developing second, artificial, nature to ensure the stability of biodiversity and the well-being of the noosphere
- Use the achievements of these rapidly developing disciplines and technologies with great economic potential to create a smart second nature that adaptively changes with changes in man himself and his needs
- Create the necessary scientific tools to ensure the fulfillment of the first two goals
- Structure an umbrella science containing the core components of knowledge and technology needed by professionals involved in the design and operation of smart cyber physical infrastructures and systems serving modern society.

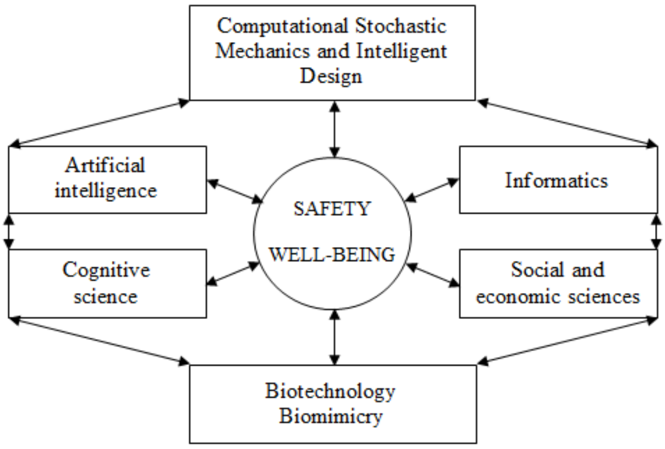


Fig. 1: *Components of MABICS convergent technologies*

None of the existing disciplines can provide the necessary solutions to such infrastructure problems. MABICS technologies are initially human-centric. In this regard, prof. A. Gheorghe (Old Dominion University, Virginia, USA) in 2007 proposed creating an umbrella science, which he named *Infranomics* (*Infra*structure + Eco*nomics*). This science is to serve as a universal discipline of disciplines, collecting all knowledge, which may someday be required to solve problems of political economy and economics of critical infrastructures. At the same time, A. Gheorghe did not indicate how to collect and structure this knowledge base and database [12].

Another main reason for creating an umbrella science for cyber physical infrastructures is the need to train modern specialists in the field of their design and operation.

The presence of such structured umbrella science simplifies and speeds up the training of specialists who are fluent in MABICS technologies and disciplines, and the formation of scientific groups to study infrastructure systems.

The author called the umbrella science based on MABICS technologies *infranetics* (*infra*structure + cyber*netics*), and considers infranetics as a branch of infranomics.

Infranetics includes all studies of MABICS technologies related to the design, management and governance of bio-socio-technical infrastructures at all stages of their life cycle.

Unlike NBIC technologies, the convergence that is ensured by nanotechnology, which allows blurring the line between physics, chemistry and biology, the fusion of MABICS technologies has a different nature. The gradual convergence of MABICS technologies is ensured by two factors:

- The common denominator – mankind and planet Earth, which set all the initial, boundary conditions and maximum permissible values of life support parameters for both humans and humanity during the design, construction and operation of all types of infrastructures (in general, all artificial nature)
- The unstoppable development of artificial intelligence (science and technology), which inevitably will take over the solution of an increasing number of problems currently being solved by MBICS technologies.

III. Knowledge base (KB) of MABICS technologies and Infranetics team of authors

To define the KB and its creators, the author turned to the leaders and organizers of world scientific schools and renowned scientists with a request to send their most important, in their opinion, key and review articles related to the topic of risk analysis of infrastructures. Following specialists responded: M. Beer (Leibniz University Hannover, Germany), B. Ellingwood (Colorado State University, USA), A. Gheorghe (Old Dominion University, USA), J. Li (Tongji University, Shanghai, China), N.A. Makhutov, V.V. Moskvichev (both from the Russian academy of sciences RAS), E. Patelli (University of Strathclyde, UK), M. Stewart (University of New South Wales, Australia), E. Zio (Polytecnico di Milano/Mines Paris/PSL, Italy/France). Some of the sent papers are shown as references [13–34].

The received key reviews and articles (in which 1,500+ publications were considered) were analyzed by objects, their properties and research methods. The results of this analysis are presented on the website *www.managementofrisk.ru* for the opportunity to review, post comments and add significant publications to the Infranetics' KB, and published in a preprint [35]. Despite being limited and inevitably subjective, the starting knowledge base (KB) of infranetics quite adequately reflects the research results of the world's leading schools. It is considered as author's modest attempt to outline the path for the creating, preserving and developing the infranetics' KB.

It is expected that this initial KB will expand as new knowledge in the field of infranetics and MABICS technologies is accumulated. The task of maintaining and developing the infranetics' KB is left open to all scientists and specialists who want to supplement and clarify it, using their experience and knowledge. The authors of publications included in the starting knowledge base of infranetics are, in essence, the founders of this umbrella discipline, and the content of these articles constitutes their contribution to MABICS technologies.

Infranetics as an umbrella science is carved out to solve the central problem of safe sustainable development of a territory / municipality / industry / corporation by harmonizing the regional risk of the second, artificial nature. This methodology is deliberately reduced to the following working hypothesis:

The sustainable development of a modern risk society in a market economy is mainly determined by the quality of management/governance of smart systems of interdependent biosociotechnical infrastructures IBSTI.

For this purpose, the following integral criteria for IBSTI governance and optimization are proposed [36]:

- regional average life expectancy in good health at birth (RALE)
- regional/municipal life quality index (RLQI)

- (sub/supra)resilience of regional systems of interdependent critical smart infrastructures (RSICI)
- entropy of development and degradation of regional systems of cyber physical infrastructures
- social entropy of regional society in ordinary and extraordinary conditions
- *N*-dimensional carbon footprint of regional CIS.

IV. Predictive management of territorial technogenic risk

The predictive management of territorial technogenic risk is constructed in accordance with five criteria, which are briefly discussed below.

4.1. Regional average life expectancy (ALE) in good health

The main ideas of managing territorial infrastructures according to the ALE criterion are [37]:

- determining the quantitative dependence of the life support system efficacy on the cost of creating the critical infrastructure, which ensures the livelihood of the population, and its safe operation
- optimal distribution of the fixed municipality budget according to the criterion of maximum life expectancy and the quality of life of citizens.

To achieve this goal, methods were developed for assessing the size, structure, and dynamics of the gross municipal product GMP and a study was conducted of the quantitative relationships between the total and specific (partial) budget expenditures of a large municipal entity and changes in the life expectancy for the same municipality, in our case, the city of Yekaterinburg [38].

The study of the dependence of life support on the quality of critical infrastructure operation is an important new direction of interdisciplinary scientific research, as it makes possible to ensure the safety of the population of territories and municipalities, and their sustainable socio-economic development.

