

Alternative approach to evaluate the data of ecological monitoring of ecotopes for highways in Ukraine

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Abstract. We propose alternative approach to evaluate data from ecological monitoring of ecotopes along the roadways of Ukraine, taking into account raised accuracy of treating the ecological impact on the roadside environment. Methodology includes sources analysis, development of a workflow model for monitoring and identifying the main components of input data and their optimal features by system analysis. The monitoring of ecotopes of green plantations along highways in the steppe zone of South Ukraine increases the accuracy of evaluating the ecological trace on roadside environment and facilities. Scientific novelty of study combines various data sampling, physical equipment, and road measurements with information services (computing, analyzing and treating input data, forecasting of system development, and monitoring management through feedback control). The system analysis of data deals with the optimal linear constraints of the roadside ecotope capacity, leading to a simple mathematical model of the monitoring. The problem of processing environmental monitoring data with such data is reduced to the linear programming problem. Specifically, this mathematical model allows for the consideration few factors influencing the ecological situation and provides the ability to analyze and forecast the development of ecosystems along roads. Conclusions of study are criteria for an objective assessment of the degree of pollution of the environment and its impact on soil cover, vegetation and road equipment. For effective monitoring it is necessary data-based quality management system on highways. It helps evaluate the predicted degree of environmental pollution by degradation of soils, vegetation, and road facilities.

1 Introduction

During the reconstruction of the highways, the environment within its protection zone is undergone with the negative impact. It includes the acoustic impact on wild flora and fauna and the changing of the regime of planar drainage due to the violation of the upper soil horizon, and the arrangement of slopes and side channels as well as the aerosol receipts of solid, liquid and gaseous chemical pollutants on the soil surface and vegetation. The impact

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on the air environment due to exhaust gases, noise, and the dust from the working mechanisms are other factors of such impact. Exhaust gases from cars pollute the air above the road; settle on plants, in the soil along the road. Because of soil and air pollution, there arise undesirable changes in the structural and functional organization of the ecosystem, and the impoverishment of the gene pool of wild flora and fauna.

After the reconstruction and commissioning of the highway under normal operating conditions, the negative impact on the environment is caused by emissions of pollutants (exhaust gases from vehicles) into the atmosphere as well as the acoustic impact due to the movement of vehicles. Another impact factors are the pollution by garbage, household sewage, and chemical pollutants due to the impact of transport infrastructure as well as the changing the mode of planar drainage due to the existence of the embankment. There are identified several forms of anthropogenic change of landscapes: geophysical one associated with changes in the physical appearance of landscape complexes; geochemical one is due to complex pollution of the environment; radioactive one is associated with irreversible changes in the genetic structure of species, the negative consequences of which are difficult to predict [12].

The soil near the road is the most intensively polluted. Many chemical compounds that enter the atmosphere are dissolved in droplets of atmospheric moisture and with precipitation fall into the soil, mainly as gaseous oxides of sulfur and nitrogen. Solid and liquid compounds in dry weather settle directly in the form of dust and aerosols. Soil contamination near the highway is visible to the naked eye. The construction of new highways, the growth of traffic load has led to a negative impact on the ecological state of the environment, flora, and fauna. Thus, in addition to some benefits, large highways pollute the environment within a radius of 5-10 km.

Therefore, intensive use of the highways is often accompanied by man-fabricated environmental degradation. Growing requirements for sustainable development of the highway industry require some constant quality control measures to provide the stable environmental protection. Meanwhile, this control is provided by various monitoring systems, which involves different means and facilities. Among them, there must be included some features designed for measurement, collection, delivery, and the processing of the studied information; the decision-making facilities and/or software; the service tools, etc. Moreover, all of these tools are combined deeply in real-time information technology systems that could provide the rich heap of tools and possibilities [10]. Among them we highlight the more crucial ones such as the collection and the delivery of the spatially targeted and key-valued information from the environment, as well as the feedback gaining, the automatic data management, the calculation of useful information from data measures, the thorough analysis and decision making, and the monitoring of the changes in environmental parameters. The number of operator-controlled parameters greatly increases along with the acquisition of new knowledge and means of control.

