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Evaluation of the Impact on the Environment at Building and Reconstruction of Motorways Using the System Analysis Method

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From the point of view of the system approach, the interrelation in the system “highway repair – environment” was investigated, which allowed systematizing the main aspects of environmental impact during the technological process of road repair. As a result of the parametric analysis of the subsystems that make up the system, the main groups of environmental parameters that are subject to the effects of technological processes of road repair were identified. The mathematical model of cause-effect relationships in the system under study allows identifying the main aspects of environmental impact during technological processes of road construction and reconstruction. Its application in environmental impact assessment allows forming a criteria base for environmental impact assessment. The article defines the relationship between the process of performing a certain stage of repair work on the project of construction of the highway of state importance N-31 Dnipro – Tsarychanka – Kobeliaky – Reshetylivka and its impact on the environment.

Keywords: impact, environment, motorway, system analysis, pollution.

Introduction

Most ecological problems are conditioned by the direct or indirect impact of society on the environment. Unfortunately, neglecting objective laws of development and restoration of the state natural resources complex has led to significant deterioration of the environment in Ukraine, particularly in terms of excessive pollution of surface and groundwater, ambient air and soil.

A threatening ecological situation in Ukraine requires faster integration of the state ecological policy into the social and economic development of the country aiming at environmental requirements provision during the process of the industrial and housing engineering, building, reconstruction and dismantling of constructions. In this context, it is important to achieve equality of the three constituents of the country's stable development (economic, ecological and social) and bring the Law of Ukraine in the sphere of the environmental protection into line with the requirements of the European Union directives.

That is why aiming at convergence with European standards, particularly monitoring the environmental pollution degree and ensuring the rights of inhabitants for the safe environment, in 2017 the Law of Ukraine *Environmental Impact Assessment* was enacted (hereinafter referred to as the EIA Law) (The Law of Ukraine *On Environmental Impact Assessment*, 2017). The necessity of enacting the law was conditioned by Ukraine's international obligations appearing from the Convention on Access to Information, Convention on Environmental Impact Assessment in a Transboundary Context, The Protocol on Ukraine's Accession to the Energy Community Treaty and Ukraine–European Union Association Agreement.

During the last two decades, the level of the anthropogenic influence of activities on the environment has significantly increased and is already correlated to the number of natural resources in the separate regions of the globe (Zaporozhets et al., 2017). Providing comfortable conditions for an individual, motorization as a category of social progress has a direct or indirect but inevitably negative impact on the ecological system (State Building Norms, 2003; Transportation Research Board, 2005; Igonova et al., 2016; Report, 1994). Thus, evaluation of the impact of the motorization processes on the environment is the tool to determine the impact. The direct

negative impact of the transport system occurs at the increased noise, radiance, emission of harmful substances (Anpilova et al., 2020) and road accidents (Frellich, 2019; Transportation Research Board, 2005). The indirect impact of vehicles is reflected in the fact that the car yearly takes more and more space essential for a human.

Methods

Methods of theoretical and empirical research were used for the analysis. The main ones are systems theory, methods of analysis and synthesis (comparison, analogy, abstraction, formalization, classification). Methods of mathematical modelling, system and parametric analysis were used to formalize the processes of the impact of building and reconstruction of roads on the environment, development of the system model, and parametric description of subsystems.

The objective of the work is the development of a system model of the cause-effect relationship for evaluating the impact of work connected to reconstruction (maintenance) of the motorway on the environment, which will allow integration of a mechanism of increasing the efficiency of evaluating the impact on the environment, especially in the aspect of the road building and reconstruction projects.

To achieve the objective, it is necessary to carry out a parametric analysis of the "maintenance of motorway – environment" system constituents.

Results and Discussion

Depending on the source of the impact in interaction with the environment, the road complex can change the geographical landscape (Naveh & Lieberman, 1994; Underhill & Angold, 2000), lead to pollution as a consequence of vehicle functioning and performance of specialized transport, from using protection against dust and black ice, and form noise pollution (Ozer et al., 2009) from maintenance materials (Table 1).