4.2. Life quality index (LQI), Social willingness to pay (SWP), Statistical cost of life (SCL)

The use of the life quality index concept [39] to assess the degree of deterioration/improvement in the quality of life depending on the level of reliability, resilience and safety of regional infrastructure operation is a main contribution to the general theory of infrastructure risk. Its conceptual model is shown in Fig.2, and its formula is given below:

$$TLQI = G^{q}E \tag{1}$$

where G is the national (regional, municipal) product (\$/person/ year); E is the life expectancy for a given region, depending on age at birth; $q = w/(1-w)$ is the ratio of average working hours to leisure time available to members of society in a given region/municipal area; w is the time spent by an individual to create personal wealth G.

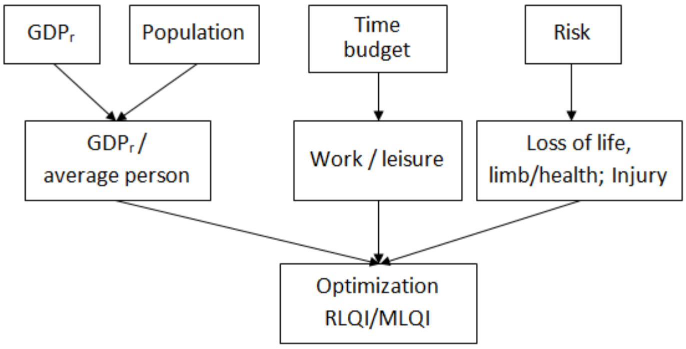


Fig. 2: *Conceptual model of the quality of life index TLQI/MLQI*

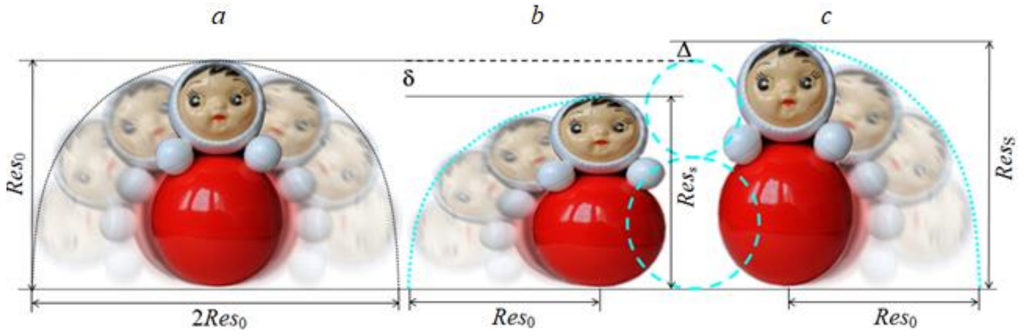
The LQI can be used as related to a country, region, territory/municipality, corporation and even a person. It is also needed to assess the so-called willingness to pay and the statistical cost for saving an anonymous life [39]. TLQI allows placing the management of technological risks in a broader context of social policy, by providing a unified framework for developing risk management strategies, in the form of four principles: (1) accountability to society, (2) maximum net benefit for all, (3) compensation for those who loses when changes occur, and (4) a long life in good health with maximum freedom of individual choice.

TLQI provides the necessary criterion for determining the maximum level of expenses, above which the costs of increasing industrial safety become unjustified. This level is called the "social willingness to pay" (SWP) measure. These principles, taken together, reflect the necessary attributes of a good life in modern society.

4.3. Criteria for sub resilience, resilience and supraresilience

The development of the transformation strategies for regional and municipal systems of infrastructures into resilient smart territories is currently a hot topic [40–45]. It is well known that to achieve smartness, territories have to first become resilient. Resilience of sociotechnical systems is better understood using the antifragility concept.

The antifragility concept was initially proposed by N. N. Taleb to describe the financial world; he went on to promote this concept as a universal master key to «benefit from chaos". The concept of supraresilience is focused on the second, artificial nature and arose as a complete analogue of the antifragility concept to describe the supra-and sub resilience traits of the smart interdependent biosociotechnical infrastructures. A visualization of the complex resilience concept is given in Fig. 3, 4.

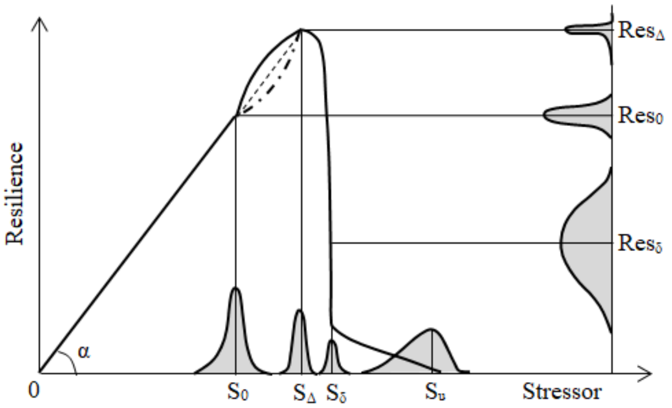


Δ – supraresilience, δ – subresilience

Fig. 3: *Visualization of the concept of resilience on the example of a roly-poly doll: a – resilience; b – subresilience; c – supraresilience*

In medicine, the biological supraresilience is called *Hormesis* and is observed, for instance, when small doses of alcohol, aspirin, Radon gas (in the case of lung cancer), and radiation are administered to mammals (including humans). The clearest examples of supraresilience are (1) human post-traumatic resilience *growth* [46], and (2) many European and Japanese phoenix-type cities that rose from the ashes after the WWII, better than before. Multiple examples of sub resilience are (1) a person stricken with post-traumatic stress disorder (PTSD), and (2) corporations and municipalities that succumbed to stressors beyond their resilience.

It is interesting to note that N. Taleb's concept of fragility/antifragility does not contain (has no room for) the sub resilience concept.



S$_0$ is the calculated, standard value of the stressor; S$_\Delta$ > S$_0$ is the limiting value of the stressor causing the effect of supraresilience; S$_u$ > S$_\delta$ > S$_\Delta$ – stressor values leading to sub resilience of the object (damage, loss of years of life; S$_u$ – stressor value leading to death

Fig. 4: *Visualization of the concepts of physical (biological) supraresilience Res$_\Delta$, resilience Res$_0$, subresilience Res$_\delta$*

In quantitative terms,

$$\text{Antifragility}(Q) = \text{Resilience}(Q) + \text{Overcompensation}(Q), \tag{2}$$

or, fully equivalent

$$\text{Supraresilience}(Q) = \text{Resilience}(Q) + \text{Overshooting}(Q). \tag{3}$$

Supraresilience and antifragility can also be defined respectively only as (resilience gain) / overcompensation. If we agree with (2) and (3), then the definition of supraresilience of regions / cities/is:

Regional/urban supraresilience is «the ability of a regional/urban system of critical infrastructure systems to withstand, adapt, and quickly recover from stresses and shocks, such as natural or man-made disasters, drought, violence, conflicts, while improving the initial parameters of its resilience».

