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Transforming Yekaterinburg into a Safe, Resilient-Smart and Sustainable City

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Abstract. The initiative (since 2014) project described in this paper is a product of a joint innovative research and implementation effort of the Civil Engineering and Architecture Institute, Ural Federal University, the Science and Engineering Centre "Reliability and Safety of Large Systems and Machines", Ural Branch Russian Academy of Sciences (both Yekaterinburg), Start-up OptiCits, Barcelona, Spain and the Old Dominion University, Norfolk, VA, USA. The project is based on using the MAICS convergent technology [1] to create a versatile multi-purpose tool for optimizing the science and art of risk based governance of resilience-smart and sustainable city infrastructure and communities operating in usual and extreme conditions. The tool being developed is tailored to the needs of the City of Yekaterinburg–the capital of the Urals Region and allegedly the third most important and vibrant city of Russia. It is also being offered to the Yekaterinburg City Administration as an every-day decision-support work-tool and addendum to the Strategic Program "Yekaterinburg 2030 – a Safe City"[2] during preparation of the city for winning and conducting the World Expo-2025. Authors believe that the findings of this research would also be useful to the Sverdlovsk Oblast cities of every size and type of communities that inhabit them, including, first and foremost, Nizhny Tagil, Kamensk Uralsky, Serov, Pervouralsk, Revda, Verkhnyaya Pyshma, multiple mono-cities et al. The project also incorporates block-chain technology, smart contracts and digital currency as an effective tool for implementing the project.

1. Introduction

This project is an integrative multi-sector research as it addresses both technological and social dimensions of a resilience-smart and sustainable city using the proposed in [1] MAICS convergent technology (Digital Computing Mechanics and Design, Artificial Intelligence (AI), Information Theory (IT), Cognitive and Social Sciences). The description of how the dimensions are integrated together is the core problem of the whole research. It is tethered to the realities of the City of Yekaterinburg and addresses following strategic domains: energy, urban civil infrastructures' resilience and planning, disaster (including draught and flooding due to climate change) mitigation and response, education, environmental footprint, life expectancy, and vital social services (including telecommunications, and transportation). Research is conducted by intersecting and cross-pollinating previously unrelated bodies of research from different branches of sciences and engineering.

The project uses following four novel generalized optimization criteria: 1) structural and system resilience (SRes); 2) regional (local) life expectancy in good health (RLE) [3, 4]; 3) modified life quality index (MLQI); and 4) two types of regional entropy (RE): [of creation REo (organization) and of chaos REc (deterioration)].

It is postulated that these four unifying optimization criteria cover all major areas of the wellbeing of contemporary and future communities of smart and sustainable cities. Moreover, these integral criteria permit convoluting the multidimensional, multidisciplinary and multifaceted heterogeneous problem of regional resilience, strategic preparedness and risk into a (quasi) single dimension problem, thereby greatly simplifying the problem of creating smart and connected communities that inhabit sustainable cities of any size (large, medium and small).

The foundation of this research is the following working hypothesis: The system of systems (SoS) of interdependent critical infrastructures (ICIs) of the built urban environment can be considered as an intermediary between the natural environment and the resource demands of a modern society and everyone who is a member of this society. Urban ICI networks are also the principal source of socio-technological hazards of the city. A point failure anywhere in the ICIs can rapidly propagate through the city with broad impacts on the citizens and the environment [5, 6]. Hence, the resilience of the urban ICIs could be used as one of the generalized independent variables of the sustainable city problem, as it allows quantitatively connecting the tangible with the intangibles. At the same time, it reveals the boundaries of this quantifiable connectedness, beyond which the relationships start to be too fuzzy [5] and uncertain. Hence, it stands for reason that management of complex urban risk may be boiled down (as a first approximation) to management of economic, environmental and physical risk for the whole urban system of the ICIs.

2. City DNA

Major cities, such as Yekaterinburg, are growing into megacities and are currently subjected to a multitude of pressures, out of which the following four are of greatest concern: 1) rapid evolution of digital technology (IoT, IIoT) and globalization; 2) fast socioeconomic changes; 3) obvious climate change; 4) the growing needs of demanding citizens, due to a combination of the above elements. All these pressures create new threats that could be effectively mitigated by the novel concept of urban resilience.

