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INFLUENCE OF THE SYSTEM OF MATERIAL FLOWS ON THE ENVIRONMENT OF INDUSTRIAL AREAS

Об'єктом дослідження є транспортна складова, як базовий елемент середовища промислових зон. У роботі розглядається аналітичний підхід до визначення закономірностей залежності екологічності системи матеріалопотоків від характеристик транспортної складової. Запропонована модель інтелектуальної системи управління ефективністю і екологічністю на основі декомпозиції промислових транспортних комплексів на дві складові, що відрізняються способами і умовами утворення викидів забруднень: підсистему стаціонарних джерел і підсистему пересувних джерел.

Отримані результати дозволяють виділити ряд особливостей природи впливу матеріалопотоків на середовище промислових зон, які згруповані у базові аналітичні групи загор і можливостей розвитку досліджуваного об'єкту з середньою експертною оцінкою (е. о.), а саме:

– група загрози: слабе стратегічне планування діяльності і його розвиток (12,8 е. о.); істотна залежність фінансового стану від об'ємів замовлень декількох видатних споживачів (9,6 е. о.); слабка правова база, що регламентує екологічну безпеку діяльності об'єкту (6,6 е. о.); впровадження зарубіжних інноваційних рішень в діяльність об'єкту (11,8 е. о.); інтенсивне оновлення існуючих механізмів екологічного захисту (2,8 е. о.);

– група можливості: кадрові можливості створення потужної інженерної бази і професійної команди менеджерів (14,6 е. о.); ефективне використання інформаційних технологій (5,6 е. о.); впровадження функцій сітілогістики (5,6 е. о.); вдосконалення якості транспортних послуг (10 е. о.); створення спеціалізованого центру управління процесом забезпечення екологічної стійкості об'єкту (10 е. о.).

Отримані результати дослідження ступеня впливу матеріальних потоків на навколишнє середовище промислової зони підтверджують робочу гіпотезу авторів. Ця гіпотеза заснована на розгляді транспортних систем і екологічної безпеки їх роботи, як єдиного цілого і ступеня їх взаємодії протягом усього життєвого циклу їх розвитку.

Ключові слова: транспортна складова, промислова зона, екологічна стійкість, екологічна характеристика, коефіцієнт трансформації.

Received date: 30.05.2019

Accepted date: 08.06.2019

Published date: 30.08.2019

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1. Introduction

Industrial enterprises and the geographical areas of their location are complex territorial entities that share natural, material, labor and environmental resources [1, 2].

The technical system of material flows of industrial enterprises operates in a closed area. Its ecological region occupies a certain territory and volume, and is separated from industrial zones by natural or man-made borders. Borders can be defined from the standpoint of the side that controls the ecology with static borders, or blurred, the so-called moving borders.

Each component of the ecology of industrial zones has its own properties, those with which it differs (or is similar) from the rest: a physical, chemical, biological or complex feature that manifests itself during the interaction of transport and environmental systems. Given the existing theoretical basis that determines the conditions for the stability of transport, in order to fulfill the tasks set in the work let's consider the effectiveness of transport systems and the environmental safety of their work as a whole.

Therefore, it is relevant to study the influence of material flows on the environment of industrial zones.

2. The object of research and its technological audit

The object of research in this work is determined by the transport component, as the basic element of the environment of industrial zones (EIZ). EIZ includes:

- street-road network of the industrial zone, providing internal and external transport links;
- rolling stock;
- access railway tracks and stations;
- cargo berths, marinas and other engineering structures;
- institutions and service enterprises operating in industrial zones.

The object of research can be attributed to the second group of sources of negative impacts on environmental sustainability (ES) of transport in the environment of industrial zones.

A feature of this object is the fact that the sources of pollution are evenly distributed over a certain area

in the environment of industrial zones. As a transport source itself, as a pollution source, the road network of a separate industrial region, within which vehicles are moving, is considered [3]. The criteria for dividing the environment of industrial zones into quarters are both their administrative boundaries and the development parameters of the road network (RN) (in particular, RN density).

The main disadvantage inherent in this object in the existing operating conditions is that mobile sources and their impact on the environmental sustainability of the transport system (ESTS) in the explicit form little depends on the traffic conditions. Therefore, when revealing the share of the influence of transport sources on the overall ESTS level for the development of organizational measures for its stabilization, these methods become uninformative.

This fact, in turn, complicates the process of searching for criteria defining a real assessment of the ESTS, and thereby makes the process of managing the ESTS ineffective.

