Information Technologies for Assessing the Impact of Climate Change and Natural Disasters in Socio-Economic Systems

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Abstract. The paper proposes to use the utility theory for the synthesis of multivariate models of assessing the impact of changing climatic conditions and the disaster assessment in the implementation of the socio-economic approach. The work contrasts two situations of environmental impact (external influence) on the society systems. A feature of each of the situations is the duration and intensity of impact, which leads to its unique consequences. Socio-economic approach takes account equally the economic, social and environmental impacts. The paper proposes a universal model to assess the impact of external influences on the system. Considering information technologies that provide a procedure for assessing risks and consequences of natural disasters in socio-economic systems.

Keywords: Information Technologies, Natural Disasters, Assessing Risks, Socio-Economic Systems,.

1 Analysis of the Subject Field

Modern society constantly faces various global challenges. Namely, climate challenges, such as global warming and shifting of climate zones or anthropogenic challenges, such as hazardous emissions, fires, tanker or well oil spills and accumulation of waste, etc. In order to ensure successful functioning of a state, its governmental institutions have to consider a wide range of scenarios and if possible counter emerging threats. Taking all potential circumstances and scenario developments into account is rather difficult and unreasonable, particularly in regard to balancing the levels of resource consumption with the achievement of desirable results. Therefore, the two following aspects gain, as a rule, increased attention: firstly, threats to life and health of the country's population, and secondly large-scale destructions or inability to use the country's main production facilities. The abovementioned first aspect assures the fulfilment of a state's main function – protection and realisation of its population potential. The second aspect provides for the public consumption level, and if the state fails to insure the necessary consumption levels, it may result in public tensions, protests, famine or pandemic.

There are hundreds of disasters in the world. The ratio of natural catastrophes to man-made disasters is presented on the Fig. 1 [1].

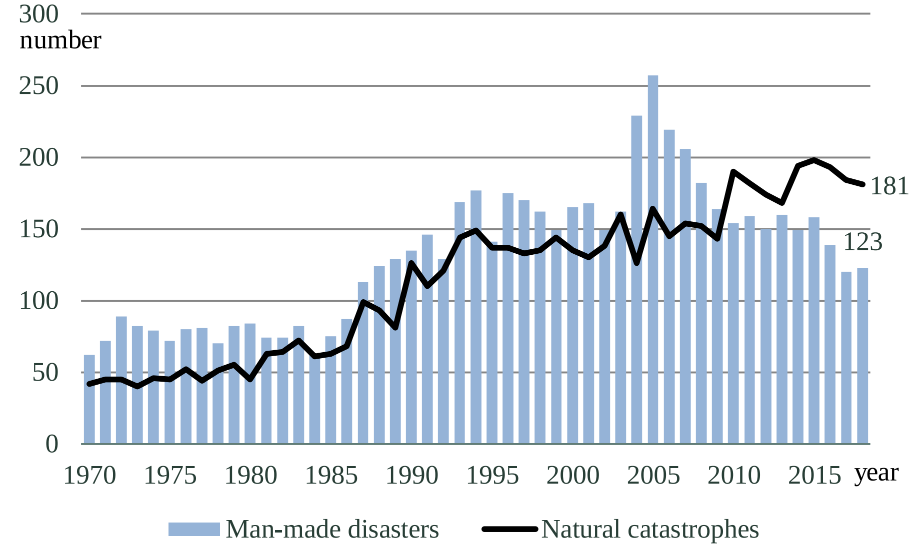

Fig. 1. Number of catastrophic events, 1970–2018.

According to the UN [2], the number of deaths among all types of natural disasters, hydrometeorological disasters come first, geological second and man-made disasters third.

About 3.3 million people (on average 82,500 people per year) worldwide died from earthquakes, hurricanes and other dangerous natural phenomenon from 1970 to 2010. Most lived in poor countries.

These statistics include only the direct victims of natural disasters. Natural disasters often provoke a decrease in consumption, for example, drought can provoke a crop failure and subsequently starvation.

For example, the drought in the USSR – 1921-1923. (about 3 million people), 1932-1933 (from 3 to 10 million people); China – 1939 (200 thousand people), 1942-1943 (about 3 million people); India – 1943 (about 1.5 million people); Kampuchea – 1975-1978 (about 1 million people); Ethiopia – 1983-1988 (about 1 million people); North Korea (about 2 million people).