Modern ICIs have following indispensable components: Risk-based diagnostic subsystems; Monitoring and/or control sub-system(s); Risk based integrity maintenance subsystems; Assets safety and security/defense subsystems. The total risk of operating ICIs is carried by its full group of possible scenarios. All these specifics should be consistently accounted for during the design, operation and risk assessment of urban potentially dangerous objects (PDOs) and ICIs [7].

3. City Resilience

The concept of resilience emerged currently as a central theme of industrial and urban development (there are more than 120 definitions of resilience, most of them are qualitative) [8–12]. For instance, the European Commission defines resilience as «*the ability of … a community, a country or a region to withstand, adapt, and quickly recover from stresses and shocks such as drought, violence, conflict or natural disaster*». As an intrinsic property of any socio-technological system, it can serve as the basis and tool for solving the most urgent issues of modern civilization, including strategic investments by leading development institutions and humanitarian communities.

Despite the importance of critical infrastructures and systems and expected growth of future climatic hazards, relatively few studies have addressed these issues and no methodology for the analysis of such an impact has ever reached a consensus. In the theory of infrastructures resilience is defined as a multi-attribute measure that describes the ability of a system of interdependent CIs to withstand a disaster shock, and its ability to recover within an acceptable envelope of time and cost. As of now, it seems (to our knowledge) that there is no quantitative definition of resilience and strategic preparedness to which a majority would subscribe.

The "Yekaterinburg-Resilient-Smart City" research covers: 1) critical infrastructure as a net; 2) urban interdependent system of critical infrastructures. The regional and infrastructure resilience/preparedness are defined in quantitative, probabilistic terms, as most of the multiple parameters on which resilience / preparedness are dependent, are either ill-defined, fuzzy or random variables (RVs), or random functions/fields (RFs). The main components of urban resilience probability vector include the physical and spatial resilience, as well as environmental (disaster)**,** economic resilience. industrial resilience, organizational (functional), and social (human) resilience. The randomness of the parameters which describe resilience quantitatively could be of different nature (epistemic, aleatory, fuzzy, vague, uncertain, indefinite, etc.). Each specific resiliencies can be parsed into partial resiliencies as related to different aspects of the considered type of resilience. The physical and spatial resilience of a system of critical infrastructures is defined through their reliability and operational risk [13].

The conditionality of the probabilities is due to the time of analysis, structural, financial, social and other restrictions for which the resilience is assessed. This multidisciplinary and multifaceted approach is used is applied to regional (municipal) critical and strategic infrastructures of different nature. It is shown how to use the concept of quantitative resilience in design, operation and mitigation of the consequences of an industrial (leak, rupture of oil/gas, water or sewage pipelines or a plant explosion/fire) or a natural disaster (e.g., incident related to global warming), and how to assess and manage regional risk and quantify the interdependence between different types of infrastructures. The super-urgent problem is formulated on how to connect the physical and spatial (core) resiliencies with the functional, organizational, economic and social resiliencies.

Urban resilience is the driver and, simultaneously, a precious quality of sustainable urban development. Considering a city as a system of systems (SoS), resilience recognizes all of them as dynamic and complex systems that must continuously adapt to various challenges of stochastic, probabilistic, uncertain, or vague character in an integrated and holistic manner. Each part of these systems has an inherent reliance on all the other parts.

In general, factors that influence city resilience include: the range and severity of hazards; the risk to life, limb, health and property; the vulnerability and exposure of human, social, and environmental systems to different types of hazards, and the degree of (strategic) preparedness of the physical, social and the governance systems to any natural, urban or industrial shocks and stressors and their consequences during an incident, accident, malicious act or catastrophe. Our resilience concept adopts a multiple-hazards approach, considering resilience against all types of plausible hazards, and refers not only to reducing risks and damages from disasters [i.e. loss of lives, limbs, health, elements of Nature (flora & fauna) and assets], but also to the quantified ability to quickly recover to the pre-event state after a physical or social disaster or catastrophe at minimal cost.

The essence and components of urban resilience consists of working to: 1) prevent any potential threat; 2) withstand any impact caused; 3) react to the crises derived from the impact; 4) recover the city's functionalities; 5) learn from the experience. All this is achieved when the city (in our case, Yekaterinburg) becomes smart. In its own right, sustainable cities of the 21-st century have to be first resilient, smart and safe in order to then become sustainable.