The reliability of the information on the state and level of pollution of environmental objects depends on the choice of data analysis methods. As a rule, for certain situations, it is necessary to choose methods of observation and research which help to receive the various and as much as possible exact information. For this purpose, the capabilities of one method are often insufficient, so to confirm, verify, expand the range of data, various methods are used, which allow seeing the object of study from different angles and in different dimensions.

During the study of the state of the environment, methods of qualitative analysis (which analyze the presence of a certain chemical element or compound) and quantitative analysis (which determine the amount or concentration of a chemical element or compounds in the environment) for the environment are used. Depending on the parameters to be measured, the methods of quantitative analysis are divided into chemical, physicochemical, physical,

and biological ones. The choice of a specific technique of research depends on the content of the analyzed substance and the chemical composition of the object under study. The application of a certain method in the study of the state of environmental objects makes it possible to determine the ingredients that are characteristic only for a particular object of study. The generally measured parameters in the highway monitoring system are mostly the parameters of roadside soil contamination and air pollution within the areas adjacent to the highway line. Many special methods have been developed for doing instrumental observations of the level of environmental pollution [11, p. 22-28].

2 The unsolved aspects of the problem

Such a complex and multi-parameter problem as highway monitoring involves different data types from various data meters and requires multi-stage analysis from different kind of knowledge. In addition, such a complex system of mutual connections as a highway monitoring creates in time the keen need in creation of a holistic mathematical model for monitoring natural complexes, which would take into account the man-fabricated specifics of the highway industry. Because of genuine complexity the monitoring data are often being underestimated which is caused by solution of multidimensional physical models by low dimension Mathematical ones. In addition, because of implicit presence in monitoring complex the ecological and the technological (engineering) components, there a few approaches helpful to involve all these features [9]. However, among the basic mathematical approaches for time-series analysis data we would gain one which help us to keep the data deeply restricted by physical considerations. A system analysis will help to take into full account the main factors in such a complex model.

3 The problem statements

Therefore, the main purpose of the current study is to carry out a detailed analysis of the primary mathematical model of ecological monitoring of certain typical ecotopes on the Ukrainian highways. We would provide further considerations in terms of the systematic analysis, determination of the main parameters of the ecological model in order to optimize the necessary number of parameters and quality control of highway monitoring.

4 The recent research analysis

The main concept of the system itself in general is so ambiguous that it is unlikely there exists a branch of science in which still there is not created a local dialect in determining the content of the system term. In particular, the terms and properties of systems are widely used within the context of the anthropogenic systems (i.e. artificially created by humans to perform the specified functions), ergatic systems (i.e. human-machine, for example, the marine vessels, the drones or the spaceships navigation), as far as technical and transportation systems (including aviation, underwater and underground ones), and also the robotics and many other industrial systems. Thus, the analysis of a separate set of aviation systems is presented in the paper [1].

5 A system analysis approach

The system itself always generates some new qualities which are absent in its compound elements). These features often arise due to the connections between the elements, which

transfer the properties between the elements of the system. The main factor to study is so called function of the system, which provide the conversion of the system inputs into their outputs; it also would provide the maintenance of structure or order of the phenomena. Because of this, it is sometimes called the algorithm of the goal achievement). So, let us take a brief of system content.

The systems usually operate within an external environment, including the necessary conditions for their existence and the development. This environment includes natural, social, informational, economic, production (industrial), and other factors that mutually interact with the system itself, providing the various impacts on its components. The system interacts with the ecological or technological environment through inputs / outputs with feedback (where the system input we treat as the environmental action or signal, while for the system output we mean the input response). Self-organization of the complex industrial systems (or ensemble of subsystems) being undergone the synergy effect generates new phenomena through the joint action of different factors. We still remember that each separate factor does not generate such a phenomenon in common. The interaction of the complex factors of highway or other technical system always forms open stationary material and information objects that repeat the features of the analyzed systems, while reproducing them each time in space and time [1]. The dynamic stability of systems as a key factor of its development and control is provided by feedback (negative and positive) and transformations (adaptive and bifurcation ones).

Compound landscape complexes (ecotopes) which we treat as biologically stable, durable, and protective objects that ensure uninterrupted movement of trains all year round provide ecological safety on the domestic highway., especially in open steppe regions of South Ukraine.