3. The aim and objectives of research

The aim of research is finding mechanisms that can isolate and quantify only that ESTS component, which falls on the share of transport in the environment of industrial zones. At the same time, they should be sensitive to changes in the ESTS caused by organizational measures aimed at ensuring the safety of EIZs.

Based on the aim, the following objectives are set that need to be addressed:

1. To formulate the features of the environmental characteristics of an industrial transport site with elements that limit its adequacy.

2. To form a mechanism for the quantitative assessment of the technogenic influence of material flows on the environment of city districts.

3. To develop a mechanism for determining a comprehensive assessment of the pollution of the natural city environment.

4. To formulate a criterion that allows to assess an acceptable level of industrial environment.

4. Research of existing solutions of the problem

Among the main directions of solving the problem associated with the theoretical description of the mechanisms of the impact of transport sources on ES, identified in the resources of the world scientific periodicals, can be identified [4, 5]. But they did not consider the patterns of influence of the reliability of rolling stock on the environment.

As a result of the studies, an approach has been formed in which transport sources are classified as continuously operating ground sources with a variable power of impact on the ecological balance of EIZs. In some studies, to assess the degree of influence on transport sources of ES, they are presented as stationary point sources. This allows extrapolating to mobile sources the patterns of impact on the environmental sustainability of EIZ stationary sources. In this case, linear elements are assigned linear elements of the transport frame, and the impact on the nodal points of the frame is considered as background [6].

Under these conditions, material flows operate within the closed boundaries of an industrial enterprise, but their technogenic factors influence a technologically open system.

The processes taking place within the boundaries of industrial enterprises and their industrial zones for industrial transport systems are the subject of work [7], but there is an unresolved issue of the interaction of pollution sources and the environment. The significance of this issue is indicated in [8]. However, the degree of influence of logistic mechanisms on these processes is not fully disclosed in this work.

Analysis of the results of transport activity in the environment of industrial zones reflects the problem of the accumulation of harmful substances over a certain period of time in soil, water, air, creates a real danger to human health [9]. It should be noted that in the analyzed system of the natural environment the state of a large number of its components is formed according to the law of the totality of natural factors. Let's use the works [10, 11] and assume that when the number of factors and the relationships between them change in the open system, the entropy of the system changes. The issue of managing ecosystem resilience in critical conditions is the subject of a scientific work [12].

However, the described parameters do not have actual evidence of the relationship of environmental and technical systems.

The cluster of reliability and environmental friendliness of material flows of enterprises in industrial zones has a classical definition [13], but the problem remains of studying the environmental factors.

Thus, it is possible to conclude that the peculiarity and fundamental difference from the well-known publications of the study being brought to attention is that it provides the results of the analysis of the laws of the dependence of environmental friendliness on the technical condition of material flows of enterprises in industrial zones.

5. Methods of research

In the study of the object, a comprehensive approach was implemented, which includes: the theory of transport processes and systems, the theory of reliability and the theory of recovery, and when analyzing the impact on the environment of material flows, an innovative direction was used – city logistics.

6. Research results

The ecological system of the industrial zone in comparison with the technical is the most complete, integrated system, which includes all natural and artificial subsystems.

In an open system, transport pollutants are scattered beyond the boundaries of the industrial enterprise, and a certain part of them, as a source transformation, reaches the industrial zone. Let's call the transformation coefficient K_{tr} the ratio of the action of the transport source A_s to the value of the action that has reached the industrial zone A_i ($K_{tr}=A_s/A_i$).

This indicator for the boundaries of the industrial site is $K_{tr}=1.0$, for dispersion within the industrial zone $K_{tr}<1.0$.

In the system of material flows, as a result of the interaction of the components, complex transport links, networks and borders are formed, and, taking into account the return actions, closed circuits of environmental impacts on the environment are formed. These properties – P or their indicators – I are functionally dependent on the

magnitude – A factors of influence on the environment of material flows and their transport processes.

The material flow system has several factors influencing the environment and is expressed by a multifactorial dependence:

$$P=f(A_1, A_2, \dots, A_z), I=f(A_1, A_2, \dots, A_z). \quad (1)$$

The adequacy between the components of the material flows and the environment within the site in the closed state is characterized by the condition:

$$Q_i=Q_{ee}, \quad (2)$$

where Q_i – an absolute organization of the industrial transport system (ITS); Q_{ee} – an absolute organization of the external environment for transport systems within the boundaries of an industrial enterprise.