Table 1. *Impact of the motorway on the environment*

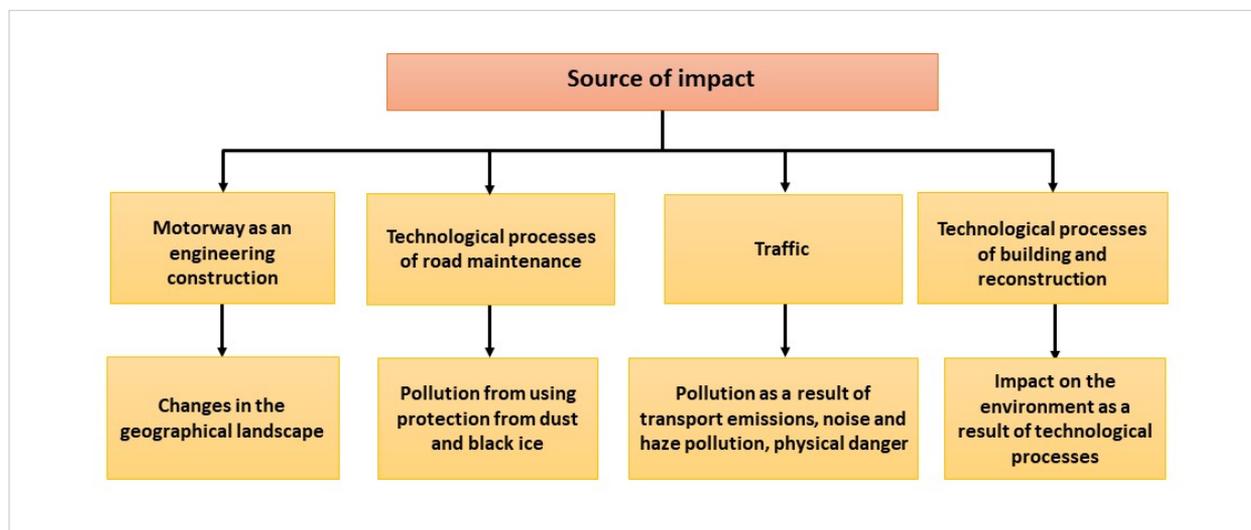
Source of the impact	Focus	Character of the impact
Motorway as an engineering construction	Changes in the geographical landscape	Is not connected to vehicles, permanent, of wider coverage, direct and indirect
Traffic	Pollution as a result of transport emissions Noise pollution. Haze pollution. Physical danger.	Depending on the intensity, traffic mode and composition, permanent, of local coverage, direct
Technological processes of building and reconstruction	Pollution from specialized transport emissions, production waste, building materials, building waste. Occupational noise. Haze pollution. Social inconveniences. Physical danger	Temporary, intensive, local, direct
Technological processes of road maintenance	Pollution from using protection from dust and black ice. Pollution from maintenance materials. Social inconveniences at the road maintenance	Temporary, low-intensity, local, direct and indirect

Focus and character of the motorway impact on the natural environment depending on the impact sources are characterised (Fig. 1).

When designing the motorway, all sources of the impact of the motorway on the environment are subject to evaluation, though the level of their performance is significantly

different. It is a characteristic feature that the ecological barrier, a dividing line which complicates a lot of natural processes in the environment, such as the movement of wildlife and loss of birds' navigation skills, occurs in the environment (Ecoducts, or animal crossings, 2012; Report, 1993). Rolling stock and sizeable infrastructure of

Fig. 1. *Impact of the motorway on the environment*



the transport expand their performance on big territories, crossing reliefs and landscapes, located in different climatic zones.

In connection with this, fauna and flora of the ecosystems are heavily and negatively influenced (Fig. 2).