Landscape complexes (green wooden stripes) under study, usually functioned as open stationary systems. They exist in order to maintain the homeostasis through exchange with the environment and within the man-fabricated systems. Ecotope itself is a closed system of *material* (non-energy) flows, circulating through the highway surroundings. Moving between products, and changing their state, the matter circulates within the technical system, but its total volume (mass storage index) does not change, regardless of what happens on the highway facilities. Meanwhile, in the socio-economic environment, material flows and processes are linear ones, and being spreading over a long period, materials that have passed successfully through the *technosphere* from their origination up to decay are returned to the environment as relocated raw materials. Output energy flows thus become a system waste, or even resources (as input flows) into another technical or live natural system. Moreover, at all stages of the *ecotope's* life, energy and materials are consumed at the inlet, and pollution occurs at the outlet. The measure of such pollution is provided by the *ecological index* of the ecotope.

The ecological index is determined by inventorying the complex factors of total ecological impact on the environment and means of its significant improvement. These stages are often mutually interrelated and must be taken into account in the formulation of the problem of analysis and the evaluation of boundaries of the system. The problem of system analysis in turn determines the content and order of further stages to change the system to certain direction. However, the problem itself determines the general purpose of environmental analysis for the studied territory. In addition, factors that affect the goal of such analysis are as follows:

1. the type of the system;
2. the comparison of the system by its main functions;
3. the addressee of the analysis result;
4. parameters given for the analysis;
5. measure of the representativeness of the parameters (whether they meet the

objectives of the analysis);

6. the general purpose of the system studied;
7. the functional unit of analysis;
8. the scale and the depth of analysis on its own (i.e. system boundaries).

The boundaries of the system under study determine the duration, complexity, accuracy and the completeness of the analysis results [2].

The boundaries of the system necessarily include stages and elements of energy balance in the analysis of the product life cycle, time period, geographical coordinates (GPS location) of the system, type of used technology, and a set of parameters of environmental impact [3]. The boundaries of the system should not be too narrow or too wide to model its impact at proper level. Thus, raw materials and energy always enter the life cycle input, and emissions always are generated at the output. The set of stages between which there is an exchange of matter and energy forms the technical limits of the cycle. Being imposed in time and space dimensions, these technical boundaries form the general boundaries of the studied system, which are necessarily taken into account at its logical and mathematical analysis.

The analyzed system is strictly limited by the a priori additional data, as a rule obtained with the help of different methods of measurement and / or analysis. It is obviously made for the reason of gaining the acceptable accuracy of results because the system without restrictions may have huge volume of data followed by overdimensioned model. Nevertheless, the limitations are given in a such manner that allow not to miss any important components of a life cycle having the essential ecological influence at the studied territory within certain period [10]. Next, we determine the functional unit of calculation (so called quantitative expression of the system function) as the base of all further calculations. All information at the stages of inventory and evaluation of negative impact refers to that functional unit. After finishing the collection of the quantitative information on material and energy flows of the system we evaluate their environmental impact (such as data on environmental emissions in different groups for various parameters), and the amount of emissions is interpreted as *environmental damage*.

6 Material and Methods

In order to characterize the behavior of a highway ecotope over the certain time over a specific life cycle, it is necessary first to determine the physical model of the object studied and then one must to create an appropriate mathematical model with proper boundary constraints based on it. As a physical model of the object under study will be evaluated an ecological model of the ecotope. This model is created based on a set of data on the transformation of protective green wooden plantations at different levels (tiers) of their location along the highway network in the steppe region of South Ukraine. The main control parameters for manipulation of this model (which will be listed below) form the basis of the mathematical model of the ecotope in its common type. The mathematical model contains fundamental links between the man-fabricated load along the highway (its measure is the capacity of the highway environment itself) and the environment that surrounds it.

The ecological model of the ecotope, which would be created, based on information about protective green wooden plantations studies the degree of anthropogenic transformation of the natural environment on the highway. For this purpose, the ecotope itself is divided into blocks that have stable constant stocks of matter and energy, which are exchanged with each other and with the environment under the study. Based on collected biological information on the green protective plantation growth rate, the *exchange rates* of inflow and outflows are set strictly. The block model does not collect the data on the

interaction of hundreds and thousands of species in the ecotope, but freely chooses variables and the subject of exchange. Thus, instead of biomass we would evaluate the concentration of important for living organisms' chemicals, pollutants and / or sediments, etc.)