The condition of their static equilibrium has the form:

$$Q_i-Q_{ee}=0. \quad (3)$$

If this equilibrium is violated, the components that affect the system environment change by dQ_i due to malfunctions, failures, and repair processes during the time interval dt . Then the condition of dynamic equilibrium can be represented as follows:

$$\frac{dQ_i}{dt} = \Delta Q_{ee} - \Delta Q_i. \quad (4)$$

Autonomy (isolation) of an enterprise's ecosystem is relative, since each ecosystem is an open-type system that has a connection with the environment. The environment affects the transport of material flows.

The ecosystem within the boundaries of the industrial enterprise is part of a higher level system, it consists of components that are formed by the interaction of its sub-objects: material flows, the industrial environment ecology and the social environment of society (Fig. 1).

To assess the design (absolute) organization of structural, functional and managerial components of the material flow system, let's use the definition of the norm of the absolute organization of the system component [14]:

$$Q_{ni} = \frac{\sum_{j=1}^m y_j^{(i)} \cdot Q_{nj}^{(i)}}{\sum_{j=1}^m y_j^{(i)}}, \quad (5)$$

where Q_{ni} – the norm (indicator) of the absolute organization of the i -th component, corresponding to the goals of the material flow system; $Q_{nj}^{(i)}$ – the norm (indicator) of the absolute organization of the j -th component of the environment for the i -th component of the material flow system; $y_j^{(i)}$ – rigidity (permissible vibration limit) of the norm $Q_{nj}^{(i)}$.

As a rule, transport systems of industrial enterprise material flows are calculated for a long period and then the norm (indicator of serviceability, reliability, recoverability) is monitored by the value of the change from the initial state to the current state and then:

$$Q_{ni} = \frac{\sum_{j=1}^f y_j^{(i)} \cdot Q_{nj}^{(i)}}{\sum_{j=1}^f y_j^{(i)}}. \quad (6)$$

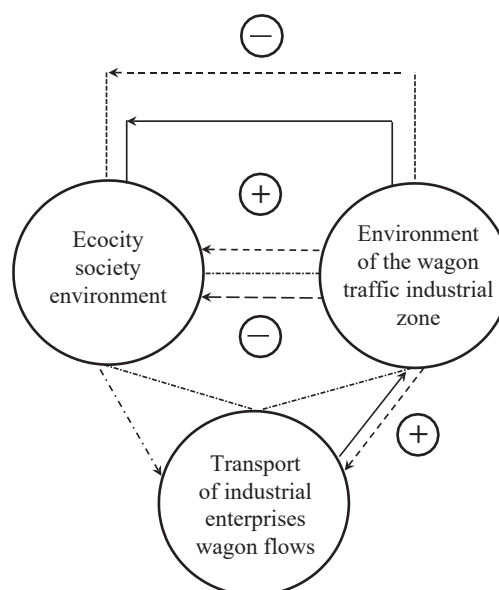


Fig. 1. Interaction in the system «industrial transport – environment» (authors development based on [11]):

---> ---> – biological connections; —> —> – technogenic impact; · · ·> · · ·> – boomerang reaction to anthropogenic impacts; (+) – positive adaptability; (-) – negative adaptability

The material flow system is a source of pollutants in the natural environment and the natural state of equilibrium is violated. Incoming pollutant substances are continuously included in the circulation of substances between geophysical media.

At the same time, let's note that there are no completely closed systems. The openness of the techno-ecological properties of the material flow system characterizes the degree of its dependence on the environment and the impact on it.

Depending on the characteristics of the techno-ecological system, its connections with the ecosystem of the environment can be large or smaller. For man-made systems, greater openness means greater use of natural resources and more industrial waste.

In the open system of the natural environment, the state of a large number of its components is formed according to the law of the totality of natural factors. Let's use the works [10, 11] and assume that when the number of factors and the relationships between them change in the open system, the entropy of the system changes. Under the influence of control actions, the ecosystem seeks to achieve an equilibrium state. If Q' is the absolute organization of the system, then differentiating Q' in time let's obtain:

$$\frac{dQ'}{dt} > 0, \text{ if } a > b, \quad (7)$$

where a – const from the derivative of the maximum entropy of the system; b – const from the derivative of the current entropy of the system.