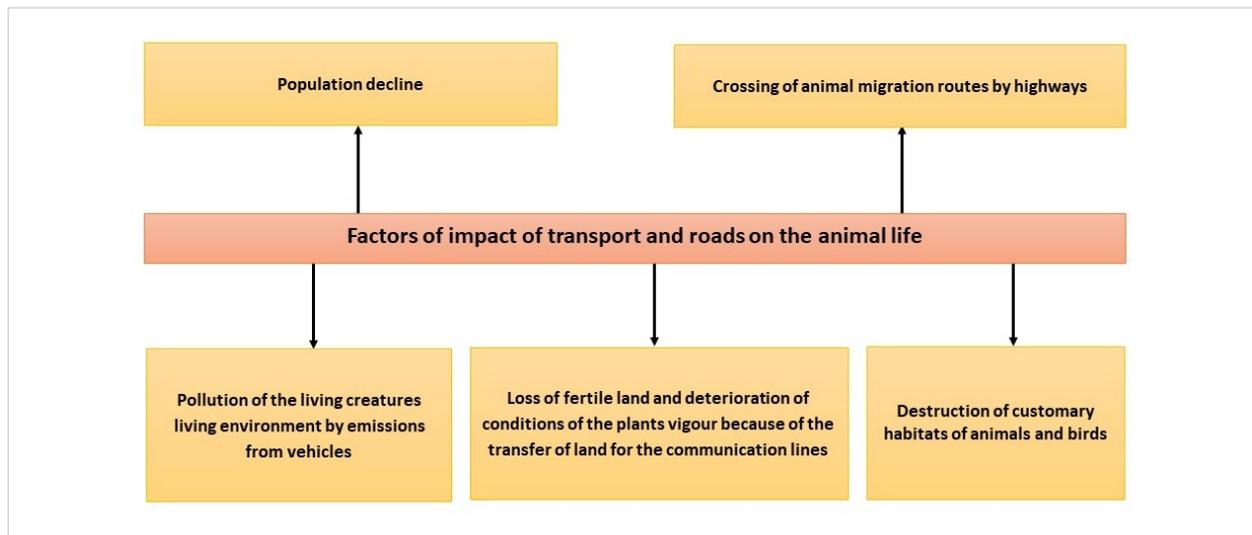
This impact is expressed through negative factors such as:

– pollution of habitats by vehicle emissions;

– loss of fertile land and degradation of plant life due to land relocation for communication lines;

– destruction of habitats for animals, birds, aquatic inhabitants and their displacement from ecological niches they occupy. The populations decline due to the ecosystem productivity loss, negative impact of the factors of noise, vibration, gas content, disturbance and direct

Fig. 2. Factors of impact of transport and roads of the living creatures environment



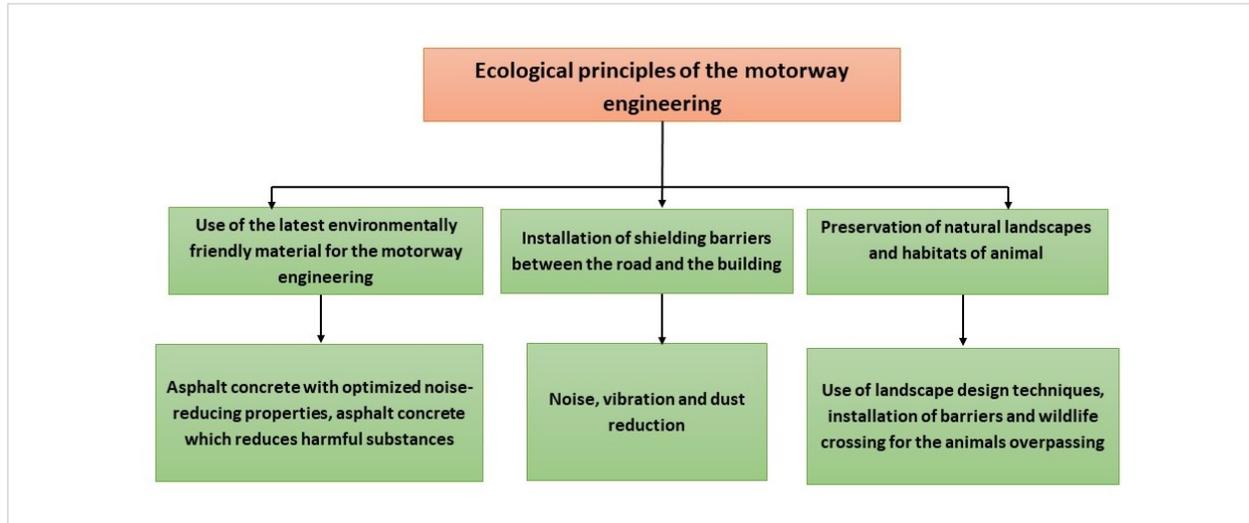
engagement with vehicles, which lead to species death; crossing of diel animal migration routes by highways, pipelines, and waterways.

