Conceptual models of information production cycles and optimal management of environmental pollution and health risks

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Abstract. In this paper, variants of the theoretical formalism are presented, which allow one to quantify the information flows in the optimal control system. The fundamental role of feedback is substantiated: observation ↔ control; information circulation through the feedback loop, when the information embedded in the object through its control, at the next time step, returns to the controlling subject in the form of information contained in observations of the object.

1. Introduction
In the literature, numerous theoretical descriptions of optimal control systems have been constructed and numerous algorithms have been described that optimize certain characteristics of optimal control. In modern conditions of globalization and awareness of planetary problems, algorithms are needed that not only optimize the characteristics of optimal control, but also allow one to quantify information flows in the optimal control system. The authors have developed the conceptual foundations of the model of information production cycles and optimal management.

2. Methods
Figure 1 shows the concept of combining natural cycles, natural homeostasis and information control cycles in the form of a square, in which there is a filtration unit (solution of the inverse problem), a control unit itself, and a control effect on the object. Also natural, material homeostasis and informational homeostasis are depicted. The unification of these two homeostasis with their informational regulation is depicted as a cycle covering all cycles. These are two different ways of depicting the communication system of these cycles. In the presented concept, \( X \) is the state of the geosystem, and \( \hat{X} \) is the estimate of the state of the system, \( X_0 \) is the desired state of the system, \( Y = h(X) \) is the observation signal supplied to the filter, the dynamics of the filtered estimate of the state of the system is determined by the Kalman equation, and \( Z \) is the control impact. The dynamics of the state of the system is determined by a nonlinear differential equation.
Figure 1. The concept of linked cycles: natural and informational.

Figure 2 shows the concept, where at the top of the information cycle, which includes a standard Kalman controller filter [1]. In the lower part, there is an object in which there is self-regulation, on which we act. We emphasize that, although these natural objects may not include any information part, no information processing at all, due to the fact that they are regulated by the anthropogenic information cycle, material realizations of information structures can be imprinted (imprinting) in them, which are a kind of analogue what we mean by the word model in information cycles.

Let us consider a more specific part of homeostasis, in which we are dealing not so much with natural, but with industrial homeostasis, industrial self-regulation of emissions of pollutants into the atmosphere and their impact on public health.

A typical local production chain model that takes into account industrial air pollution is the sequence:
• Production technology
• The amount and parameters of the emission of pollutants into the atmosphere
• Dissipation of pollutants depending on meteorology
• Exposure of the population to concentrations or doses of pollutants
• Health risks based on the toxicity of pollutants to various body systems
• Real loss of health, measured, for example, by the loss of years of life
• Social and economic losses associated with damage to health
• Management of production technology or population to reduce risk.

This sequence forms a closed loop called the Risk Assessment and Management Cycle. Let's look at this process from an emerging point of view [2, 3], and note that this is not the whole sequence of real emerging flows, since it does not take into account either the consumption of natural, social and information resources, or the supply of a product to the economy. This "chain" of models within the real cycle of risk assessment / management forms its model part, i.e. informational feedback circuit in the emerging scheme. The damage to public health (measured or calculated) plays the role of a gauge needle that can be used in production management. Figure 3 shows the associated cycles for industrial air pollution - health risk, production (material) cycle and information (model) cycle.

![Diagram](image)

**Figure 3.** Two-level presentation of the material and information part of the risk assessment and risk management process. Dotted blocks and arrows - information objects and processes, solid blocks and arrows - material objects and processes.

The bottom of the figure shows how the production management cycle takes place without external information influence: emission sources, emission formation, emission itself, emission dispersion in the
atmosphere, where, as a result, emission concentration occurs, population exposure, health damage to the population, corresponding changes in technology so that this to minimize damage.

Above this, there is, but very slowly, the information cycle, which is a reflection of the material cycle: the first is the subject, and the second is the object. The subject includes both the model, the filter, and the controller (they are not separated in the diagram). Vertical ascending arrows represent different observation channels carrying information from object to subject, and descending arrows represent different control channels. Observed values are parameters of pollution emission sources, emission intensity, measured concentration of pollution, indicators of real damage to health obtained in the course of environmental and epidemiological surveys of the exposed population. Control channels are significant changes in technology, for example, reconstruction of an enterprise, optimization of the moment and intensity of salvo emissions for optimal weather conditions (when possible), impact on the behavior of the population, including resettlement. Thus, the optimal control works "vertically". Part of its functioning is inevitably slow (for example, reconstruction or resettlement from threatened territories), but another part can work in real time, for example, responding to unexpected changes in emissions, dispersion conditions, measured concentrations, etc.

3. Results and Discussions
The two-level structure works simultaneously in two modes, each with its own "time". The information cycle operates in "optimization time", in which various risk management scenarios are tested and the optimal scenario is selected, which will be executed at the next step in "real" or "object" time. The control scenario developed in optimization time is projected at object time, and this establishes the concept of simultaneity between these two times. At the same time, the information cycle monitors changes in the state of the controlled object (pollution and public health) occurring in the material cycle in real time. These changes are stimulated through control channels and are perceived by the information cycle through observation channels. In the reflective mode, the processes occurring in both times are combined: the generation and optimization of scenarios by the model in optimization time takes into account the expected effects of the control based on these scenarios occurring in real time in the material cycle. In the noospheric context, it is reflexive control that is expected to become the main one, including the presentation of various scenarios to decision-makers and the public, in order to form their perception of potential health hazards and other significant factors in each scenario, which should determine the actions of these persons, in the material cycle. Part of these scenarios is to predict the gains to be obtained through control, with the gains at least offsetting the cost of organizing the information cycle that supports the control.