In an open system, it is possible to assume that an increase in the number of system states is determined by the difference between the maximum uncertainty of the state of the system and its current absolute organization. Based on this statement, it is possible to use the following empirical formula [12]:

$$\Delta X^s(t) = \beta_i [H_{\max}^s(t) - Q^s(t)] = \beta_i H^s(t), \quad (8)$$

where $\Delta X^s(t)$ – increase in the number of system states; H_{\max}^s, H^s – maximum and current entropy of the system; Q^s – absolute organization of the system; β_i – coefficient of proportionality and dimension.

Thus, a model for predicting the characteristics of the state of an open system can be represented as:

$$X^s(t) = X_o^s + \beta H^s(t), \quad (9)$$

where X_o^s – numerical characteristic of the state of the system in the initial state, i. e., $t=0$.

The ecosystem surrounding the industrial enterprise is an integral part (subsystem) of a higher level, but even it itself consists of smaller components. The construction of a hierarchical scheme of the eco-industrial environment depends on the type of transport system of the enterprise (for metallurgical, chemical, machine-building and other enterprises) and the goals that the researcher sets for itself. This approach allows one to take into account both external relations and internal relations between subsystems.

To assess the degree of autonomy of the industrial site ecosystem for individual pollutants, let's use the recycling coefficient:

$$K_r = \frac{B_s}{B_t}, \quad (10)$$

where B_t – the total amount of pollutants passing through the system at a specific time; B_s – the amount of substance that circulates in the system itself, without going beyond its borders (during this time).

A quantitative assessment of the technogenic effect of material flows on the medium leads to deformation of the properties of the medium. The deformation coefficient DC is the ratio of the magnitude of the change in the value of the indicator (properties, process, parameter) under the influence of the technogenic ability of the actions of V_t to the corresponding background natural value V_b :

$$DC = \frac{V_t}{V_b} = \frac{V_t - V_b}{V_b}, \quad (11)$$

where V_i – the current value of the indicator (properties, parameter).

The comparative-boundary method for assessing pollution is based on comparing the level of actual pollution (air, water, soil) by any pollutant (P) with the value of pollution acceptable for the body.

Sanitary and epidemiological values for the body as maximum permissible (MP) are accepted as permissible pollution. Estimated indicator of pollution is the coefficient of environmental pollution:

$$K_{EP} = \frac{\sum_{i=1}^k \left(\frac{P}{MP} \right)}{K_p}, \quad (12)$$

where K_p – the amount of pollutant.

For a comprehensive assessment of the pollution of the natural city environment, let's use the K_{EP} environmental pollution index by environmental pollution factors:

$$K_{EP} = A \cdot K_{ap} + H \cdot K_{hp} + L \cdot K_{lp}, \quad (13)$$

where A, a – atmosphere; H, h – hydrosphere; L, l – lithosphere.

The dependence of the properties or environmental indicators of the cargo flow system on the magnitude of the acting factors – F is called the environmental characteristic of the industrial transportation site:

$$B = f(F_1, F_2, \dots, F_n). \quad (14)$$

These factors include:

- imperfection of technology of the transportation process;
- excess downtime, insufficient rate of change in the structure of transport parks;
- loss of part of the product;
- use of rolling stock with malfunctions;
- rolling stock failures;
- accidents and their consequences;
- loss of product leakage;
- pollution at the points of preparation and repair of rolling stock;
- other factors listed above.

Damage to natural resources caused by material objects of material flows is expressed by the entry into the natural environment of gaseous, solid and liquid substances that adversely affect the components of the atmosphere $\{A\}$, hydrosphere $\{H\}$, lithosphere $\{L\}$.

The relationship between the technogenic factors of material objects of industrial enterprise material flows and the environment is realized through the transfer function. The transfer function corrects the phenomena of dispersion, transformation and other transformations.

The transfer function of the system $H(s)$ converts the load from the factors of the negative influence of the material flows $Y_n(s)$ entering the environment into the corresponding reaction at the output of the damage factors $F_Y(s)$, forming a communication function:

$$H(s) = \frac{Y_n(s)}{F_Y(s)}. \quad (15)$$

Individual damage factors and exit reactions form a transfer matrix (Table 1).

When transporting dangerous goods of industrial transport, an accident leads to a deviation from the permissible operating conditions of wagon flows.

Table 1

Communication transmission matrix

Environment	The transfer function of the j -th factor «technosphere – environment»					
	1	2	...	j	...	n
Atmosphere $\{A\}$	$H(s)a1$	$H(s)a2$	...	$H(s)aj$	...	$H(s)an$
Hydrosphere $\{H\}$	$H(s)h1$	$H(s)h2$	...	$H(s)hj$	...	$H(s)hn$
Lithosphere $\{L\}$	$H(s)l1$	$H(s)l2$	...	$H(s)lj$	...	$H(s)ln$

Dangerous goods include: explosive and pyrotechnic substances, gases, flammable liquids and solids, toxic, infectious and oxidizing substances, organic peroxides, radioactive substances, etc.