Environmental capacity is our common unit to take into account during the ecotope's behavior modeling. We treat this capacity as the maximum load that the ecotope can withstand for a long time without severe violating its inner structure and key functions. It should be noted that there are no reliable approaches for determining this indicator. The energy approach presents capacity as the maximum allowable variation in the flow of biological energy conversion at the separate site. However, simplified capacity evaluation is based on quantitative results of bioindication, as well as hygienic and toxicometric standards justification. The maximum degree of variation in the *state* of the ecotope is achieved when the integrated by the area of the site studied the reduced (normalized) concentration of impurities equals ~ 1 . Critical concentrations as a rule do not exceed environmental standards (for example, minimum phytotoxicity, zero mutagenicity and carcinogenicity are less than standard maximum permissible concentrations). The use of hygienic standards is only a temporary measure in the absence of environmental standards and appropriate laws.

The ecological balance of the ecotope development model is introduced through the simple criteria of plant balance within the plantation stripe. The optimal model of such a balance is based on its unit analysis. This means that the ecotope scheme contains four mutually interconnected units. They are as follows:

- the unit of highway economy (R_E) contain biotechnological factors of anthropogenic load;
- the unit of highway transport (R_T) contain a source of anthropogenic impact on the environment;
- the unit of ecotope (E_B) contain natural objects and processes of nature management;
- the unit of control (C_B) contain any control algorithms and mathematical software.

The development model of highway ecotope contains the following data: basic resources for the activity of the ecotope itself and highway network; a set of raw materials and supply at the entrance, the processes of transportation of people and goods; natural and climatic conditions at the exit of the ecotope system. Raw materials and supply are grouped into two separate groups: natural resources and technological means. Thus, ecotopes on the highway form a holistic system, which we treated as a set of technological and biological factors that interact in the production process of the highway and meet environmental requirements.

The quality of the ecotope correlates well with the quality of the environment under study. The latter is evaluated by the quality of green protective plantations only for two simple and accessible indicators: viability (Table 1) and protective efficiency. The latter indicator is divided in turn into four classes [4]:

1. *good* mark means that plantations are not damaged, or weakly damaged by anthropogenic factors;
2. *satisfactory* mark means that adverse factors partially significantly weakened plantations at given site;
3. *bad* mark means that one of the adverse factors significantly weakened plantings; and
4. *very bad* mark means that plantations are significantly damaged by many factors.

Table 1. Ecotope viability [after 4].

Viability	External signs of plantings	Class
High	Mostly healthy pointed trees, single specimens are withering. Sanitary condition is good, soils are covered with fallen leaves, grass cover is absent / liquid (GA)	1
Reduced	Mostly healthy trees, stupid copies, number of withering trees $\leq 25\%$. Sanitary condition is good / satisfactory, soil is loose / hardened, grass cover is not more than medium density (GM)	2
Low	Top-dry and fully withering trees are up to 75%, associated specimens do not dry out. Sanitary condition is poor, the soil is hardened or hard, the grass cover is average (GM), dense (GD)	3
Very low	Plantations are mostly dry, low. Sanitary condition is bad / very bad, soils are hardened, grass cover is dense with a lot of root plants (GR)	4

The mathematical model of highway ecotope capacity (evaluated as flows of matter and energy) on the highway environment contains the following factors:

1. the relationship of environmental, technological, and control parts of ecotope's model;
2. flows of the matter and energy (input ones x_{RE}, x_{RT}, x_{EB} ; and output ones y_{RE}, y_{RT}, y_{EU});
3. energy and matter scattering data E_{RE}, E_{RT}, E_{EU} ;
4. data on v_{RE}, v_{RT}, v_{EU} as a highway waste bulk;
5. properties, relations and interaction of units RE, RT, EU, CU .

The purpose of the system is the transportation of passengers and goods at the minimum expenses of substance and energy with the maximum ecological safety. It is the typical problem of linear programming with various simplex approaches. Human interaction with the environment under study is determined by the flow of matter, energy, and information. The variation of the flow of mass, energy, and information, as well as human action (from the least significant to the maximum possible) generates a number of states of interaction within the system "man – the environment of the highway".