This concept is expanded to investigate the existing (but yet not discovered or fully understood and quantitatively described) connections [e.g., (semi) quantitative dependencies/correlations] between physical resilience of a system of systems of ICIs and the 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. As one of the results of this research the urgent problem is formulated: how to assess the connections between the physical and spatial (core) resiliencies and the functional, organizational and social resiliencies, which largely depend on the type of the society.

The described above multidisciplinary and multifaceted approach is applied to the analysis of critical and strategic infrastructures of different nature of the city in consideration. A methodology is being developed to study how to assess and manage: 1) reliability/safety levels of interdependent infrastructures taking into account the human factor, including errors and mishaps of human beings who operate or use the ICIs [13]; 2) physical regional resilience by managing reliability/safety of the systems of ICIs, and 3) the vector of societal resilience by managing the probabilistic vector of the physical resilience of the ICIs or with purely social tools (which are being defined during the research).

All the above is applied to: urban critical civil infrastructures (energy, transportation (including oil/gas, water and sewage pipelines [14, 15]) and urban planning, disaster mitigation and response, education and learning, health and wellness, including healthcare, social resilience, safety, and social services.

This research is also implementing the life quality index (LQI) and the willingness to pay concept (WTP) for designing, constructing and operating components of urban infrastructure, managing not only the economic loss mitigation but also, simultaneously, the risk to life safety and health. This promotes and expedites reaching the National 80-years-life-expectancy goal by 2030.

Results of the conducted research are useful to the decision makers (DMs) at the regional, municipal and plant level, considering short-term and long-term priorities associated with sustainable growth of the interdependent critical infrastructures (ICIs) under their jurisdiction using the above criteria. The DMs will also be able to monitor how their decisions influence the quality of life and the level of happiness of their constituents, as related to the decisions they make in disaster and ordinary times, including optimal distribution of their budgets. The envisioned methodology, as developed, may also serve as a useful tool for managing risk of potentially dangerous objects (PDOs), interdependent critical infrastructures (ICI) of different nature, and their systems, according to the above criteria.

4. Urban resilience system architecture

The architecture of the urban resilience system (URS) mimics the long time existing on the market different monitoring and maintenance optimization systems designed to enhance performance of critical industrial infrastructures. The difference is in that the urban infrastructure, in its entirety, is a very specific complex system of interdependent systems (SoIS), being widely spread over the whole territory of a municipality, is 1) intensely used by the city community and 2) elements of its transportation infrastructures (cars, trams, buses, metro carriages) continuously move. The URS is designed to provide, in the first place, raw and processed data about how this SoIS functions and degrades in time.

To implement the resilience methodology for creating a smart and sustainable city with a well connected community it is necessary to have in place an urban resilience subsystem (URS). A typical URS is comprised by: sensors/CCTV, distributed over the whole territory of the city; geolocation subsystem; information subsystem; security subsystem, and the situation room SR, which serves as the ultimate place where the decision makers formulate, simulate and calibrate their actions in response to different incidents, emergency situations, and catastrophes. This URS identifies the weakest spots in the urban SoIS and reacts faster and more efficiently during and after an impact or crisis. Administrations of some cities (i.e., Barcelona, Bristol, Lisbon, Norfolk, et al.) that have the smart cities as a goal for their status, established the position of a Chief Resilience Officer (CRO), whose responsibility is dealing with urban crises and systemic stress.

The problem of urban resilience management consists of: 1) Assessing the full possible damage and all its components; 2) Designing means and methods for reduction the potential consequences of an initial failure in the system of ICIs as related to the physical and the social component of the smart community. This problem can be solved only through interdisciplinary approach, and by convoluting the heterogeneous parameters, which define the operation of the CI, into few integral parameters, which should be simple to understand and use.

The main conceptual problem of assessing, monitoring, and managing resilience/risk of smart and connected communities embedded into ICIs is defined by following three factors: the dimension of the problem is huge (could be tens of thousands of interdependent parameters); the problem is multi-disciplinary, and the parameters involved when solving the problem are from different sciences and branches of engineering, and currently are, as a rule, hard, if not impossible to convolute; the ICI risk cannot be adequately described without explicitly accounting for the Human Factor (HF). Hence, before attempting to solve the problem in consideration, it is necessary to introduce some unified measures of safety/risk, which account for the human factor in socially meaningful terms.