N. Taleb's theory of antifragility, developed for the financial world was then proposed as a universal tool for *taking advantage of chaos*. A detailed mathematical analysis of this theory showed [47] that it is based on the assumption that during operation of the (financial) system a PDF of the "profit–losses" type is always and constantly available. While it is available for a financial scheme, it is not available for any engineering system, which is designed and maintained for the sole sake of producing income/profit and avoiding by all means any losses. Applicability of the antifragility concept for objects of second nature is entirely based on the fundamental availability of statistical information about the heavy tails of the distributions under consideration. Due to the fact that they are unavailable (do not exist), the antifragility theory is inapplicable to engineering science and technology. On the other hand, the fragility concept is applicable as it is considering only the losses due to system failure.

The concept of supra- and sub-resilience opens the door to meaningful exploration of quantitative dependencies/correlations between physical resilience of a system of systems and the biological/psychological/societal resilience of people who live inside and extensively use this system of ICIs in the context of different types of communities – from megacities, to big, medium size and small towns, to villages/settlements and tribal areas.

4.4. Entropy criteria (physical, statistical, informational and social)

Despite the universality of the entropy concept, its application to solve problems of risk analysis and safety of critical infrastructures requires using many other methods that are necessary for a quantitative description of the entire process of development of a disaster - from its inception (initiating failure) to complete collapse. This is because entropy, although a function of time, is a purely scalar quantity. Hence, any quantitative expression of entropy must be unambiguously linked to a certain state of the given system described by corresponding mathematical equations and socio-economic indicators. In other words, it is necessary to have an one-to-one correspondence between the state of a system and its integral entropy.

Many types of entropy are used in infrastructure risk theory. For instance, entropy is used (1) to model interdependence of components of multi-element stochastic systems (differential entropy) [48]; (2) to optimize the place where to build a facility in a city (informational entropy) [49]; to define some components of RALE (Keifitz type entropy) [50]; to construct heavy tailed distributions of dragon king type of stressors (Tsalis type entropy) [51]; to capture the social unrest during and after a major urban infrastructure accident (time dependent quant entropy).

The Dragon King (DK) is a dual metaphor for an event that is both extremely large and influencial (the "King") and has a unique origin (the "Dragon") compared to its counterparts (other events from the same set). Didier Sornette developed DK theory [52]. This theory is based on the hypothesis that many crises are actually DKs rather than black swans, meaning they can be somewhat predictable. DK events are generated by or correspond to mechanisms such as positive feedback, tipping points, bifurcations, and phase transitions that occur in nonlinear and complex systems and amplify DK events to extreme levels (the perfect storm). The DK theory makes it possible to study extreme events, carry out their dynamic monitoring and achieve some predictability of such events, which is especially important for long-term forecasting of the risks of operating strategic infrastructures and systems.

The aforementioned is illustrated by the case of describing extreme wind speeds in the Arctic zone of Russia [53]. In this case the requirement that all sample data belong to the same family is violated. The main array of “intermediate” extremes (called *White Swans* WS), and the appearance of the largest and rarest phenomena in this sample (called *Black Swans* BS) belong to the same Weibull distribution. The other set of extremes belong to a different (but also Weibull) distribution, have a different genesis (dragons, dragon kings) and characterize fundamentally different objects (Fig.5). Using the κ-deformed Kaniadakis κ-statistics based on Tsalis type entropy it was possible to construct a generalized PDF that correctly assesses the most rare events (Figure 6), thereby reducing the space of possible *Black Swan* events [54–56].

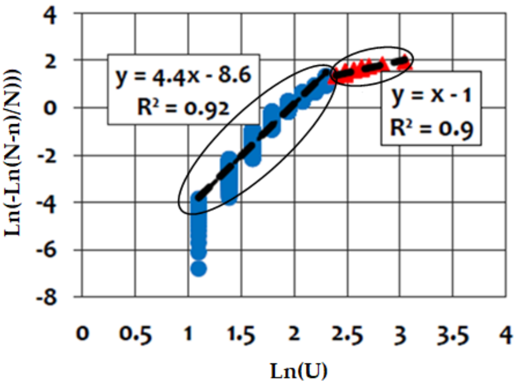


Fig. 5: *Empirical distributions of extreme wind speeds of the year (1966–2013) [53]*

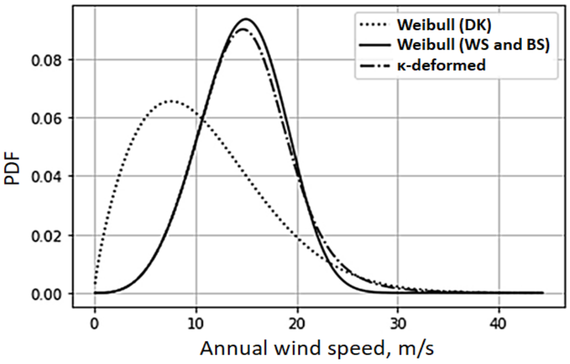


Fig. 6: *Empirical PDFs of wind speed extrema, corresponding to three families of Weibull distributions: "WS and BS", "DK" and κ-deformed [54]*

The most challenging aspect of studying the reliability and resilience of socio-technical systems (STS) is the interdependence of their physical and social components over time, influenced by various stochastic stressors of different nature. Existing STS models inadequately consider the relationship between cyber-physical infrastructures (CPI) and the society that simultaneously utilizes, inhabits and owns the CPI environment. It is evident that further progress is required to assess the community resilience and quantify the socio-economic interdependencies that exist between the society and its cyber-physical systems. When assessing STS resilience, it is necessary to evaluate concurrently the resilience of both the physical and social components. It is clear that the resilience of the physical component directly influences the ability of the STS to support the activities of the society it serves, thereby affecting its overall resilience. The main question is: what parameter(s) should be used to connect the tangible with the intangible?

Recently a new approach was developed to quantify social unrest that inevitably occurs after each accident or natural disaster associated with the loss of operation of urban life support infrastructures [57] based on data from social networks (in the form of views, likes, comments, and reposts). This approach is characterized by connecting in real-time, simultaneously, the level of social entropy (as a measure of dispersion, chaos) on one side, with the level of STS physical damage; and on the other side, with the decision makers' (DMs) actions, aimed at mitigating the consequences of the high entropy accident. By revealing this connection, the correlation is established between physical damage and social discontent, and between the discontent and DMs' actions. Further analysis permits finding how effective these actions (governance) are in lowering the dangerous entropy level.

A quasi virtual scenario was constructed using data from a flood disaster that took place in 2016 in Southern Louisiana. According to this scenario there was a sudden drastic decrease in the number of users involved (points A and B), followed by a lengthy period of rather weak communication (from point B till point C) followed by a sudden increase of user activity (point C) caused by multiple reports of delayed insurance payments (Figure 7). Activities did not fade for a long time due to the inability of the Administration to respond appropriately.

The times when the social entropy (in our case, intensity of communications) was dramatically changing are connected to the specific actions taken by the City Administration, and to the values of the observed social entropy (points A and D). This kind of data collected after each incident can serve as a reference source, and be used for defining the strength and character of the interconnection of the material and the social.