Having evaluated all the negative factors of the impact of transport and roads on the environment, we can distinguish principles of the motorway engineering according to the current environmental standards and requirements (Fig. 3) which are used during the motorway building and/or maintenance processes. According to the Branch Building Norms (2011), there are two types of maintenance of the motorway, namely comprehensive maintenance and ongoing repairs. It is worth noting that the terms “maintenance of the motorway” and “reconstruction of the motorway” are identical in our research.

Reduction of the impact of motor transport activities on the environment and human is possible through a thorough examination of the issue, adhering to the ecological principles of the motorway engineering because the level of the transport influence on the environment

depends on the correctness of the designed motorway, and considering ecological factors. For example, an effective way to minimize the human-animal conflict is building wildlife crossings, cattle trails, special bridges and tunnels which allow animals to cross the motorway (Sijtsma et al., 2020; Askins, 2012; Guarnieri, 2019).

The first safe motorway crossings for animals – wildlife crossings – have been built in France (Ecoducts, or animal crossings, 2012) since the 1950s. Further, a few European countries, including the Netherlands, Switzerland and Germany, started building them as well (Reck et al., 2019). There are more than 600 tunnels in the Netherlands established under the main and secondary roads and highways, among them the world’s longest wildlife crossing of 800 meters in length. Crossings for the wildlife representatives have become more and more popular in Canada and the USA. The most popular of them are located in the Banff National Park in Alberta, where the natural park is divided into two parts by a big commercial road Trans-Canada Highway.

Fig. 3. Ecological principles of the motorway engineering

To reduce the effect from human intervention in nature, 24 crossings and tunnels have been built, thus providing preservation of the habitat and protecting motorists from road accidents. Two types of such crossings are used: above the road and under it. The use of a particular type of the crossing depends on the species diversity and geographical peculiarities of their relocation.

Noise impact of transport and roads remains an important task. Noise-reducing measures need to be planned on the territories, belonging to populated ones. If the limit noise level is exceeded, measures on its reduction need to be taken. Distance from the edge of the carriageway on the highway to civil buildings is set taking into account provision of the standard noise level in the living area (Zaporozhets et al., 2017; Lytvynenko, 2013). Nowadays two groups of measures on the noise abatement are stated and reasoned: technical and planning-constructive.

The following technical measures on the noise abatement can be mentioned on the example of European countries: improvement of the road surface dressing, which allows reducing noise on their surface, and improvement of vehicles constructions (tyres with the lower level of noise when moving). Ecological engineering principles have been determined, the practical use of which is a multifactorial task and requires further research (Khrutba et al., 2015).

The next stage of our research is to study the scheme “maintenance of motorway – environment” using the

system analysis method. The systems analysis (Horban & Bakhrushyn, 2011) allows in most cases for decision making in studies of individual system elements. In research on the interaction of anthropogenic impacts on the environment (in the aspect of impact and pollution), it is necessary to consider the many interrelationships of the various elements that form the overall goal of the system.