The territory within which a harmful effect is detected is called the affected area in an emergency.

The amount of damage caused as a result of the accident to the environment in general is determined by the formula:

$$D = D_a + D_w + D_l + D_g + D_f, \quad (16)$$

where D_a – damage from emissions of harmful substances into the atmosphere; D_w – damage from contaminants entering water bodies; D_l – damage from pollution and land degradation; D_g – damage from clogging of the territory or reservoir with waste (garbage); D_f – damage from the negative impact on the objects of the plant and animal world.

The consequences of emergencies depend on the location of the source of the accident, especially the formation of spills, as well as the physico-mechanical and chemical properties of the pollutant. These features, as well as climatic conditions dictate the appropriate methodological and technical measures aimed at reducing the environmental impact.

In general, an emergency response plan includes the following steps:

- assessment of the extent and danger of the accident, determination of the plan and scope of work, the composition of performers;
- detection and localization of the source of the accident;
- collection of spilled liquid or contaminant;
- safe storage and disposal of collected pollutant;
- restoration of the affected areas;
- organization of a monitoring system.

Chemical pollution of soils and soils is assessed by the total indicator of chemical pollution Z_c . The total indicator of chemical pollution characterizes the degree of chemical pollution of soils and soils of the studied territories with harmful substances and is determined as the sum of the concentration coefficients of individual components of pollution by the formula:

$$Z_c = K_c + \dots + K_{c_i} + \dots + K_{c_n} - (n-1), \quad (17)$$

where n – the number of determined components; K_{c_i} – the concentration coefficient of the i -th polluting component, which is equal to the ratio of the excess of the content of this component over the background value.

In case of pollution of material flows of soil with transport processes by substances of organic or inorganic origin, the degree of soil pollution is estimated.

The main indicators of atmospheric air quality at the transport site are the maximum permissible concentrations of harmful substances (MPC) in the air at an altitude of 2 m from the land surface.

When several substances of unidirectional action material are simultaneously contained in air, the following condition must be fulfilled:

$$\frac{C_1}{MPC_1} + \frac{C_2}{MPC_2} + \dots + \frac{C_n}{MPC_n} \leq 1, \quad (18)$$

where C_1, C_2, \dots, C_n – the concentration of 1, 2, ..., n harmful substances in the air; n – the number of harmful substances in the air.

The quality of atmospheric air is subject to periodic monitoring, i. e., the compliance of atmospheric air indicators with the requirements of normative and technical documentation is checked. They control air quality, emissions and other atmospheric parameters. To assess the quality of atmospheric air, single and complex indicators of air pollution are used (17).

As a result of the accident, the amount of damage from emissions of harmful substances into the atmosphere is determined by the formula:

$$D_a = M_{i_{atm}} \cdot H_{b_{i_{atm}}} \cdot C_e \cdot C_i, \quad (19)$$

where $M_{i_{atm}}$ – the actual emission of the i -th polluting substance; $H_{b_{i_{atm}}}$ – the basic standard for the charge for the emission of 1 ton of the i -th pollutant within the established limits; C_e – coefficient of the ecological situation and the ecological significance of the city district where the accident occurred; C_i – indexation coefficient to the basic board standards.

Emissions of pollutants into the atmosphere from stationary sources (loading and unloading, repair processes with rolling stock), charges for emissions of pollutants in amounts not exceeding the maximum allowable emission standards are determined by the formula:

$$P_{H_{atm}} = \sum_{i=1}^n C_{H_{i_{atm}}} \cdot M_{H_{i_{atm}}} \quad (\text{at } M_{i_{atm}} \leq M_{H_{i_{atm}}}), \quad (20)$$

where i – the type of pollutant; $C_{H_{i_{atm}}}$ – the rate of payment for the emission of 1 ton of the i -th polluting substance within the permissible emission standards; $M_{i_{atm}}$ – the actual emission of the i -th polluting substance; $M_{H_{i_{atm}}}$ – maximum permissible emission of the i -th polluting substance.