The last problem that crowns the full solution of urban community risk management is designing and implementing risk mitigation control means using the LQI and the WTP concepts. There are two approaches to solve this problem. The direct problem is posed as follows: With given means for improving CIs safety S_{giv} choose such a set of measures that maximizes reduction of incident A probability $Q_i = P / A$. The inverse problem is formulated in following terms: With minimal expenditures EX choose such a set of measures, implementation of which lowers the incident probability $Q_i = P / A$ down to an acceptable (preassigned) level $P_{acc}(A)$ [16].

Technological dimensions that are explored in this research: (1) analysis of the epistemic and aleatory digital data flow from different urban critical infrastructures [13], its integration and management; (2) constructing and using new algorithms and frameworks for digging and correct interpreting large volumes of diverse and complex deterministic, probabilistic, fuzzy and uncertain data related to urban infrastructures and community; (3) innovative engineering management and systems engineering approaches for integrating cyber [10], physical, and social parameters and security, safety and wellbeing concerns in a large-scale system-of-systems context with multiple stakeholders.

Social dimensions that are being researched, include: (1) qualitative and quantitative understanding of institutional changes and social behavior and responses to different types of intelligent technological change within different types of communities; (2) short- and long-term responses of communities to natural catastrophes, industrial and malicious disasters; (3) methods for measuring and predicting community challenges and opportunities.

5. Integration of interdependent technological and social dimensions

The described research considers and demonstrates following cases of integrating the interdependent technological and social dimensions in time: (1) IT and AI based innovative concepts and methods of supporting communities in their quest to improve quality of life; (2) novel methodologies for seamless integration of flexible urban infrastructure systems into the fabric of sustainable cities; (3) prediction, analysis, and mitigation of physical and/or institutional challenges to sustainable cities from new technologies, forms of data, and infrastructures; (4) algorithms and representations for enabling design of human-centered infrastructures; (5) new technologies and practices to improve community-level decision making under uncertainty associated with highly complex systems and infrastructures; (6) the dual role of emerging technologies in shaping innovative and harmonious human-technology-environment partnerships leading to career longevity via life-long learning of new skills of the 21-st century in communities of practice.

Following the above working hypothesis, the research aims at creating a meaningful and objective picture of how the physical infrastructure system supports and at the same time provides (generates) most of the risks to the modern communities that live in such surroundings, which are supposed to be resilience-smart, sustainable and safe cities. There are two competing concepts of such cities [16, 17]. The first concept is used to equip the urban infrastructures and services for optimal managing of the city as the path to create a resilient city. In the second concept the optimal management of a city goes through already resilient network of services and infrastructures equipped with smart technology to create a smart and sustainable city. In the latter case the concept of a resilient-smart and sustainable city is formulated and builds up around optimizing implementation of following five key ideas:

- the win-win exchanging/sharing of goods and services between citizens and communities, using the common heritage or private property;
- the minimal environmental consumption and energy efficiency (minimal environmental footprint of the city), by recomposing the mix of energy consumption and the self-production of renewables;
- the free and fluid communication among social stakeholders (citizens, communities, companies, and institutions) using new technologies;
- city-wide integration of new information and communication technologies, robotics and intelligent systems that maximize delivering the needed information to end users ubiquitously and with transparency;
- the reliable and safe network operation, which is the basis of resilience, to: 1) achieve maximum security of supply of goods and services with the right energy and environmental consumption; 2) make good use of the available infrastructure and 3) provide the necessary social communication that will enable the city to adapt and recover functionalities in case of an impact.

Implementation of these ideas may include changes in the design and management of: 1) infrastructures, with emphasis on the redundancies and interconnections; 2) interdependent services, focusing on the ways they could support each other in case of an incident; 3) behavior of citizens in ordinary and, especially, in critical situations (the fundamental strategic element for improving urban resilience and sustainability). To meaningfully solve the problem of smart and sustainable cities, the second approach is used.

6. Governance and decision support software

The hotspot in implementing the smart resilience concept in every-day management of cities is in creating and using specially tailored software for managing the interdependent urban critical infrastructures. In the described research the well established software product, originally developed by OptiCits, HAZUR, is used [18]. OptiCits has accumulated considerable expertise, using HAZUR, in providing practical support to such smart resilient cities as Barcelona and its sattelites La Garrotxa, Sent Cugat de Valles, Terrassa, Tremp, (all Spain), Lisbon (Portugal) and Bristol (UK) [19, 20, 21,22]. In this research the enhanced version of HAZUR, based on joint findings of the described above endeavour, is used. It permits: 1) processing the data from diagnostics and monitoring sensors for studying, analyzing and managing the city resilience, 2) optimizing the compatibility, coordination, operation of different services (agents) based on gathered data, and 3) running simulations to illustrate how the city community and its ICIs will react in the case of an impact [23]. HAZUR supports city leaders and executive officers, public administration staff, city operators and professionals and advisors willing to work with all city stakeholders.