Since 1980, more than two million people and over $3 trillion have been lost to disasters caused by natural hazards, with total damages increasing by more than 600% from $23 billion a year in the 1980s to $150 billion a year in the last decade [3].

Middle income countries suffer as a rule the greatest damage.

Examples demonstrating that natural and man-made disasters are widespread and often.

As can be seen, natural disasters can occur in any region of our planet. Unquestionably, for a certain type of natural disaster, there are relatively calm regions, but if viewed in a complex, and take into account the changing climate of the planet, all regions of the planet are at risk of natural disasters.

The aggressive impact on the system should include not only natural disasters, but also man-made disasters. Man-made disasters have already equaled many types of natural disasters in their scale and consequences. Yield them only in predictability. Natural disasters are more difficult to predict and to develop an event to compensate the effect.

2 Types of external influence

During the research, different types of effects of the aggressive environmental impact on the system were identified. Should be allocated:

1. Short-term impact and consequences. For example, a strong gusty wind breaks branches and disrupts outdoor advertising, car fires and more. The point is that an exposure lasts no more than a few days, and it is also possible to completely eliminate the consequences in a few days. For example, fires, torn off roofs, broken tree branches.
2. Long-term impact – short-term consequences. For example, accumulation of garbage, dust, snow. The process is time-consuming, but regular regulatory activities (filter replacement, garbage removal, snow removal) are enough to eliminate the consequences. For example, snowdrifts, abnormal temperatures.
3. Short-term impact – long-term consequences. For example, tsunamis, hurricanes, earthquakes, major industrial accidents involving emissions of toxic substances. All of them last a limited, often small period of time, but the damage is huge and it can be eliminated in a few years. For example, tsunami, flooding, volcanic ash.
4. Long-term impact and consequences. For example, enterprise emissions that gradually poison groundwater and soil, exit points for gas and oil products that mix with groundwater and can accumulate in various cavities in the ground. Poisoning and accumulation of critical mass occurs gradually, purification requires long and costly procedures.

The classification is symptomatic because the time spent on remediation is related to available resources and technologies. Some consequences are not eliminated, leaving nature to overcome the consequences on its own.

Climate change should be placed in the fourth category (long-term impact and consequences).

3 Description of the problem

3.1 Definition of a System

Undeniably, addressing the issue of countering potential risks should be based on the methods and principles of system analysis [4, 5]. Definition of an abstract system, which is most practical and convenient for modelling, is the set-theoretical one presented in the works by N. Bourbaki [6].

In this case, a system is defined as a set of homogeneous or heterogeneous elements $M = \{m_i\}, i = \overline{1,n}$ with a set of relations $R = \{r_j\}, j = \overline{1,k}$. Then the Cartesian product

$$C = \{M \times R\} \tag{1}$$

defines the universal set of structures of an abstract system. Qualitative and quantitative characteristics of the sets M, R make it possible to determine the exact structure of any system: social, economic, and ecological, etc.

Every particular model of the structure (1) has a certain set of obvious or latent properties $P = \{p_l\}, l = \overline{1,g}$. Thus, $P = F(C) = F\{M, R\}$.

Given the abovementioned, the initial definition of an abstract system may be expanded and presented as follows [7]

$$S = \langle \{M \times R\}, P \rangle. \tag{2}$$

3.2 The Process of Decision-making

Making a decision is an integral part of any purposeful human activity: household, professional, production, environmental, social, and political, etc. Despite the abundance of the application areas, it is possible to list common stages of the decision-making process. They are as follows [8]:

- formulating an objective;
- defining a set of possible X^P and admissible $X \subset X^P$ decisions to achieve the formulated objectives (decisions);
- selecting and conceptualising a metric to determine relative efficiency of possible alternative decisions $x \in X$ i.e. efficiency criterion $K(x)$;
- solving the task of finding an efficient solution

$$x^0 = \arg \underset{x \in X}{extr} K(x). \tag{3}$$

According to V.M. Glushkow [9] a solution, which may be considered efficient, meets the following criteria: promptness, integrity (complexity) and optimality. A decision that is prompt is made simultaneously with the occurrence of a hazardous situation, in accordance with the emergence of the reliable initial information neither prior to (in this case it will not reflect the current state of affairs) nor long after it. This means timely, resourceful, logistical and informational coordination of the decision realisation process. A decision that is complex takes as many system affecting factors (variables) and their correlation (interrelations) into consideration as possible. A decision that is optimal reflects the formalisation requirement of the problem in order to enable the use of formal objective methods to define the emergency solution (3) instead of implementing intuitive subjective procedures.