The outlined algorithm of real time entropy analysis of the social activity of citizens in the case of critical urban infrastructure operational failure is comprised of:

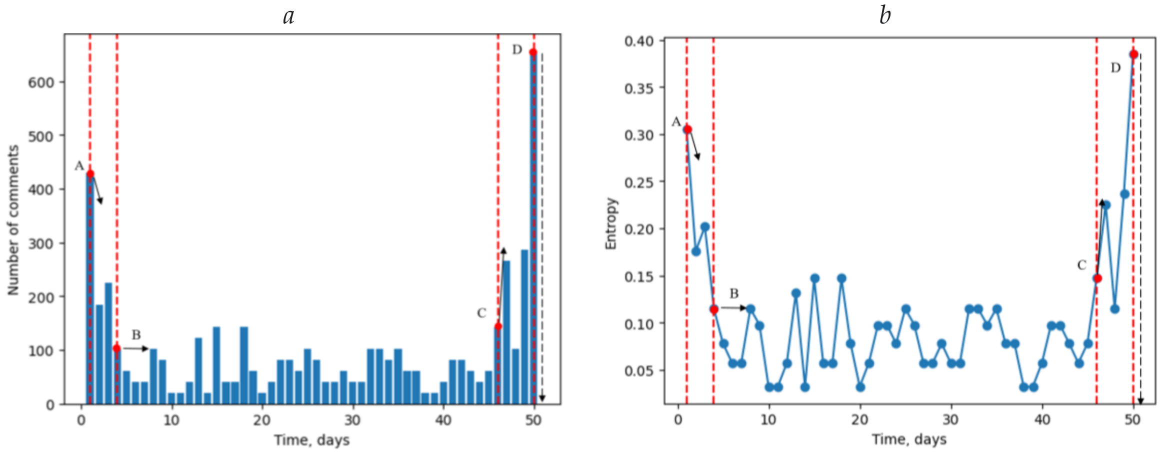


Fig. 7: *Graph of the number of comments in time (a) and the day-by-day quant entropy curve (b)*

- Plotting the total number of comments about the accident in social networks (an AI bot is being developed to automatically collect the needed information as it emerges in time)
- Constructing total and partial graphs of comments classified by their content (negative, positive, neutral, informative)
- Constructing an analytical PDF for each constructed histogram
- Constructing a quantized function of citizens' discontent entropy
- Constructing the first derivative of the discontent entropy function
- Pairing the time points of DMs decisions on mitigating the accident consequences with the time points of change that occurs in the intensity of discontent entropy generation
- Defining the entropy thresholds at which DMs start making decisions to mitigate/eliminate the consequences of an accident
- Accumulating a data base of dependency pairs "*entropy quant size vs DM reaction type*"
- Comparing different accidents with the same STS by social entropy indicators
- Developing decision support recommendations for DMs based on entropy analysis findings.

In author’s view, social entropy analysis can potentially become one of the most important and versatile quantitative tools for city governing, as it provides a currently missing correlation between the measurable damage to cyber-physical infrastructure (CPI) and the poorly measurable (intangible) social damage to the community, and between DMs’ decisions and mitigating actions and the decrease of social unrest entropy.

4.5. Carbon footprint of infrastructure life cycle

Over time, this criterion will become a determining tool when assessing the quality of functioning of bio-socio-technical infrastructures during their life cycle (stages of emissions: construction, operation, fugitiveness, and disposal). This criterion seamlessly connects the local restrictions on pollution with the overall planetary boundary conditions [58].

V. SP RASOSR® (Resilience and Security of a Smart Region)

In order to utilize the discussed above components of infrastructure governance, special software is needed. The first step in this direction was made by creating the RASOSR® (Resilience and Security of a Smart Region) cloud based software package [59] as a service (Figure 8) allowing management of infrastructure systems using the described above generalized regional quality criteria. The first module of this package:

- Ensures continuity of business flow of digital services and infrastructures
- Provides operational support for making management decisions based on the criteria of RALE and RLQI and willingness to pay (WTP)
- Organizes the living laboratory of convergent technologies activities
- Allows building a virtual digital model of regional resilience
- Supports the process of involving various regional and city actors in solving the resilience problem
- Structures the collected information (Big Data) about the relationships of serviced objects and modeling cascading effects
- Provides DMs with the opportunity to make informed choices about how to respond collectively and harmoniously to the ever-increasing shocks and stresses facing a region.

The MABICS approach to solving various problems of infrastructure systems reliability, resilience, risk-analysis and safety management and governance is visualized in Figure 9, in which a variant of governance/management is given using the MABICS convergent technologies. As an example of using the interdisciplinary approach to solving problems that comprise the algorithm shown in Figure 9, consider the task of creating the full group of risk scenarios (FGRS) of an accident which is needed to assure that all probabilities are taken into account (first line of the algorithm in Figure 9). The methodology of building such a FGRS involves applying the cross-entropy principle to Bayesian network models for creating most likely scenarios of the accident (Figure 10). In some cases, this FGRS is supplemented by scenarios that are generated by a group of people with specific cognitive capabilities (to be sure that the obtained FGRS is as complete as possible).