The division of connections in the figure into material and informational from an emerging point of view is insignificant, since both contribute to the emerging balance. In this respect, the cycle of monitoring and managing the risk from environmental pollution is archetypal for the main characteristic of “noospheric solutions” - limiting material and energy flows by ensuring the growth of global “emerging power” by translating most of emergia into informational form.

There are several generally accepted measures to characterize the damage to health that can be used in global models: loss of person-years of working time; loss of person-years of life; disability-adjusted life-years lost (DALY) [4]. Further we will talk about the last option. For local assessments, DALY is too generalized: it works with intentionally coarse characteristics of environmental pollution and the relationship of this pollution to public health effects.

A natural way of supplying local risk management cycles with observational information is local measurements of environmental pollution. Unfortunately, due to the significant temporal and spatial variability of this pollution, this method is extremely expensive, although it is used in some large enterprises. Therefore, we proposed an alternative - space observations by means of remote sensing of the Earth, although this source of information is also more adapted to global problems. Space observation - remote sensing - is the observation of a plume, a terrain parameter that affects the scattering.
Both cycles, informational and material, are represented by a general cycle, as in figure 1. Unfortunately, the information system passes through the administrative system, which is capable of reducing the effectiveness of any regulatory cycle to zero.

One of the subjects of conceptual research is the combination of local options with the global one, which is shown in figure 4. Local cycle - one enterprise and the resulting air pollution, damage to public health or a group of enterprises in a city. There is a second global layer in the concept - this is a model of atmospheric circulation, into which data on industrial emissions (dust, smoke particles, sulfates) are entered. This is a global analogue of what is happening at the local level. And an analogue of the calculation of damage to health at a separate enterprise has not yet been done. Assessment of global health damage is not currently taking place. The most that is done is the assessment of health damage using the DALY method on the scale of one country.

![Figure 4. Local production and pollution and the risk assessment / management cycle within the global emerging scheme. Solid lines and contours are material objects and flows, dashed lines are information components and flows. Material components are shown locally only. Internal threads in local loop are not shown.](image)

The real processes associated with the assessment and management of health risks will be called the natural health risk cycle, and their model representation, which forms a computational cycle isomorphic to the natural one, will be called the information cycle for assessing / managing the risk to public health associated with environmental pollution.

Information cycles work with estimated health damage, the probabilistic assessment of which is risk. Ensuring a high correlation between risk assessment and real damage to health is one of the most significant problems of information processing in the field of "environment-health", which corresponds to the problem of optimizing the information component of optimal control - the discrepancy between the true state of the controlled system $X$ and its estimate $\hat{X}$. 


With regard to the second part of the optimization criterion - the deviation of the state of the controlled system from the desired state - the discussion continues about the type of criterion by which the damage to health should be measured.

In our work, DALY was chosen as such a criterion, which has been widely used in recent years and is included as an indicator in socioeconomic models, including the LCA type and the emerging type. However, although the DALY is based on the same release-concentration-toxicity-health hazard logic as the risk assessment, it is adapted for use in a global or regional context and neglects the local specificity of release dispersion and population exposure. In [4], an approach to DALY localization is proposed: harmonization of its regional parameters and local algorithms for risk assessment. Therefore, it is further assumed that the role of assessing the expected damage to public health in the information cycle of risk management is played by DALY or its analogue.

After calculating the pollution according to the Life Cycle Assessment (LCA) [5, 6], the health risk posed by this pollution can be assessed, and through it - the DALY. Such estimates are very coarse, since the LCA does not take into account, for example, the spatial distribution of pollution over the territory and other significant factors. In addition, the LCA does not take into account the feedback that is created by the fact that the health risk posed by pollution is a subject of public scrutiny and generates measures to manage this risk, including through changes in the parameters and structure of production. However, this degree of coarsening of the LCA estimates of contamination is consistent with the coarsening of the DALY association of pollution with health, and is broadly roughly in line with the global level of information in terms of this paper.

Unlike LCA data, which is an aggregation for whole sectors of the economy, work on assessing and managing health risks from environmental pollution uses detailed, local, sample data. LCA is, as it were, a calculation based on regional or global averages, and its territorial detailing suggests itself - a sample survey that refines the averages. LCA tries to abstract from different conditions of pollution spreading, local in space and time. This is done, for example, in the basic calculations [7], whose indicators of specific damage from DALY / kg emissions are used both in LCA and in emerging calculations. And for risk assessment, it is precisely this spatio-temporal information that is of greatest interest. From an emerging point of view, ignoring local information, as is done in LCA, is a violation of the principle of maximum for information, leading to a distortion of the calculated emerging flows (going out of balance). Equilibrium must be restored in the evolutionary perspective of the development of computational methods in economics and ecology, leading to the inclusion of this information.

4. Conclusion

Environmental pollution and the resulting health risk is a promising area for the real application of emerging models that combine the global and local levels. Since the “environment-health” sphere is already based on the concept of risk assessment and management [8], it represents a ready-made ground for the application of an emerging approach. This is already happening, but so far the work using the emerging approach is based on purely global models, such as the DALY, and the work devoted to the assessment and management of health risks from environmental pollution is limited to a purely local level.

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