7. Stakeholders of sustainable cities

The stakeholders of urban resilience, safety and sustainability are four major different groups of organizations: 1) multilateral bodies (key to the urban safety and resilience market), as they provide financing for UR improvement projects in emerging and developed cities, management and its benefits to citizens, economic operators, and decision-makers, support of policies for improving safety, resilience and sustainability; 2) research centers, which play a fundamental and vital role in this regard; 3) businesses that catalyze UR development; 4) governments of all caliber cities that are the end users of the UR product. It goes without saying that residents of the communities that live in cities that want to be smart and sustainable are the ultimate beneficiaries of urban sustainability, safety and resilience and, hence, should be the most active component of the same.

For this reason one of the main problems of sustainable cities is the formation of a motivated citizenry interested in making their home safe, smart and sustainable. Analysis gives that for achieving this goal it is necessary to preserve and expand the size of the middle class of each smart, sustainable and connected community. The main existential threat to the middle class are the fast-changing intelligent technologies, that historically soon will make many types of middle class jobs obsolete, among them, just to name a few: car and truck drivers, conveyor belt and construction workers, welders, translators, low-level accountants and bookkeepers, librarians, sales persons. Some forecasters even mention medical diagnosticians, surgeons of average traumas. It is known that computers already can prove some original theorems (provided they are well formulated by humans).

Hence, the main existential problem of every resident of a 21-st century smart and sustainable city/community is to figure out how to be permanently useful in a fast-changing world and thereby make a decent living allowing following her/his aspirations. It is also very important that smart sustainable cities/communities as entities provide a tangible input to peace and happiness to its members.

Community engagement in this research is achieved by creating a virtual community occupying a virtual City of Yekaterinburg, which will have a Chief Resilient Officer (CRO) and a Situation Room that also serves as a living lab**.** The above stakeholders of the smart community conduct pilot projects which include reacting to some representative disaster scenarios. During this process they identify key issues, plan and implement projects, make decisions, and evaluate outcomes, support data collection and/or interpretation within the community context. They may also be instrumental in providing data, facilities, resources, and expertise to the project. The scenarios are executed via 3D computer simulation [23, 24].

8. Conclusion

1. Initial results of an interdisciplinary project on developing a methodology of urban risk management via risk governance of ICIs systems are presented.

2. Results of the research may be useful to the municipal level decision makers (DMs), who make decisions related to optimal distribution of their budgets, taking into account sustainable growth of entities under their jurisdiction. They will also be able to monitor how their decisions influence the quality of life / level of happiness of their constituents as related to the decisions they make in the disaster and ordinary times.

3. In order to implement the resilience methodology to create a smart sustainable city it is necessary to build up for it an urban resilience subsystem URS, its architecture outlined in this paper, and create in its frame work a Resilience Office that is the core of dealing with urban crises and systemic stress. This URS would identify the weakest spots in the urban System of Systems and react faster and more efficiently during and after an impact or crisis.

4. Results of this research provide additional impacts in: (1) novel methods of optimization of the type and number of means for mitigating system risk; (2) more effective engineering engagement of societal problems from a new and novel perspective based on inclusion of previously disparate streams of knowledge; (3) path-finding methods for predicting, analyzing and mitigating physical challenges to sustainable cities and its communities; (4) considerable improvements of decision support methods and decision making under uncertainties; (5) advances in modern ways of learning [25].