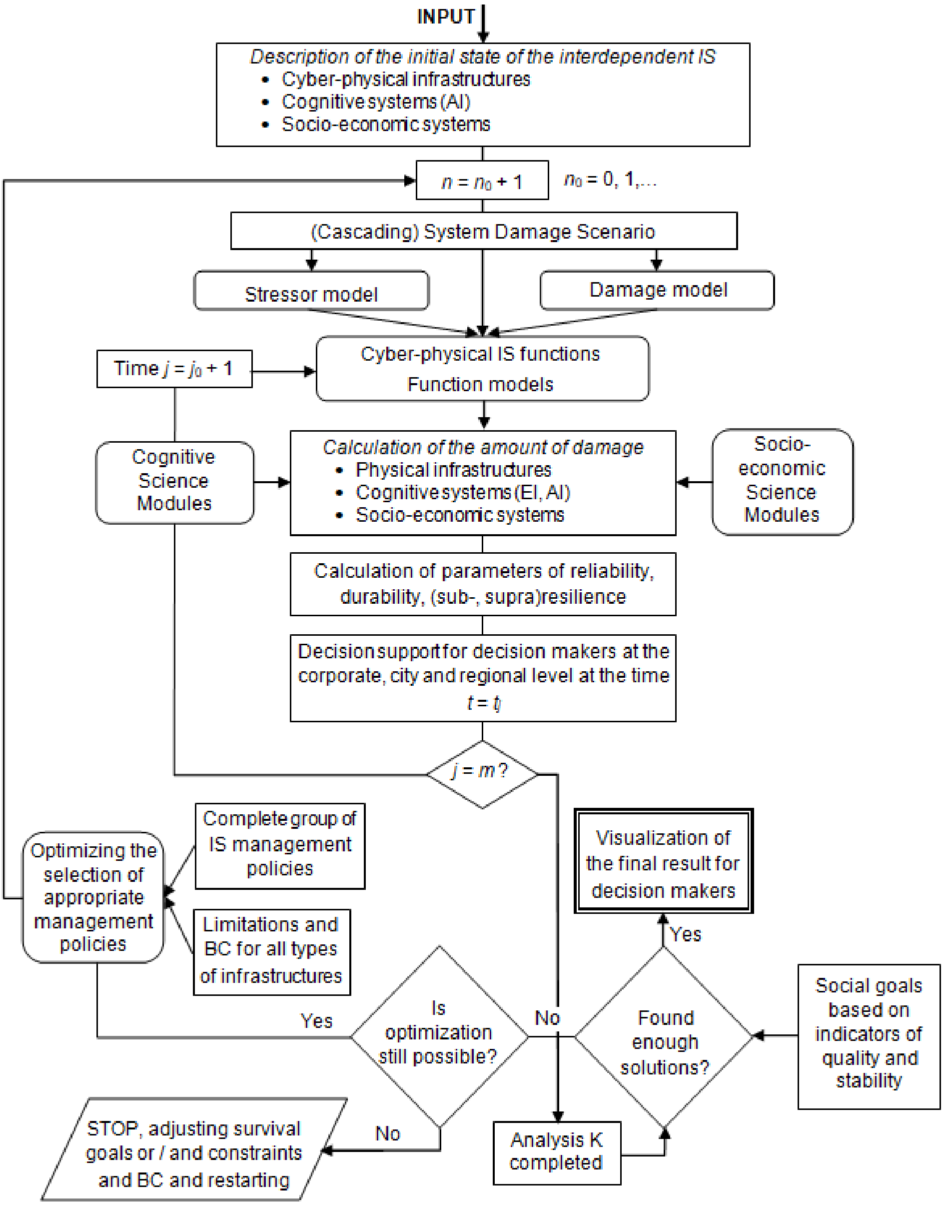


Fig. 8: *Schematic block-modular diagram of the cloud-based SP RASOSR® as a service with built-in artificial intelligence (Version 1.3); BC – boundary conditions*

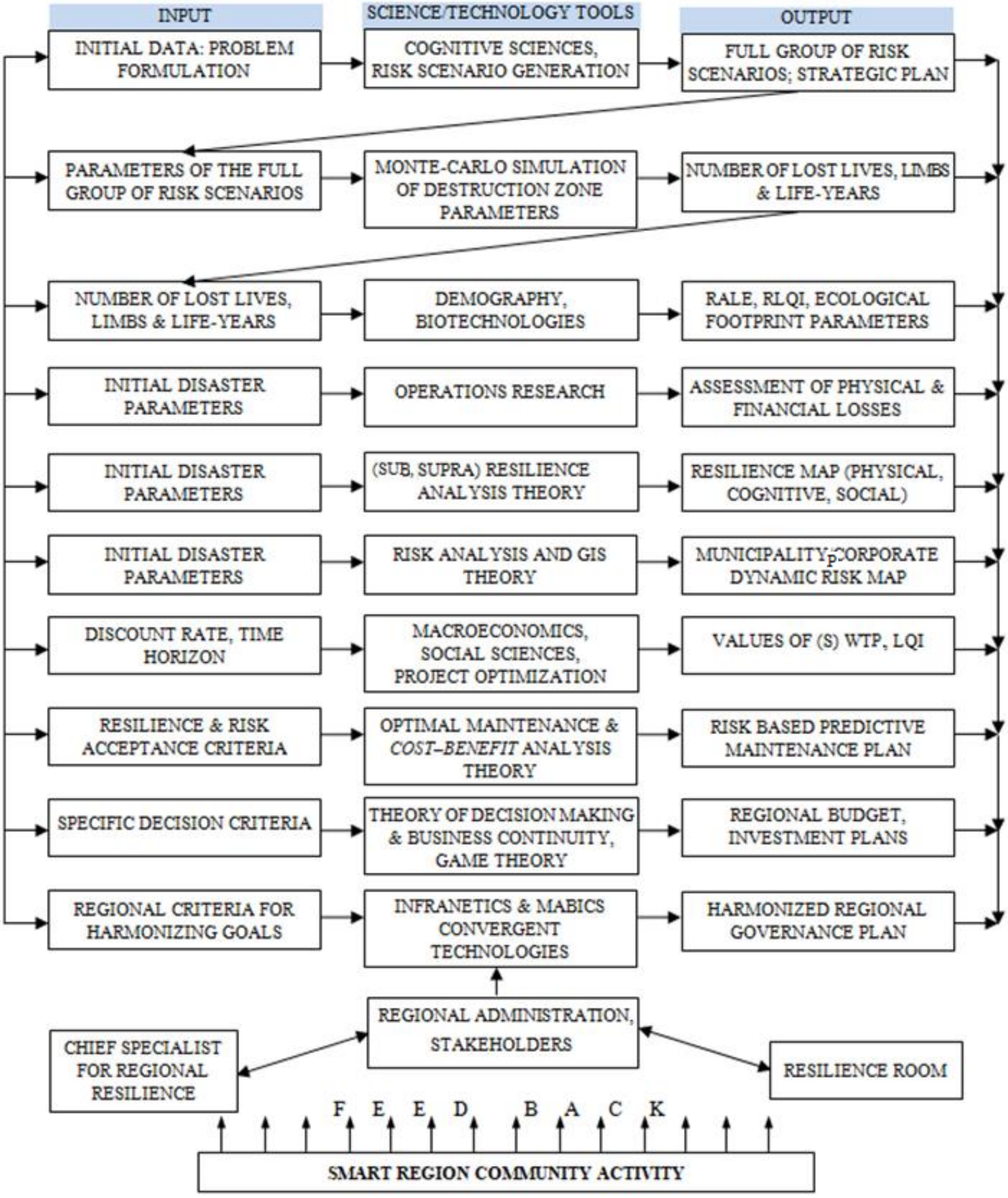


Fig. 9: *Variant of a governance/management strategy based on regional resilience using infranetics tools and MABICS convergent technologies*