The charge rate for the emission of 1 ton of the i -th polluting substance within the permissible emission standards is determined by the formula:

$$C_{n_{i_{atm}}} = H_{b_{n_{i_{atm}}}} \cdot C_{e_{atm}}, \quad (21)$$

where $H_{b_{n_{i_{atm}}}}$ – the basic norm for the charge for the emission of 1 ton of the i -th polluting substance within the limits not exceeding the maximum permissible emission standards; $C_{e_{atm}}$ – coefficient of the ecological situation and the ecological significance of the atmosphere in this city district.

The fee for exceeding the allowable emissions of pollutants from mobile sources (wagon flows) can be determined by the formula:

$$P_{c_{n_{trans}}} = \sum_{j=1}^p P_{n_j} \cdot d_j, \quad (22)$$

where j – the type of vehicle; p – the number of vehicles; P_{n_j} – payment for permissible emissions of pollutants from the j -th type of vehicle; d_j – the share of j -type vehicles that do not meet the standards (defined as the ratio of the number of vehicles that do not meet the requirements of the standards to the total number of vehicles tested).

Industrial wastewater from repaired wagons is usually contaminated with oil products: fuel oil, lubricants, gasoline, kerosene. In addition, phenols, suspended particles, organic (paint, solvents) and synthetic surfactants, heavy metal salts may be present in wastewater.

Domestic effluents contain organic pollutants (carbon and nitrogen compounds), surface effluents include rain and snow effluents from plant sites, enterprise territories, sludge of rolling stock, roofs of industrial and office buildings. Surface water flushes hazardous substances such as alkali into the soil.

Damage from the ingress of pollutants into water bodies resulting in a change in water quality as a result of an accident [9] is calculated by the formula:

$$D_w = 25 \sum_{i=1}^j M_{i_{wat}} \cdot 10^{-6} \cdot H_{bi_{wat}} \cdot C_{e_{wat}} \cdot C_i, \quad (23)$$

where $M_{i_{wat}}$ – the actual discharge of the i -th polluting substance; $H_{bi_{wat}}$ – the basic norm for the charge for the emission of 1 ton of the i -th pollutant within the established limit; $C_{e_{wat}}$ – coefficient of the ecological situation and the ecological significance of the surface of the water body.

The task of environmental forecasting of the influence of material flows includes determining the concentration field by the amount of pollution, and determining the corresponding state of ecological equilibrium by the concentration field.

It is necessary to have some Q criterion, which allows to assess an acceptable level of functioning of material flows. The planned emission of pollutants V will determine the concentration field within the industrial site, which will correspond to the biota Y of the ecosystem that is different from the initial Y_0 , then $[Q(Y) - Q(Y_0)]$ the increment in the usefulness of the ecosystem state and criterion Q has the form:

$$Q = [Q_u + Q(Y) - Q(Y_0)]. \quad (24)$$

The decision rule is that the total usefulness of the measures is positive, and then based on this, a decision is made to continue the operation of the rolling stock. If the measures taken are negative, an appropriate decision must be made.

An industrial transport complex (ITC) that implements stream processes from raw materials to finished products is created for an effective system for managing its environmental safety, environmental protection from the negative impact of its pollutants on the environment.

The relationship of environmental factors of the industrial site of material flows, the ecological zone of the industrial city district and the social environment of society is shown in Fig. 2.

ITC is characterized by factors that determine the formation, distribution and accumulation of various types of pollutants in space and, as a result, the possibility of occurrence of zones of environmental adverse situations, differing in size and stability.

Based on the ITC peculiarities, the decomposition of the conditions for the occurrence of pollutants into two components is carried out, which differ in the methods and conditions for the formation of pollutant emissions:

- subsystem of stationary sources (loading and unloading operations, maintenance system and repair);

- subsystem of mobile sources (technology of the transport process, failures ceasing to failures, and the impact of accidents on the environment).

Theoretical principles (paradigm) of logistics and environmental friendliness of wagon flows of industrial enterprises include:

- methods and models of transport logistics;
- methods of managing reliability and environmental friendliness;
- methods for assessing the life cycle of wagons;
- methods of re-equipment of wagon fleets;
- logistic models of environmental sustainability of repairs;
- methods of safe and environmentally friendly material flow support;
- decision making methods.