Control physical parameters of above mentioned highway ecotopes are as follows:

- 1) the vertical structure and tiers (such as tier of dominant trees; middle tier; shrub tier; moss-grass tier;
 - a) the tier of rhizomes and roots of herbaceous plants in the upper soil layer at $H = 0.15-0.2$ m depth;
 - b) the tier of herbaceous plants with deeper location of roots at $H = 0.5-0.7$ m depth;
 - c) the tier of roots of shrubs at $H = 1-3$ m depth; tier of roots of tree species at $H = 5-6$ m depth;
 - d) the forest litter at $H = 0.01-0.03$ m depth;
 - e) the humus horizon at $H = 0.2-1.5$ m depth;
 - f) the leaching / accumulation horizon at $H = 0.0-0.2$ m depth;
 - g) the transitional horizon at $H = 1.5-1.8$ m depth);
- 2) the horizontal structure: number of rows, width of rows, placement of trees in rows and scenes, number of scenes, etc.

The viability of the ecotope $S(t)$, the components of which are functions of the time t and the space R , changes as a result of actions $L(t, R)$ and control $u(r, m)$, where $r \in H_K$ are certain technologies from the Hilbert space of H_K (highways, interoperability, intensification passenger and freight traffic, etc.), $m \in H_m$ are technologies from H_m Hilbert space (which present machines and mechanisms).

The model of ecotope $S(t) = A(S(\tau), u)$, where A is viability and protective efficiency at the time $t \in [t_0, T]$ given from vector $S(\tau)$, $\tau \in [t, t_0]$. The discrepancy in the rates of turnover of energy and substances in the production and natural subsystems on the manifold M

generates inconsistent ecological and biotechnical relations. You should find the optimal management strategy $u_0 \in M$, which satisfy the *maximal* capacity of ecotope: $F_{RT} = \varphi \{ \eta_i^{BE}(u_i), \eta_i^{ES}(u_n) \} \rightarrow \max$, where the factors $\eta_i^{BE}(u_i)$ indicate the bioenergetical efficiency while the factors $\eta_i^{ES}(u_n)$ indicate the ecological safety and factor φ stands for inversion criteria. Systems of linear algebraic equations define three systems of constraints in three units of the model studied: highway economy E_{RE} , highway transport E_{RT} , and ecological unit E_U [4]. These linear systems of equations should be solved using the known numerical algorithms based on dual methods of linear programming [5]. This paper fully describes the selection of a specific variant of the algorithm and provide the study of its numerical stability under conditions of incomplete assignment of observational data at the system input.

7 Results and discussions

Based on the above-defined common mathematical model of the ecotope around the highway, it is necessary to carry out a consistent ecological analysis of the state of the ecotope at strictly defined time intervals. At the same time, the movement of highway and road transport [6] will make the greatest contribution to the technogenic degradation of the ecotope.

The results of the ecological analysis of ecotope reveals that the structure and composition of information flows of anthropogenic action correspond to the structure and functions of the ecotope, in coordination with the modes of nature management. Diagnosing the *ecotope* objects is based on the ratio of environmental capacity to the nature capacity of the *ecotope*.

Nevertheless, unlike spontaneous habitats, which arose spontaneously during long-term organic evolution and have natural mechanisms of self-regulation, ecotopes are the result of intelligent work. Thus, biological objects perform the functions of engineering structures on the highway network. Their origin is spontaneous and elemental, while the mechanisms of self-regulation are of social nature. Production (industrial) activity covered the biosphere, and found itself in a single loop of management of the *sociosphere*, as its trophic, resource and environmental base. Thus, its state is fully regulated by the *sociosphere*.

The ecological analysis of the common *ecotope* in order to achieve the environmental safety on the highway includes the following algorithmized steps:

1. the identification of the ecotope (recognition of the plantation stripe as an ecotope);
2. the evaluation of the ecotope potential (stocks and facilities to perform the protective functions);
3. the classification of full-profile and incomplete-profile ecotopes (i.e. strip structure);
4. the installation of ecological capacity (maximum technogenic load, which will withstand for a long time the certain ecotope without severe violating its inner structure and functions);
5. the evaluation of the spatial and functional role of the ecotope, compliance with environmental standards in the use of ecotope resources;
6. the substantiation of completeness and efficiency of measures on ecological safety on the highway.