Fulfilment of the abovementioned required efficiency criteria obstructs the decision-making process. Particularly, ensuring the integrity (complexity) criterion requires expansion of the task and increasing the number of variables, including those that are not fully defined, it complicates the models describing their interrelations, and as a result places the issue of decision-making under multi-criteria circumstances as well as partial (interval) uncertainty of the initial data. On the other hand, in the essence of the decision-making process lies the informed choice of one alternative from the set of admissible ones. This means that the process of decision-making is an intellectual, subjective procedure realised individually or collectively by the persons with the delegated decision-making power. Therefore, such persons or experts elaborating the decision are considered the carries of information required for the formalisation of the decision-making process. This raises the issue of getting the necessary information from its carriers. Methodology of the described issue is known as expert assessment.

The issue of getting expert information becomes particularly acute when dealing with multi-criteria optimisation (choice) of decisions. Under multi-criteria circumstances the efficiency criterion $K(x)$ (3) is an n-tuple, rather than a scalar one $K(x) = \langle k_i(x) \rangle, i = \overline{1,n},$ with $k_i(x)$ as the criteria, which are heterogeneous in essence and dimension, determined in different scales, with varying direction of dominance and are local (particular), each of the criteria characterises local properties (quality) of decisions, whereas taken as a set these criteria fully describe the system as a whole. In this case, an admissible set of decisions X is a composition of two subsets $X = X^D \cup X^C$, with X^D, X^C as the corresponding subsets of concerted (dominated) and compromise (non-dominated, Pareto-optimal) decisions [7, 10].

According to its definition, optimal decisions belong to the compromise space and the issue of decision-making (3) reads as follows: $x^0 = \arg \underset{x \in X}{extr}\, k_i(x), \forall i = \overline{1,n}.$

According to Hadamard [11] such an objective is incorrect, particularly due to the fact that there is no solution for all different contradictory criteria simultaneously reaching their maximum value.

3.3 Structural and Parametric Identification

The essence of structural identification is limited to the selection based solely on the heuristic considerations of one of the following polynomial models: additive $F_K(x) = \sum_{i=1}^{n} \lambda_i k_i(x)$, multiplicative $F_K(x) = \prod_{i=1}^{n} k_i(x)$, combinational and Cobb-Douglas model $F_K(x) = \prod_{i=1}^{n} k_i^{\beta_i}(x)$, where $\Lambda = \langle \lambda_i \rangle, i = \overline{1,N}$ is the tuple of weighting coefficients and $K = \langle k_i \rangle, i = \overline{1,N}$ is the tuple of disparate factors. Currently, the most widespread model is the additive one. Each of the listed polynomial is a fragment of the Kolmogorov-Gabor polynomial

$$F(x)=\lambda_0+\sum_{i=1}^{m}\lambda_i k_i(x)+\sum_{i=1}^{m}\sum_{j=i}^{m}\lambda_{ij}k_i(x)k_j(x)+\sum_{i=1}^{m}\sum_{j=i}^{m}\sum_{k=j}^{m}\lambda_{ijk}k_i(x)k_j(x)k_k(x)+... \quad (4)$$

The pros of opting for the Kolmogorov-Gabor polynomial list as follows [12]:

- in his work Kolmogorov showed and Gabor subsequently summarised that a polynomial enables precise approximation of any function of disparate variables;
- a polynomial contains both additive and multiplicative linear in their characterising factors $K(x_i)$ components and therefore enables formation of any polynomials on their basis;
- when elaborating values and assessment of such complicated structures as organisational systems, duplication of these values is unavoidable, whereas a polynomial can compensate their influence.