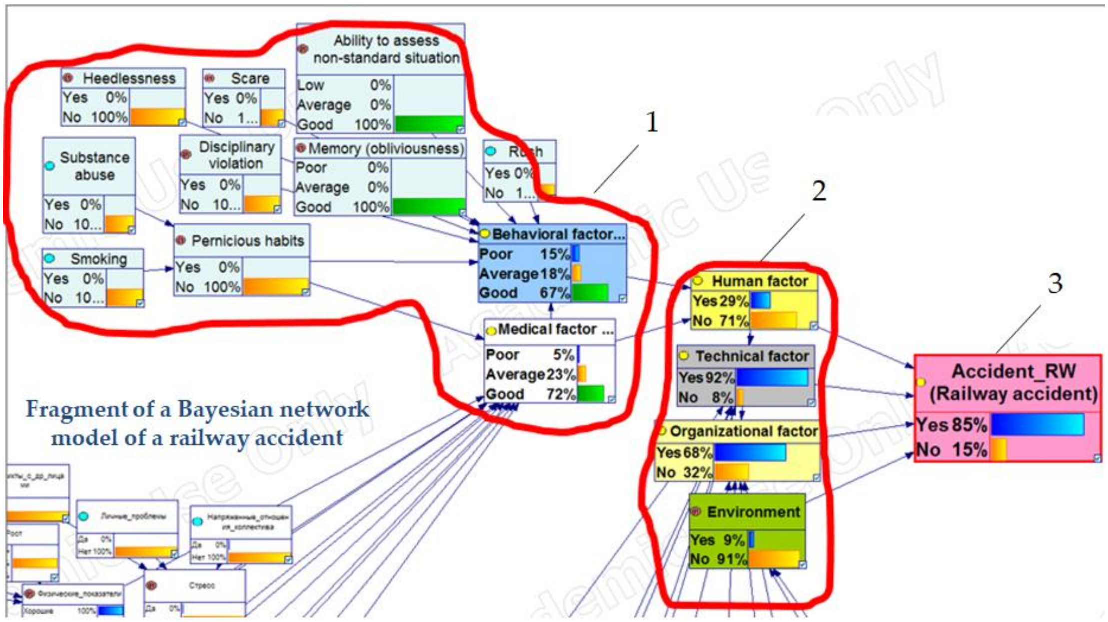


Fig. 10: *Using cross-entropy to build a complete group of events when using Bayesian networks that model the development of various types of accidents, including those on the railway: 1—nodes of detailed accident reasons; 2—nodes of main accident reasons; 3—main accident node [60].*

Modern science and computer technology are not ready to solve quantitatively some important problems of resilience and safety of large systems of systems of critical infrastructures. In these cases, the concept of a living laboratory of convergent technologies (LLCT) for governing a smart region is recommended [61]. The LLCT concept is a total rethink of a real life experiment that was first conducted in Boston, when architects and interior designers tried to get a sophisticated feedback from the end users of their product — a new apartment with built in furniture [62]. They actually built such an apartment and let a group of people to live in it for some time, and then asked them to give their opinion about the design.

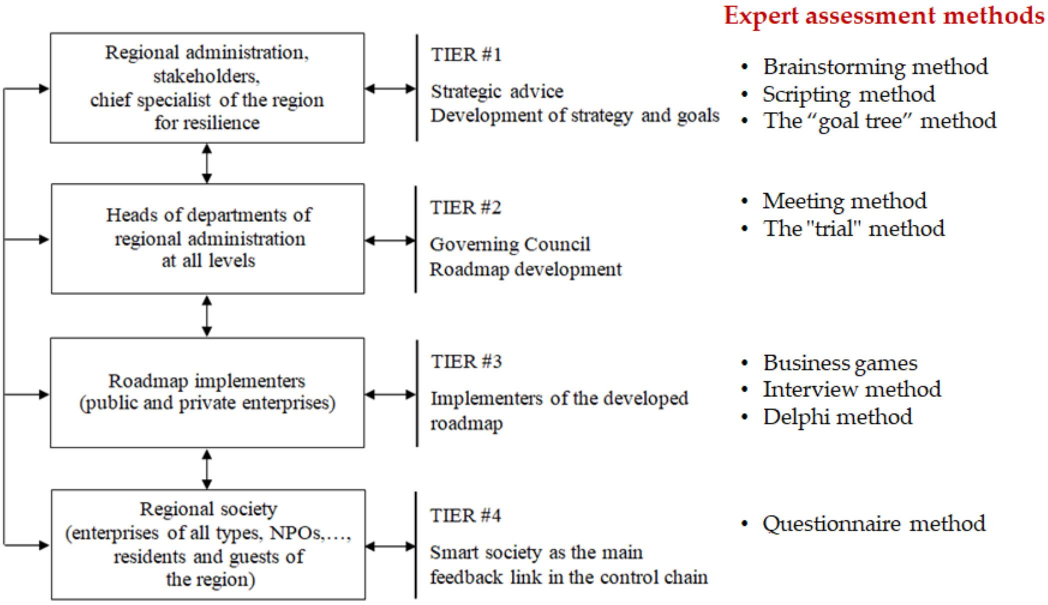
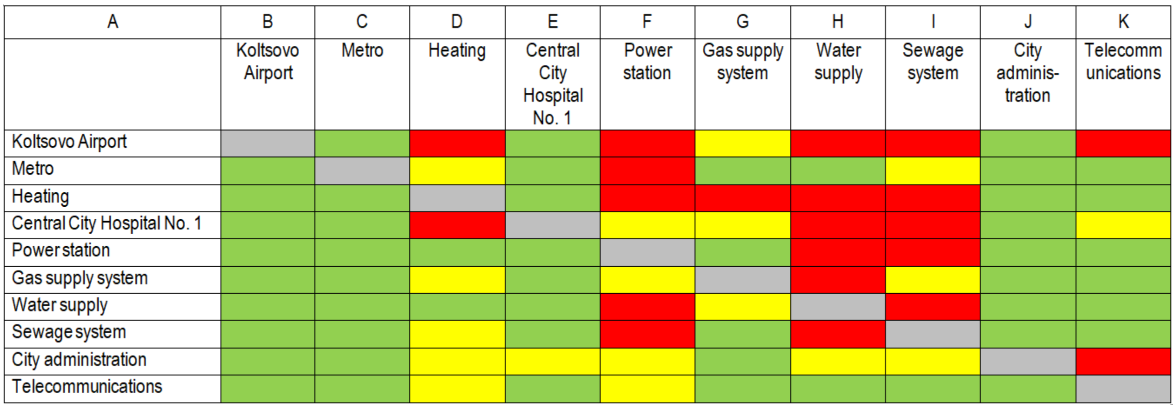


Fig. 11: *The concept of a living laboratory of convergent technologies (LLCT) for governing a smart resilient and safe region*

LLCT is a concept according to which the problem of resilience of an urban system of systems (SoS) is solved by the people who best know the SoS. Namely, by the specialists who run the SoS. They are the designated experts/*actors* (see Fig. 11, Tier #3). In order to understand better the concept, consider using the LLCT in Yekaterinburg.