Let’s review the “maintenance of motorway – environment” system from the point of view of the system analysis based on the classical model of the “black box”. The model of the “black box” can be expressed as a set of two processes: $X^T = \{x(t)\}$ and $Y^T = \{y(t)\}$, $t \in T$.

Even if considering $y(t)$ to be the result of a certain R process of the transformation $x(t)$, that is $y(t)=R(x(t))$, the model of the “black box” considers that this transformation is impossible. Thus, a mathematical model of the “maintenance of motorway – environment” system determines a set of inputs, states, outputs and connections between them:

$$X \xrightarrow{\sigma} R \xrightarrow{\eta} Y \quad (1)$$

Specifying sets of X , R and Y and representations of σ and η , we can pass to the “maintenance of motorway – environment” system management. Discreteness and continuity over time in the system depend on whether the R set

is discrete or continuous. Most frequently in the “maintenance of motorway – environment” systems where X , R and Y are linear spaces, and σ , η are linear operators.

Input parameters for the processes of implementation and maintenance (reconstruction) of the motorway (X_i) are current work plans on building and maintenance of the motorway, available road building materials, and project design documents. Output parameters of the process (Y_i) are quality of the completed work and level of impact on the constituents of the environment. Limits upon the process are standards determining requirements for road building materials, current building regulations on the motorway building, maintenance and/or reconstruction work, requirements for the quality of the completed work, industry-wide environmental standards, regulations on the environmental pollution level, maximum acceptable concentration (MAC) and permissible exposure limit (PEL) indices and other regulatory environmental documentation. Process R, which converts input parameters into output indices, includes changes in technological processes, replacement of technologies and technical means or road building materials, etc. A system model of the motorway reconstruction conduction with an aspect at the environment preservation is provided (Fig. 4).

The analysis of the model shows that permanent monitoring and control of the completed work as well as of the

environmental state is an important component of the performance of the motorway building and maintenance work. This allows conducting decomposition of the system into two separate subsystems, namely maintenance of motorway and environment.

Research of interaction of the two given subsystems should be reviewed from the point of view of parametric analysis. Indices showing external characteristics of the system, which is analysed and allows evaluating its impact on the effectiveness of the problems solving by the supersystem of a higher level, correspond to the upper level of the subsystem structure. Separate partial indices of the management system elements will be the lower level accordingly.

By reviewing the “maintenance of motorway” subsystem, we can study all technical and technological processes following the maintenance work fulfilment. The following groups of parameters correspond to the upper level of the subsystem structure: subgrade and drainage (SD), road clothing and surface (RCS), and artificial structures (AS). Each of them is characterized by separate partial indices of the management system elements.

Parametric description of the comprehensive maintenance processes in the “maintenance of motorway” subsystem is shown in Table 2.

When researching the “environment” subsystem, we can identify possible constituents of the environment, which

Fig. 4. *The system model of the motorway reconstruction with an aspect at the environment preservation*