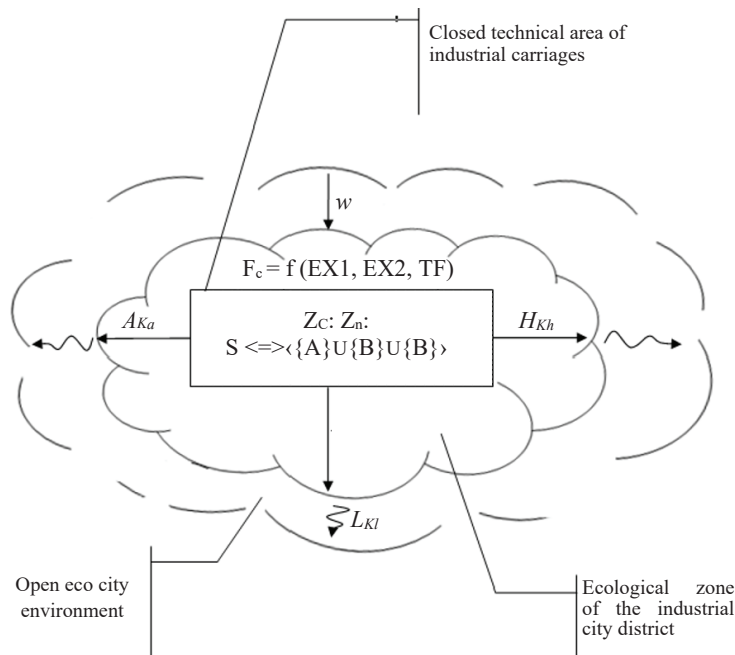


Fig. 2. The relationship of the system of wagon flows of the transport site of the industrial zone and environmental facilities

In Fig. 2:

- $S \Leftrightarrow \langle \{A\} U \{B\} U \{U\} \rangle$ – the system of wagon flows of industrial enterprises and its components: $\{A\}$ – the set of wagons and objects of the wagon fleet; $\{B\}$ – the set of logistic transport wagon flows; $\{U\}$ – the set of control decisions;
- $Z_c; Z_n$ – stationary and mobile sources of pollution in the S system, respectively;
- $A k_a; H k_h; L k_l$ – boundary indicators $A; H; L$ of the atmosphere, hydrosphere and lithosphere and, accordingly, their environmental pollution coefficients k_a, k_h, k_l ;
- w – external environmental impact on the accumulation and spread of pollution;
- $F_c = f(EX1, EX2, TF)$ – the functional relationship of the transport and ecological system of the city district (a set of environmental characteristics and the transfer function TF).

To display the results obtained, a SWOT analysis of expert assessments of the state of the transport component in the conditions of industrial zones was carried out, the results of which are shown in Fig. 3.

Strengths	No. Expert										Average value	Weaknesses	No. Expert										Average value		
	Expert 1		Expert 2		Expert 3		Expert 4		Expert 5				Expert 1		Expert 2		Expert 3		Expert 4		Expert 5				
	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank			Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank			
Experts – periodicals exploring the issue of market conditions																									
1	Operational market monitoring, well-established sales network	3	5	4	1	2	4	3	2	4	4	9.8	1	Unbalanced production capacity	2	3	3	4	4	3	2	3	5	9.8	
2	Certified quality system, highly qualified staff	4	4	3	5	4	2	3	4	3	1	10.8	2	High manufacturing costs	1	2	2	1	2	1	4	4	3	6.8	
3	Balanced product range	3	2	3	2	3	5	3	5	2	3	9.6	3	Supply failures	4	4	1	3	2	2	3	5	3	8.2	
4	Differentiation of fields of activity	4	1	3	4	4	1	3	3	4	2	7.4	4	Legal framework governing the market	3	5	2	5	3	4	4	3	4	4	13
5	Availability of industrial site with developed infrastructure	3	3	2	3	4	3	4	1	3	5	9.2	5	Non-participation of staff in management decisions	4	1	3	2	2	5	4	1	1	2	5.2
Threats	No. Expert										Average value	Opportunities	No. Expert										Average value		
	Expert 1		Expert 2		Expert 3		Expert 4		Expert 5				Expert 1		Expert 2		Expert 3		Expert 4		Expert 5				
	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank			Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank			
1	Weak strategic planning of the enterprise and its development	4	5	3	2	3	5	4	1	2	4	10.6	1	Personnel capabilities to create a powerful engineering base and professional management team	4	3	3	5	4	1	2	4	2	3	9
2	Significant dependence of the financial condition on the volume of orders of several major consumers	3	3	4	1	4	4	3	5	4	2	10.4	2	Digitalization of management processes	2	1	4	4	3	5	4	2	1	2	8.6
3	Licensing by domestic manufacturers of their products	2	1	3	5	3	2	3	2	3	5	8.8	3	Implementation of SMART elements in the technological chain	2	2	3	2	3	2	3	5	4	4	9.4
4	Entrance to the market of foreign suppliers	4	4	4	4	4	1	3	4	4	1	10.4	4	Product quality improvement	4	4	4	1	3	4	4	1	3	5	10.2
5	Low intensity of re-equipment of production	2	2	1	3	3	3	2	3	4	3	6.8	5	Creating a cluster of enterprises in this market segment	2	5	3	3	2	3	4	3	4	1	8.2