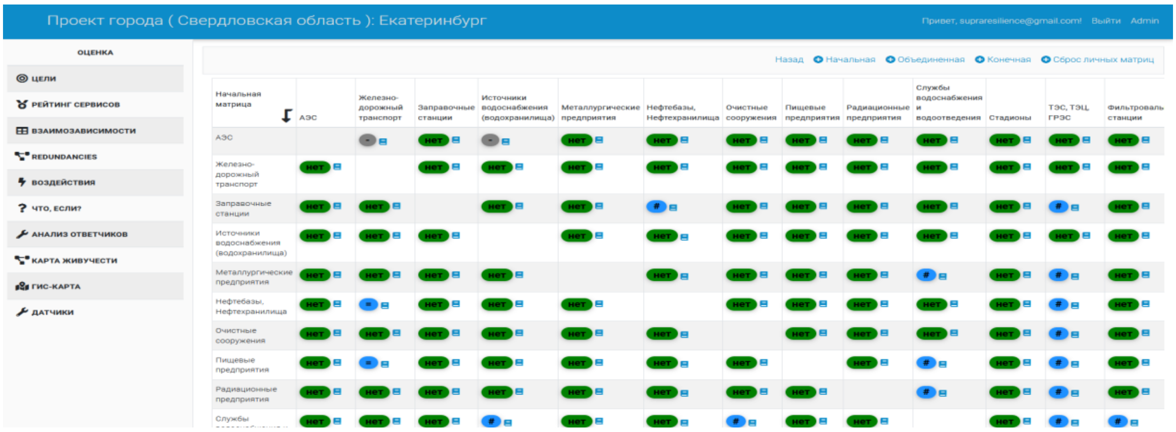
At the initial stage, service representatives collect the information about city services (of different levels and scales) and their infrastructures, and enter it into a matrix. At the next stage, actors (representatives of city services most knowledgeable about their functioning) form a matrix of interdependencies (Fig.12), where the colors in the cells indicate the degree of influence of one infrastructure on another: red – strong influence, yellow – moderate influence; green – insignificant influence



A	B	C	D	E	F	G	H	I	J	K
	Koltsovo Airport	Metro	Heating	Central City Hospital No. 1	Power station	Gas supply system	Water supply	Sewage system	City adminis-tration	Telecommunications
Koltsovo Airport	⬜	🟩	🟥	🟩	🟥	🟨	🟥	🟥	🟩	🟥
Metro	🟩	⬜	🟨	🟩	🟥	🟩	🟩	🟨	🟩	🟩
Heating	🟩	🟩	⬜	🟩	🟥	🟥	🟥	🟥	🟩	🟩
Central City Hospital No. 1	🟩	🟩	🟥	⬜	🟨	🟨	🟥	🟥	🟩	🟨
Power station	🟩	🟩	🟩	🟩	⬜	🟩	🟥	🟥	🟩	🟩
Gas supply system	🟩	🟩	🟨	🟩	🟨	⬜	🟥	🟨	🟩	🟩
Water supply	🟩	🟩	🟩	🟩	🟥	🟨	⬜	🟥	🟩	🟩
Sewage system	🟩	🟩	🟨	🟩	🟥	🟩	🟥	⬜	🟩	🟩
City administration	🟩	🟩	🟨	🟨	🟨	🟩	🟨	🟨	⬜	🟥
Telecommunications	🟩	🟩	🟨	🟩	🟨	🟩	🟩	🟩	🟩	⬜

Fig. 12: *Matrix of Yekaterinburg infrastructures and their relationships*

Each actor fills out his personal matrix of interdependencies of his service with other services and their infrastructures. All personal matrices are combined into a final matrix, which represents the interdependence of all city services and their infrastructures (Fig. 13).



Начальная матрица	АЭС	Железно-дорожный транспорт	Заправочные станции	Источники водоснабжения (водохранилища)	Металлургические предприятия	Нефтебазы, Нефтехранилища	Очистные сооружения	Пищевые предприятия	Радиационные предприятия	Службы водоснабжения и водоотведения	Стадионы	ТЭС, ТЭЦ, ГРЭС	Фильтроваль станции
АЭС		-	нет	-	нет	нет	нет	нет	нет	нет	нет	нет	нет
Железно-дорожный транспорт	нет		нет	нет	нет	нет	нет	нет	нет	нет	нет	нет	нет
Заправочные станции	нет	нет		нет	нет	#	нет	нет	нет	нет	нет	#	нет
Источники водоснабжения (водохранилища)	нет	нет	нет		нет	нет	нет	нет	нет	нет	нет	нет	нет
Металлургические предприятия	нет	нет	нет	нет		нет	нет	нет	нет	#	нет	#	нет
Нефтебазы, Нефтехранилища	нет	#	нет	нет	нет		нет	нет	нет	нет	нет	#	нет
Очистные сооружения	нет	нет	нет	нет	нет	нет		нет	нет	нет	нет	#	нет
Пищевые предприятия	нет	#	нет	нет	нет	нет	нет		нет	#	нет	#	нет
Радиационные предприятия	нет	нет	нет	нет	нет	нет	нет	нет		#	нет	#	нет
Службы	нет	нет	нет	#	нет	нет	#	нет	нет		нет	#	#

Fig. 13: *Final matrix of interdependencies of services (and their infrastructures)*

Based on the interdependency matrix, a diagram of service interdependencies is constructed. It allows to (1) clearly see its suppliers and consumers for the selected service, (2) build a critical path consisting of the most vulnerable suppliers and consumers (who will fail if the selected service fails), (3) build a diagram of interdependencies at the infrastructure level. It is important to note that all tiers of the urban society can use LLCT, as every tier has its own set of expert assessment methods.

It also permits visualizing cascade failures of interdependent infrastructures (Fig. 14). This, in turn, facilitates using the supply chain risk assessment methodology, according to which risks are identified based on expert judgment and a combination of Failure Effects Analysis (FMEA) and Intuitive Fuzzy Analytic Hierarchy Process (IF-AHP). Supply risks (demand, supply, logistics, finance, operations) are classified and prioritized. Recommendations for their reduction are developed according to their degree of importance (priority).

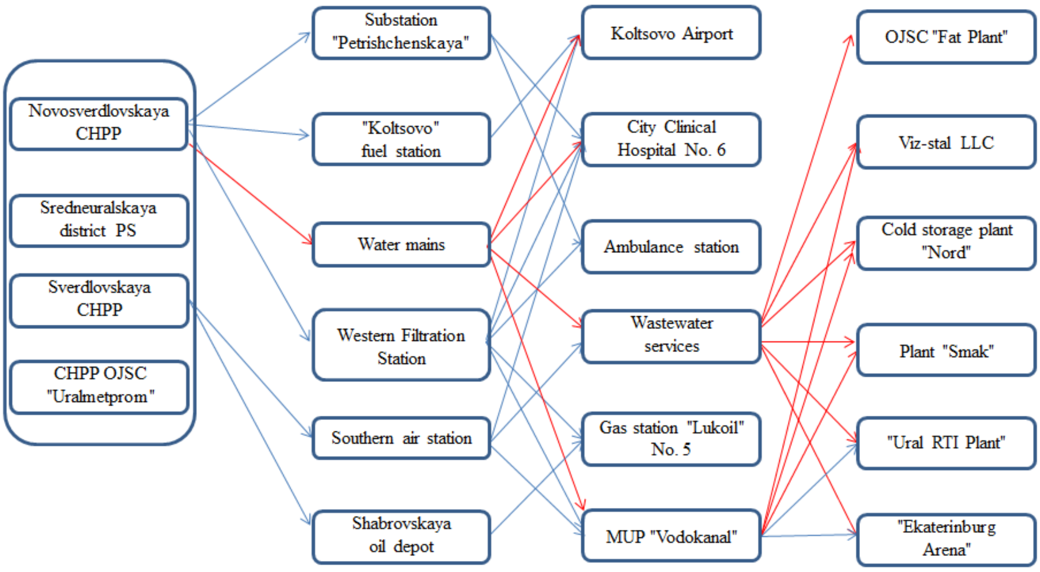


Fig. 14: *Visualization of cascade failures of interdependent infrastructures*

VI. Artificial intelligence as a central convergent discipline of MABICS technologies

It was noted above that AI is the link that connects all other components in the MABICS convergent technologies, as it takes over more and more problems from their scope. Indeed, it is promising to use the achievements of artificial intelligence, every time when there is an intrinsic lack of information about the system and methods of its operation.