Furthermore, the system utility is a smooth monotonic function, therefore it is recommended to include the terms of maximum second degree. Then it is possible to implement the below mentioned truncated Kolmogorov-Gabor polynomial as a universal model structure (4):

$$F(x)=\sum_{i=1}^{m}\lambda_i k_i(x)+\sum_{i=1}^{m}\lambda_{1i}k_1(x)k_i(x)+\sum_{i=2}^{m}\lambda_{2i}k_2(x)k_i(x)+\ldots+\lambda_{mm}k_m(x)k_m(x).$$

However, it is impossible to make an informed choice of one of the models based on the heuristic method of expert assessment.

In order to objectively identify the polynomial structure, it is recommended to apply the genetic algorithm method [13].

3.4 Problem Statement

A social-economic system of any hierarchal level (large enterprise, district, city, region) is constantly under the threat of an emerging natural or man-made disaster.

Various forecasts and statistical data analyses make it possible to predict with some level of certainty the occurrence of natural disasters. A set of measures $Z=\{z_1,z_2,...,z_n\}$ aimed at the prevention of impact of various natural and man-made disasters may be elaborated based on the statistical data and forecasts.

Every such measure may be aimed not only at the prevention of the impact but also at the reduction of damage following the disaster.

It is important to decide on the subset of measures, which will jointly have the highest efficiency. Efficiency is described as summarised general result of the realisation of a subset of taken measures $z\in Z$. These results may encompass the following:

- reducing the number of casualties among the population due to timely warnings and well-organised evacuation plan;
- reducing material damage – smoke detectors and other elements of fire protection system help to ensure timely fire alarms. Some fire protection systems automatically begin the process of fire outbreak elimination, minimising the reaction time and reducing the damage;

- reducing the environmental impact – emission, leak and breakage, etc. registration systems help to timely alarm the operator about the threat or independently take statutory measures.

4 Features of the Development of Events

It is important to emphasise the following particularities of the given task:

1. Threat-countering scenarios may be mutually exclusive, which may be the case within one threat or scenarios of countering various threats may contradict one another. Namely, one of the scenarios requires a prompt and unhindered escape from the building of great masses of people, whereas another scenario involves setting up extra barriers such as turnstile and metal detectors, etc.
2. Realisation of all threat-countering scenarios is not possible due to the lack of resources.
3. Realisation of a number of scenarios of countering one single threat may be possible, namely, setting up fire suppression systems, smoke detectors, fire-distinguishers, and evacuation plans, organising trainings, etc.
4. Realisation effect of a number of scenarios may differ from the set of expected effects. This has to do with the emergence of the control system as opposed to combined realisation of a number of scenarios.
5. Realisation of a scenario shall have a certain efficiency level of threat-countering, it may either be the complete elimination of consequences or elimination on the $[0,1]$ scale. On this scale, 0 is a complete lack of threat-countering efficiency (e.g. certain measures are carried out in order to appear to have the situation under control and to calm down the population, thus indirectly countering the threat of panic and riots); and 1 is the successful threat-countering and complete elimination of all consequences (e.g. diversification of critical commodities suppliers, thus in case of a failure to fulfil the contract terms by one or several suppliers, the commodities will be delivered due to an increased participation of other suppliers). Moreover, realisation of a scenario shall have certain social consequences. For example, some measures may be considered by the population as the ones improving their wellbeing and therefore supported and some as needless waste of taxes and therefore rejected. Apart from economic and social effects, realisation of certain scenarios may have environmental consequences. For example, hazardous emissions may result in changes to regional flora and fauna, making it a barren lifeless area.

Apart from the international standards on the estimation of the impact of natural disasters almost every country has its own procedures and methods to estimate the effects. A greater part of measures to counter natural disaster impacts is limited to economic measures: establishment of contingency funds, insurance, methods and mechanisms to calculate profit and taxation. Unilateral character of these measures reduces the efficiency of solving the problem in general.

5 Synthesis of the Model Formation of a Generalized Assessment

As mentioned above, every scenario, which has to be assessed in order to choose a set of scenarios for realisation, is characterised by the three following aspects: economic, social and ecological. Thus, a summarised assessment of scenario realisation P(z) includes assessments of three indicators:

$$F(z) = F\left(I_E(z), I_S(z), I_{EC}(z)\right),$$

with $I_E(z), I_S(z), I_{EC}(z)$ as summarised scalar assessments (indicators) characterising respectively the state of economic, social and environmental elements.