Quantitative score (from 1 to 4 points, where 4 is the highest value, and 1 is the lowest)

Ranking score (where 1 is the lowest value and 5 is the highest)

Fig. 3. The result of the SWOT analysis of expert assessments of the state of the transport component in industrial zones

The obtained results allow to highlight a number of features of the nature of the influence of material flows on the environment of industrial zones, grouped into basic analytical groups of threats and development opportunities of the investigated object with an average expert rating.

7. SWOT analysis of research results

Strengths. Personnel capabilities to create a powerful engineering base and a professional management team leads to the effective use of information technology, the implementation of city logistics functions, the improvement of the quality of transport services and the creation of a specialized control center for the process of ensuring the environmental sustainability of the facility.

The positive effect in this direction on the results of the research is a new approach to environmental sustainability based on an analysis of the laws of environmental dependence on the technical condition of rolling stock as a transfer function of the process. This determines the theoretical novelty of the article.

Weaknesses. The lack of efficiency of the transport system in industrial areas is determined by a range of factors, namely:

- multi-criteria tasks, which are characterized by the need to take into account the degree of influence of the technical condition of the rolling stock on the environment;
- low informational component of the transport and technological process, which does not allow for the operational management of the environmental sustainability of transport processes.

The variety and degree of influence of these factors on the environment is also determined by the nature of the malfunctions, failures, operation technology and recovery processes of transport units.

Opportunities. Environmental responsibility through environmental management is designed to identify environmental potentials for the success of the enterprise, its advantages in the field of resource conservation, environmental safety, as well as environmental risks associated with its activities. This is the basis for determining long-term goals and ensuring their implementation through the application of a sound system of measures and tools.

The authors believe that the research results can be implemented in transport systems in a metastable economic environment of industrial zones, which are characterized by high dynamics of processes. The practical implementation of the results when they are introduced into the control system will allow to get a comprehensive assessment of the pollution of the natural city environment.

The presented theoretical dependences for calculating a comprehensive assessment of the pollution of the natural city environment can be of interest and be useful for other countries from the standpoint of the uniqueness of the approach to taking into account the technical, technological and environmental components of the material system of industrial zones.

Threats. Threats that impede the implementation of research results include:

- poor strategic planning of activities and its development;
- a significant dependence of the financial condition on the volume of orders of several major consumers;

- weak legal framework governing the environmental safety of the facility;
- implementation of foreign innovative solutions in the facility;
- intensive updating of existing environmental protection mechanisms.

8. Conclusions

1. The features of the ecological characteristics of the industrial transport site with the elements limiting its adequacy, which are dependent on the environmental indicators of the material flow system on the magnitude of all existing factors, are formulated. These factors include:

- imperfection of technology of the transportation process;
- excessive downtime;
- insufficient rate of change in the structure of transport parks;
- loss of part of the product;
- use of rolling stock with malfunctions;
- rolling stock failures;
- accidents and their consequences;
- loss of product leakage;
- pollution at the points of preparation and repair of rolling stock.

2. A mechanism has been formed for the quantitative assessment of the technogenic influence of material flows on the environment of city districts, taking into account the relationship between the technogenic factors of material objects of industrial enterprise material flows and the environment. This connection is realized through the transfer function, which corrects the phenomena of dispersion, transformation and other transformations.

3. A mechanism has been developed for determining a comprehensive assessment of the pollution of a natural city environment based on an indicator of environmental pollution by the coefficients of pollution of the atmosphere, hydrosphere, and lithosphere.

4. A criterion has been formed that allows to assess an acceptable level of the state of the industrial environment, taking into account the planned release of pollutants within the industrial site.

Thus, an analysis of the impact of material flow systems on the environment allows to conclude that a decrease in the level of harmful effects on the ecosystem of an industrial zone is possible if it is persistent to block the influence of factors of the transport system of material flows, external and internal influences. And also, if it is organized quite internally varied and further research will be aimed at identifying the dependence of the properties or indicators of the environment of the material flow system on the magnitude of the acting factors.

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