AI, in particular, artificial neuron network (ANN), already is used to predict reliability and resilience of water supply systems [63]. It is useful when it is necessary to increase the diagnostics accuracy of defects in pipeline systems, to assess the reliability, resilience and safety of cold and hot water supply, and sewage systems, to ensure their uninterrupted operation (Fig. 15).

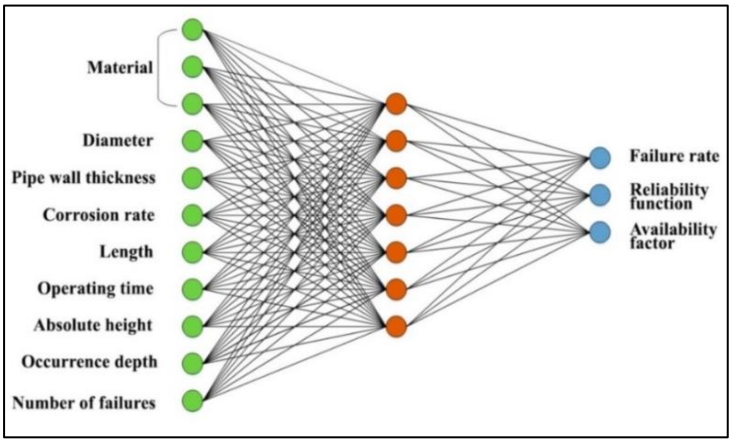


Fig. 15: *Architecture of the multilevel perceptron (MLP) 11-7-3 ANN model of the Kamyshlov city water supply system [63]*

VII. Application of block chain technology (BCT) in infrastructures operation [64, 65]

The block chain technology is useful to downsize the dimension of the infrastructure system model and to improve its accuracy. To this extent, BCT provides: Time stamp (registration of creation time) of documents; Verification of diagnostics (sensor data, control commands, events); Monitoring and maintenance of infrastructures of all types, reliability of records; Temporary chains of readings from sensors and devices with complete trust for network participants (Figure 16); Confirmation of damage assessments from incidents, accidents and disasters; Accounting for transactions in IoT (Internet of Things); Optimization of regional governance; Identification of geographic zones and user groups; Improving the security and survivability of regional interdependent facilities.

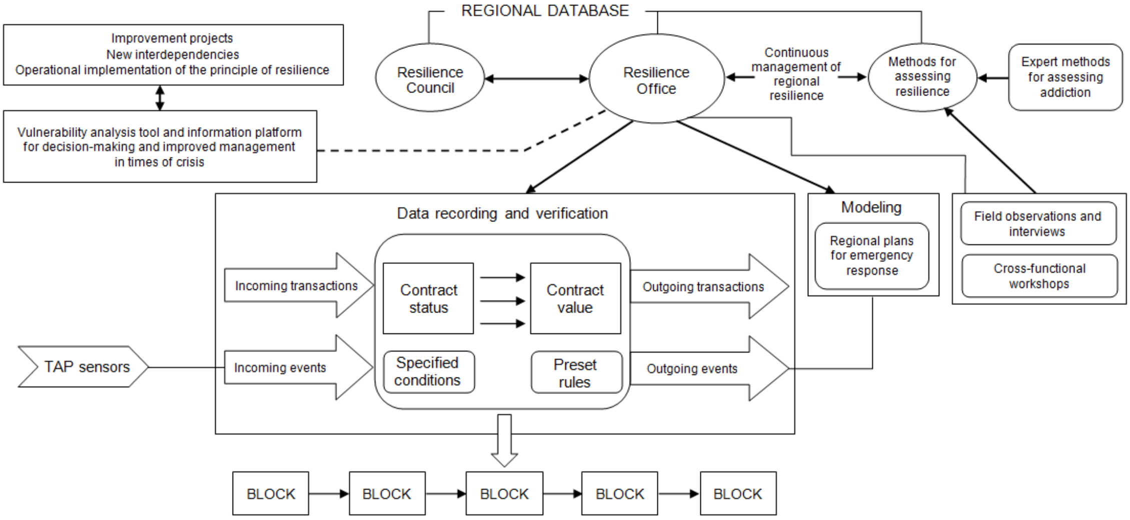


Fig. 16: *Scheme for transmitting information to DMs from sensors using block chain technology*

VIII. Conclusion

The results of the complex multifaceted analyses of papers related to reliability, resilience, risk and safety of critical and strategic infrastructures and their systems described in this paper lead to following conclusion.

The idea of convergence in relation to cyberphysical infrastructures and socio-technical systems has long been in the scientific world. Many leading scientists working in the field of technical sciences have long used this concept by default, without formulating it explicitly. Thus, E. Zio writes [29]: "In the community of experts in the field of risk, safety, reliability and security, there is a feeling that a new paradigm is needed for the analysis and management of complex distributed systems and critical infrastructures that form the basis of modern industry and society. A new risk scenario for modern industry and society poses some unprecedented challenges for research and practice, so that a new risk paradigm and new methods for analyzing reliability and risk may be required." At the same time, the observed anthropocentricity of global politics pushes scientific thought towards continuous convergence of disciplines that are, at first glance, distant from each other when solving social problems of infrastructures.

In this context, the MABICS convergent technologies, with explainable Artificial Intelligence as the key convergent science and technology, and infranetics as umbrella science could serve as the needed answer to this global challenge.

Infranetics as a synthetic umbrella science uses a targeted approach and is positioned as a cross-pollinating discipline of a number of fundamental and applied sciences, the goal of which is the optimal design and harmonious governance of the second, artificial nature of the planet at all stages of its life cycle.

Sub-resilience, resilience and supraresilience (knowledge gap in cognitive, social losses/gains), social entropy (connects quantitatively the tangible with intangible) are the prominent problems of biosociotechnical infrastructures that need attention, research and solution.

DM_s of a regional scale and persons equated to them, using the methodology of infranetics, will be able to optimize the parameters by which the effectiveness of their activities is assessed (growth of GDP, number and life expectancy of the population, level of education, employment, wages, volume of life support infrastructure construction, level of citizen confidence, etc.).

The author hopes that the reasons and logic for creating the MABICS technologies as the core of infranetics will find their supporters, adherents and followers, which will accelerate their application in practice by current and future generations of scientists and specialists.

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