Each of the abovementioned indicators is in its turn a summarised assessment of a certain tuple of indices characterising local properties of each of the abovementioned elements:

$$I_E(z) = I_E\left(Q_1, Q_2, \ldots Q_H\right), \quad I_S(z) = I_S\left(S_1, S_2, \ldots S_K\right), \quad I_{EC}(z) = I_{EC}\left(O_1, O_2, \ldots O_L\right)$$

with *Q, S, O* as assessment of a certain tuple of indices; *H, K, L* as number of indices.

Lower basic level of the analysed hierarchy of the assessment system is composed of directly measured values of the state of the object. These initial assessments form the basis of the corresponding indices, namely: $Q_h = \langle q_r \rangle, r = \overline{1,R},$ with q_r as a certain initial property of Q_h index.

Thus, a certain metric (measurement system) of quantitative and qualitative assessments of the stability level of technobiosphere system development is formulated. Main requirements of this system list its informational completeness and description precision of the three interrelated elements (subsystems) forming the technobiosphere system [14].

Numerous organisations and scientific groups constantly research this issue, nevertheless, currently there is no unified generally accepted definition of qualitative and quantitative composition of summarised assessments and methods of their formulation. Furthermore, qualitative and quantitative composition may be adapted to each individual case when elaborating the assessment system, whereas choice of the assessment model is of fundamental importance. Therefore, the main objective of the current subchapter is to synthesise the model of scalar multivariate assessment.

Particular characteristic of multivariate assessment is the fact that its initial information measurement basis is composed of values with differentiated semantics and consequently differentiated physical values, vary in intervals of probable values as well as scales and prevalence direction. This means that all factors of the scalar multivariate assessment model are to be presented in the normalised form: $P(z) = P(\Lambda, K(z)),$ with P(z) as the summarised scalar assessment; P as the operator determining the structure of the assessment model; $\Lambda = \langle \lambda_t \rangle, t = \overline{1,T}$ as the tuple of weighting coefficients; $K = \langle k_t \rangle, t = \overline{1,T}$ as the tuple of disparate factors.

6 Further Actions

Having made complex scalar assessments P(z) of each separate measure out of the set Z, which incorporate economic, social and ecological aspects of the society life, it is possible to formulate a subset of recommended measures to take.
The list of recommended measures should take the following into account:

1. The number of elements in the subset is limited by the amount of available resources (material, human, financial, informational and organisational). As mentioned above, available resources cannot cover the realisation of all measures, furthermore, some actions require the same resource, i.e. they are mutually exclusive.
2. Some measures require a certain order of execution. One action has to take place only following the completion of the other one. For example, trainings on the evacuation to emergency shelters can take place only after the construction of such shelters.
3. Some measures have to be taken jointly in order to increase their efficiency. For example, having set the fire-extinguishing systems, it is necessary to offer introductory lectures and trainings to inform the employees and residents about the features of the system and enable them to react properly in emergency situations.

In order to decide on the subset of measures out of the set Z, formal or expert methods should be applied. Having formulated varying alternative subsets (lists), it is necessary to make a summarised assessment of every alternative using the multi-criteria decision-making approach described above.

The DTW algorithm may be used in order to analyse the dynamics of changes to factors within ecological, economic and social areas [15].

The resulting list of measures will have high efficiency and take different factors and aspects into consideration.

7 Conclusions

This paper defines the issue of countering threats as the process of choosing the set of scenarios to reduce or possibly eliminate the impact of threats consequences. In order to make such a decision it is recommended to thoroughly consider economic, social and ecological aspects. In order to synthesise a summarised assessment including the consumption of material resources, efficiency of threat-countering, social importance and influence on the environment, it is suggested to use the utility theory.
The following aspects should be noted:

- The number of natural and man-made disasters is comparable. The impact of natural disasters is considerably bigger than that of the man-made disasters. This is due to the fact that natural disasters are difficult to predict and therefore to counter efficiently.
- Natural and man-made disasters can occur in any region of our planet.

- Elaborating the measures to prevent damage is a complex and controversial process, requiring nontrivial decisions.
- When choosing the measures to counter the impact of natural disasters, it is important to consider their economic, social and ecological effect.
- In order to elaborate the list of measures to prevent damage, it is possible to apply the mathematical tools of multi-criteria assessment.

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