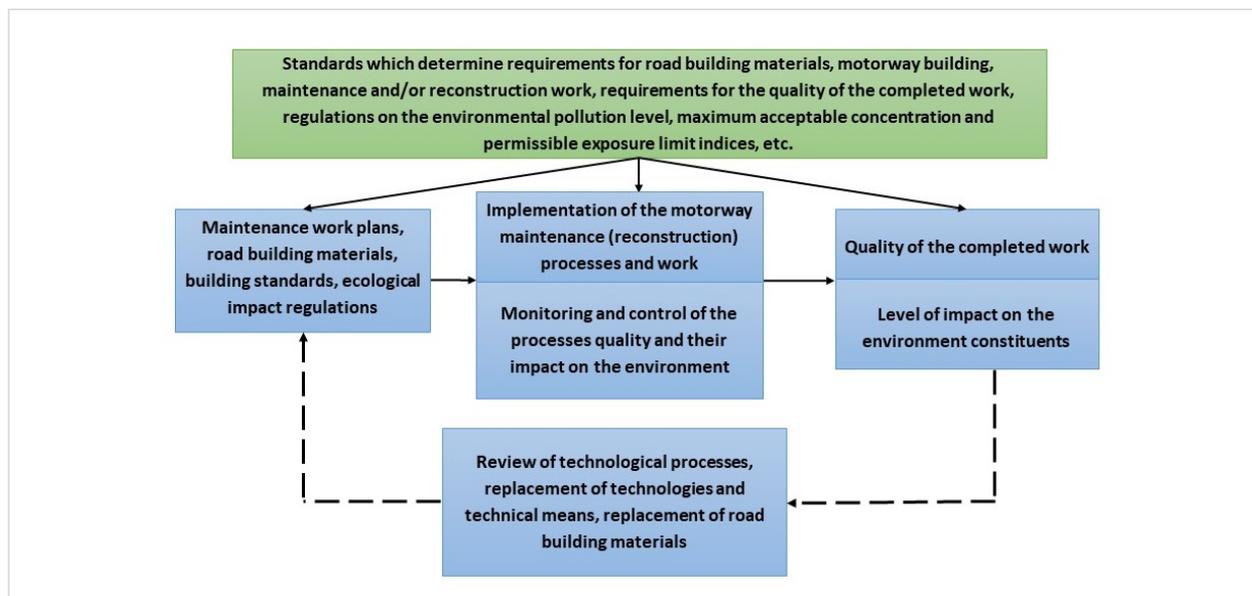


Table 2. Parametric description of the "maintenance of motorway" subsystem

Nº	Name of the "maintenance of motorway" subsystem parameters	Designation
1. Subgrade and drainage group of parameters (SD)		
1.1	Repair of subgrade in the plan, longitudinal and cross-section profiles	SD ₁
1.2	Elimination of destruction which occurred as a result of insufficient drainage, natural disasters or sliding processes	SD ₂
1.3	Arrangement of drainage, isolating layers, slopes protection and other work which ensures the resistance of the subgrade	SD ₃
1.4	Reconstruction of current drainage, bank protection and sewage constructions and installation of the new ones	SD ₄
1.5	Arrangement of subgrade and drainage on widening for additional traffic lanes, acceleration and deceleration lanes, stopping and parking places for vehicles	SD ₅
1.6	Excavations disclosure for providing visibility on the curves in the plan	SD ₆
1.7	Bringing geometrical parameters of the subgrade to the standard regulations	SD ₇
1.8	Recultivation of the land which was used as soiled banks and sandpits as well as during placement of the road elements and constructions when paving in the new direction	SD ₈
1.9	Arrangement and reconstruction of lane lines, slopes and subgrade kerbs fortification	SD ₉
2. Road clothing and surface group of parameters (RCS)		
2.1	Reinforcement (with the longitudinal and cross-section profiles alignment) or arrangement of new road clothing with separate points in the places of the roadway widening, repair and reconstruction of subgrade	RCS ₁
2.2	Installation of border stones and arrangement of fortified lines on the surface edges	RCS ₂
2.3	Removing tracks deeper than 40 mm with the replacement of unstable layers of the road clothing using milling and recycling (regeneration) methods for a width of one or several traffic lanes or for the whole width of the surface with laying down one or several layers of asphalt concrete and alignment of longitudinal and cross-section profiles	RCS ₃
2.4	Reconstruction of the profile of the crushed stone and gravel surfaces adding rock material of more than 500 m per one kilometer	RCS ₄
2.5	Arrangement and repair of steep turns on horizontal curves	RCS ₅
2.6	Relaying paving stones with total or partial replacement of sand base or arrangement of other surfaces using old paving stones as a basis	RCS ₆
2.7	Arrangement of sidewalks	RCS ₇
2.8	Fortification of kerbs	RCS ₈
2.9	Arrangement of exits, jughandle left turns, waiting lanes for the vehicles U-turn, parking and resting places as well as acceleration and deceleration lanes	RCS ₉
3. Artificial structures group of parameters (AS)		
3.1	Fortification, distribution of bridges and bringing their gauges and/or load capacity to the standard ones	AS ₁
3.2	Arrangement of above-ground and underground pedestrian crossings	AS ₂
3.3	Replacement, reconstruction and fortification of supports, surface shotcrete, repair of massive supports lining, cementation of the masonry, replacement of drainage, alleviating local erosion near supports	AS ₃
3.4	Replacement and arrangement of barriers	AS ₄
3.5	Replacement and arrangement of pavement blocks	AS ₅
3.6	Replacement and arrangement of waterproofing and surface of the roadway	AS ₆
3.7	Replacement and arrangement of bridging plates connecting the bridge with the embankment, including reconstruction of the drainage covering	AS ₇
3.8	Reconstruction and arrangement of retaining walls, avalanche galleries, protective buildings, regulatory structures, etc.	AS ₈
3.9	Reconstruction, arrangement of the drainage system	AS ₉
3.10	Maintenance and arrangement of tunnels, galleries and avalanche constructions (settlement, waterproofing, drainage, etc.)	AS ₁₀
3.11	Replacement and distribution of culverts	AS ₁₁
3.12	Replacement of small bridges to pipes-line	AS ₁₂