The bioenergy analysis takes into account the direct costs of energy, substances and resources, as well as the labor in the calculation of the coefficient of bioenergetical efficiency. The latter is calculated as the ratio of energy accumulated in the product / service (energy content), to the total cost of energy and its production (energy

consumption): $\xi = E_i / \sum_{i=1} \sum_{j=1} C_{ij}^k x_{ij}^k$, where E_i is the energy content of highway transport, in GJ/c; C_{ijk} is energy equivalent of the k -th element of the i -th type of costs of each technological process j , in GJ/(c, m², people/hour); x_{ijk} is the value of the k -th element of the i -th type of costs of each technological process j , c, m², people/hour; i, k are types of costs and their elements: such as direct ones (for example, electricity, fuel, natural complexes, etc.), and indirect ones (impact of highway infrastructure: mechanical, physical, chemical, biological, aesthetic appearance); and j stands for technological processes.

Ecological monitoring of quality is preferably conducted according to two leading indicators: functions and structure of the *ecotope*. To account it properly, it is necessary to have the reliable, timely, complete information about the current state of the components of the common highway ecotope as well as the technogenic factors that affect them. Ecosystem monitoring involves the establishment and evaluation of the biocomponents state within the ecotope (i.e. its function) and the state of the geocomplex (i.e. its structure) of the ecotope, as well as the monitoring of natural and man-fabricated hazards in the transportation of dangerous goods. The model impresses the properties of common natural plantation stripes complexes such as multiple connectivity, stability, commutativity, additivity, invariance, multifactor correlation of their components). The essence of these properties is deciphered in the paper [4].

The proper evaluation of the full impact of highway facilities on the environment with the help of monitoring their multispectral quantitative indicators requires the development of a digital spatial basis [7]. However, this basis will be the subject of next research.

8 Conclusions

Thus, the ecotope monitoring of the ecotope increases the adequacy of the model of the ecological condition of the highway as well as the reliability of monitoring data itself. The reliability of information is provided by the use of the following approaches:

1. the use of Pearson statistics, and taking into account the reaction of ecotopes to external influences;
2. the detection of the influence of specific external factors on the condition of the highway;
3. the study of the influence of the relationships of different parameters and their variability in time and space (analysis of spatially distributed data);
4. the evaluation of quantitative parameters of natural and anthropogenic processes;
5. the forecast of tendencies of influence of natural and anthropogenic factors;
6. the optimal number of parameter measurements in the ecotope;
7. the sufficient monitoring accuracy.

The design of new *ecotopes* (as well as the optimal management of existing ones) involves a number of measures including the follows:

- the ecotope's structure optimization (search for the best option by comparing all possible options);
- the statistical analysis of ecotope units (related to inputs / outputs of matter and/or energy flows);
- the phytoremediation of soil (cultivation of a complex of remediatees: mycorrhizal fungi, associated plant microorganisms having the potential of rhizosphere bioremediation of soil);
- the bioengineering structures (plantations that preserve bio- and landscape diversity at the intensification of the highway traffic, increase the productivity of the ecotope, self-restore, ensure the ecological safety of the territory, preserve the ability of the ecotope to perform economic and environmental functions of the highway at the given site).

- the minimization of pollution and environmental hazards, protection of ecotopes, creation of an ecological network of new and existing ecotopes.

Based on the above-described approach, some environmentally balanced highway management solutions should be advised as follows:

- complete and balanced (indicators allow to use the chosen evaluation strategy, meet the monitoring objectives, determine the degree of pollutant emissions, as well as other environmental quality issues);

- sensitive (each variable has its own range of values, having correct methods of determining them, and there are some correlations between the state of the system and the ecotope);

- interpretable (transparent, accessible, reliable, scalable to increase the amount of environmental information while saving its costs).

Creating a comprehensive mathematical model of environmental monitoring is a real digital basis for a creation of decision-making system for environmental safety in highway transport. This model is one of the important components of the national transport safety management. Thus, the prospect of further research in this direction is to integrate the data collection into the GIS environment.

Especially, it is necessary to develop an automated system for processing and interpreting the environmental monitoring data based on open-source Wroclaw QGIS media supported with open data of highway ecotopes monitoring. The next step will be the generalization of data gained and the creation of a knowledge base and expert information and analytical system of nature management in the highway transport.

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