References

[1] Timashev S A 2016 Infranetics-Off-Shoot of Infranomics – a New Convergent Science of the 21-st Century *Nauka Urala* **5-6**

[2] 2018 *Strategic Program "Yekaterinburg 2030 – a Safe City*" (Yekaterinburg: City Administration)

[3] Tatarkin A I, Timashev S A, Kozlova O A et al 2015 Assessing the Impact of Factors on the Average Life Expectancy of the Population in the Municipality (on the Example of Yekaterinburg) *International Journal of Applied and Fundamental Research* **9-2** 128–32

[4] Timashev S A 2014 Average Life Expectancy as a Criterion for Regional Risk Management *Journal of Risk Analysis and Crisis Response* (Paris: Atlantis Press) **4(1)** 10–19

[5] Oboskalov V, Timashev S, Bushinskaya A and Gusev S 2016 Stochastic Network Reduction Technique for Calculations of Electrical Power System Structural Reliability *2nd Int.l Symp. on Stochastic Models in Reliability Engineering, Life Science, and Operations Management*, *SMRLO 2016* 144–49

[6] Robert B, Morabito L and Quenneville O 2007 The preventive approach to risks related to interdependent infrastructures. *Int. J. of Emergency Management* **4(2)** 166–82
[7] *ISO 31000:2009*. Risk management – Principles and guidelines
[8] Gheorghe A V, Vamanu D V, Katina P F and Pulfer R 2018 *Critical Infrastructures, Key Resources, and Key Assets* (Switzerland: Springer International Publishing)
[9] Holling CS 1973 Resilience and stability of ecological systems *Annual Review of Ecology and Systematics* **4(1)** 1–23
[10] Hollnagel E, Woods D and Leveson N. (Eds.) 2009 *Resilience engineering: Concepts and precepts* (New York: CRC Press. International Organization for Standardization)
[11] Jackson S and Ferris T L J 2013 Resilience principles for engineered systems *Systems Engineering* **16(2)** 152–64
[12] Timashev S A and Krimgold F 2014 Resilience and strategic preparedness of interdependent critical infrastructures. *Proc. of the 11th All Russia Science and Technology Conference Safety of Critical Infrastructures and Territories Yekaterinburg/Abzakovo, UB, RAS P 11 ALL RUSS SCI TE* 43–6
[13] Timashev S A and Bushinskaya A V 2017 Assessment of Probability of Failure of Building Structures in Uncertainty Conditions *Proc. of the Inter. Conf. on Construction, Architecture and Technosphere Safety (ICCATS 2017)* **262**
[14] Timashev S A and Bushinskaya A V 2016 Diagnostics and Reliability of Pipeline Systems *Springer Verlag*
[15] Timashev S A 2015 Predictive maintenance – key component of providing integrity and safety of pipelines *Proc.of 8th Annual Global Pipe Tech Summit* (Budapest, Hungary)
[16] Timashev S A 2017 Regional Resilience as a Functional of Infrastructures Operational Risk *Proc. of the 26th Annual Conference/Meeting of the Society for Risk Analysis – Europe (SRA-E)* (Lisbon, Portugal)
[17] Timashev S A 2017 Resilient Urban Infrastructures – Basics of Smart Sustainable Cities *IOP Conference Series: Materials Science and Engineering (ICCATS 2017)* **262**
[18] 2017 *HAZUR* Software (Barcelona)
[19] Evans B, Chen A S, Prior A, Djordjevic S, Savic D A, Butler D, Goodey P, Stevens J R and Colclough G 2017 Mapping Urban infrastructure interdependencies and fuzzy risks *7-th Int. Conf. on Building Resilience ICBR* (Bangkok, Thailand) 816–23
[20] Velasco M, Russo B, Maigrat P, Fontanals I and Vendreli E 2018 Holistic resilience assessment to cope with climate input in urban areas-implementation in Barcelona *SmartMobility World Congress*
[21] Fontanals L, Tricas J, Canalias F and Fontanals I 2014 Territorial resilience, service management vector. Case Study of the Garrotxa Business Studies **1 144**
[22] Fontanals L, Tricas J, Sempere J and Fontanals I 2012 Improving the resilience of cities: Industrial knowledge applied to the Management of the City *CONAMA 2012* (Spain)
[23] Gheorghe A and Timashev S A 2015 Designing resiliency of city infrastructures comprised of present and next generation systems using gaming technology *Int. Conf. «Economic & Technical Aspects of Civil Engineering Critical Infrastructures» SAFETY2015* (Yekaterinburg) 5–6
[24] Guryev E S, Poluyan L V and Timashev S A 2014 Construction of Dynamic Risk Maps for Large Metropolitan Areas *J. of Risk Analysis and Crisis Response* (Paris: Atlantis Press) **4-2** 72–6
[25] Timashev S A, Alekhin V N, Poluyan L V and Guryev E S 2015. Innovative Master's program "Safety of civil engineering critical infrastructures and territories" *WEEF2015 «World Engineering Education Forum»* (Italy)