can be potentially influenced by motorway maintenance. The following groups of parameters correspond to the upper level of the subsystem structure: quality of ambient air – ingredient constituent (AP), quality of water environment (WP), biological diversity (BD), impact on the land and the land fund (LP), physical factors of impact

(PhI), geological factors (GP), waste generation and management (WGM), and social pressure (SP). Each of them is characterized by separate partial indices of the management system elements. Parametric description of processes of impact on the environment in the “environment” subsystem is shown in Table 3.

Table 3. Parametric description of the “environment” subsystem

Nº	Name of the “environment” subsystem parameters	Designation
1. Quality of ambient air – ingredient constituent group of parameters		
1.1	Indices of mass emissions and concentration of pollutants in the ambient air near the road reconstruction processes	
1.1.1	Carbon monoxide	AP ₁
1.1.2	Carbon dioxide	AP ₂
1.1.3	Nitrogen oxides	AP ₃
1.1.4	Sulfur dioxide	AP ₄
1.1.5	Mineral dust (solid particles)	AP ₅
1.1.6	Benzo(a)pyrene	AP ₆
1.1.7	Paint and varnish materials aerosol	AP ₇
1.1.8	Formaldehyde	AP ₈
1.1.9	Xylol	AP ₉
1.1.10	Ethylbenzene	AP ₁₀
1.1.11	2-methoxy-1-methyl acetate	AP ₁₁
1.1.12	Dimethoxymethane	AP ₁₂
2. Quality of water environment group of parameters		
2.1	Heavy metal content in water bodies near the road	WP ₁
2.2	Other pollutants content in water bodies near the road	WP ₂
2.3	Mechanical pollution of water bodies near the road	WP ₃
3. Biological diversity group of parameters		
3.1	Impact on flora	BD ₁
3.2	Impact on fauna	BD ₂
3.3	Impact on fungi	BD ₃

Nº	Name of the “environment” subsystem parameters	Designation
3.4	Impact on the objects of the nature preserve fund	BD ₄
4. Impact on the land and the land fund group of parameters		
4.1	Heavy metal mass content in the soil near the road	LP ₁
4.2	Concentration of pollutants in the soil near the road	LP ₂
4.3	Setting land resources for the reconstruction objects	LP ₃
5. Physical factors of impact group of parameters		
5.1	Noise (acoustic) pollution	PhI ₁
5.2	Vibration pollution	PhI ₂
5.3	Thermal impact	PhI ₃
5.4	Radiation impact	PhI ₄
6. Geological factors group of parameters		
6.1	Geological and karst creation processes	GP ₁
6.2	Replacement of soil hydrological processes	GP ₂
7. Waste generation and management group of parameters		
7.1	Amount of created waste	WGM ₁
7.2	Created waste danger	WGM ₂
8. Social pressure group of parameters		
8.1	Population incidence rate as a consequence of the maintenance work	SP ₁
8.2	Decrease of the population living comfort near the maintenance work performance	SP ₂

Separately, we specify parameters of weather and meteorology conditions which can have impact on motorway maintenance and reconstruction work processes, such as rain (WMC1), snow (WMC2), frost (WMC3), ground frost (WMC4), and fog (WMC5).

Integration of the two subsystems allows a systematic study when technological processes during the motorway maintenance can have the most dangerous impact on the elements of the environment, natural one first of all.

Analysis of the data from Table 2 and Table 3 allows defining interconnection between the process of the maintenance work first stage and its impact on the environment. Let's present the given cause-effect relationship in the "motorway maintenance – environment" system as a mathematical model (2) as a combination of parameters presented in Tables 2 and 3 and weather and meteorological conditions.

$$\left[\begin{matrix} SD_1 - SD_9 \\ RCS_1 - RCS_9 \\ AS_1 - AS_{12} \end{matrix} \Rightarrow \begin{matrix} AP_1 - AP_{12} \\ WP_1 - WP_3 \\ BD_1 - BD_4 \\ SP_1 - SP_3 \\ PhI_1 - PhI_4 \\ GP_1 - GP_2 \\ WGM_1 - WGM_2 \\ SP_1 - SP_2 \end{matrix} \Leftarrow \{WMC_1 - WMC_5\} \Rightarrow [\min; 0] \right] \quad (2)$$

Thus, the suggested model is the basis for identifying the impact of separate work connected to the motorway building and/or reconstruction (maintenance) processes on the environment, natural one first of all. The use of the model will allow developing a mechanism for improving the effectiveness of evaluating the impact on the environment, especially in the aspect of road building and reconstruction projects.

This model was used in preparation of the Environmental Impact Report for the construction project of the H-31 State Road Dnipro — Tsarychanka — Kobeliaky — Reshetylivka from Loboikivka village to the border of Dnipropetrovsk Oblast (Environmental Impact Report, 2018). The model allowed revealing the relationship between the processes of a certain stage of repair works and their impact on the environment. Table 4 shows a fragment of the result of the

parametric analysis of the impact of production processes on the environment.

Table 4. Example of a parametric analysis of the project's environmental impact (Environmental Impact Report, 2018)

Production process	"Environment" system parameter	Marking
Intersection and adjacency Arrangement of transport interchange on PC 44 + 50	Indicators of mass emissions and concentrations of pollutants in the air near the road reconstruction processes	-
Arrangement of pavement "torn" ring	Carbon monoxide	AP1
Arrangement of pavement "torn" ring	Nitric oxide	AP3
Adding green area	Impact on flora	BD1

Conclusions

The study has shown the application of parametric analysis in relation to the negative factors of the impact of road construction and reconstruction processes on the environment, allowing systematization of aspects of the impact on the environment of individual production processes, taking into account existing environmental standards and requirements. The developed mathematical model shows the cause-and-effect relationship in the system "road repair – environment" as a set of environmental parameters and weather and meteorological conditions

The model allows identifying interconnection between the process of carrying out a specific stage of the maintenance work of the project of construction of the H-31 State Road Dnipro — Tsarychanka — Kobeliaky — Reshetylivka and its impact on the environment. The use of the proposed tool in the preparation of the Environmental Impact Assessment Report minimizes the time for both the preparation of the Report and its review for obtaining a permit for the planned activity.

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of the State Road H-31 Dnipro-Tsarychanka-Kobeliaki-Reshetylovka from Loboikivka village to the border of Dnipropetrovsk oblast the I-b technical category with 4 lanes (2 lanes in each direction) bypassing the settlements of Loboikivka, Petrykivka, Mohyliv, Kytaihorod, Tsarychanka, Liashkivka. Dnipro, 459 p. (in Ukrainian). Available from: <http://eia.menr.gov.ua/uploads/documents/533/reports/c48123fd437084451578dce5fdf127b1.pdf>



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