Possible Implications for Land-Use Planning Mechanisms when Considering the Results of Monitoring and Modelling Air Pollution by Industry and Transport on the Example of Kazakhstan Cities

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Abstract: For many Central Asian cities, the era of Soviet rule was – if not even reason for their existence – at least determining their historical and contemporary economic alignment. Even today in many cities of Central Asia such as Pavlodar, Dushanbe, Bishkek or Tashkent the secondary sector forms the economic backbone. That is also the case in Ust-Kamenogorsk, Kazakhstan. Due to declining public transport systems, growing motorization and comparatively old car fleets emissions from the transport sector became the second important source of air pollution inside the cities. Together with the emissions from the secondary sector, transport emissions can – under certain weather conditions – lead to health threatening living conditions in some parts of a city. Although filter technologies in the industry, an update of the car fleet and further investments in public transport might alleviate some of these effects they are for manifold reasons often not very easy to implement. Therefore, this paper tries to assess already existing and potential possibilities to consider potential emission hot-spots already during the process of planning urban extensions, specifically new living quarters. As a result, this investigation draws upon experiences that have been made in cities worldwide but specifically in Ust-Kamenogorsk, Kazakhstan.

Keywords: modelling; air pollution; environmental monitoring

1 Interrelations of Land Use and Transport

As land is one of central to the lives of people, we need to be working to secure land tenure for us, while implementing a plan for the sustainable development and environment protection [1]. Industrialization, increased intensity of land use and technological changes has had adverse environmental consequences. Land use is a dynamic process [2, 3]. Land resources are constantly undergoing quantitative and qualitative changes associated with the impact of various natural and man-made processes. Effective land use management means organized land use adapted to economic, social, and, of course, environmental conditions [2, 3]. There are two concepts in the practice of land use: rational and optimal land use. Optimal land use and development assume the use of the maximum functional potential of the land, which is possible in specific environmental conditions, at minimum cost, without negative consequences. Practice shows that the implementation of this approach is unlikely, since any intrusion into the environment, even if it leaves no visible traces, leads to a change in the natural situation.

Different land-use participants can bring conflicts between the goals of urban development and life, ecological protection and production (Figure 1). McHarg was the first who proposed the ecological evaluation based on GIS in 1960s [4]. He developed the "pastry mode" of land suitability assessment [4]. A landscape evaluation model on behalf of conservation planning ideas was developed by Steinitz in 1990s [5] and by Aljoufie M. in 2020s [6].

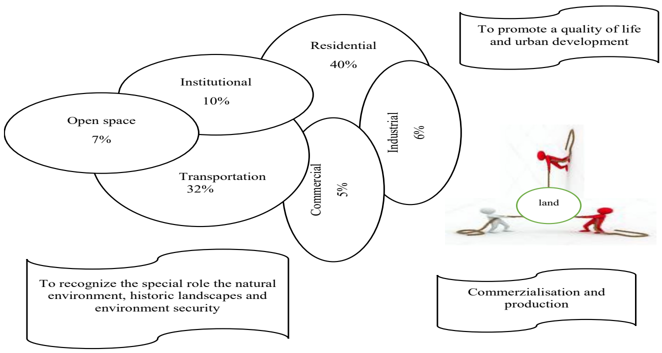

Figure 1
Urban land use types

The problem of information and software support of atmospheric air monitoring in large industrial cities is one of the most urgent for today. The main polluters are the enterprises of non-ferrous and ferrous metallurgy, motor transport, heat and power plants. It is necessary to attract modern automated tools and systems that allow to analyze the received data quickly, predict adverse environmental situations and visualize the obtained and predicted data on the map using GIS technologies to solve this problem. According to the development goals of land use management, urban land use types can be divided into residential land, industrial land, transportation, and so on (Figure 1).

The main goal of this study is to improve environmental safety by developing information and software support for estimation the current condition and forecasting the development of an environmental situation that meets the need to automate the collection and processing of reliable, scientifically grounded and consistent information about the condition of the environment, depending on the organization of traffic.

It is necessary to solve the following tasks to achieve this goal:

- to estimate the current condition of information technology use for solving environmental monitoring problems;
- to formalize the natural-man-made system and its conditions from the position of describing complex systems;
- to develop a method for identifying the conditions of ecological sustainability of the transport system;
- to develop a model for the classification of conditions for the environmental sustainability of the transport system to identify the critical - the condition of an emergency situation;
- to build an information model of the subject area, containing a description of objects and subjects of monitoring;
- to provide visualization of evaluation results using GIS, as well as issuing recommendations for a particular condition,
- to prepare recommendations of land use taking into account environmental safety (public transport traffic organization, road markings, installation of additional road signs, etc.).

2 External (Societal) Effects of Transport

In recent years, the development of transport infrastructure in large cities has led to the fact that the process of movement began to occupy a significant part of the time [18, 5]. People usually choose the route, type of transport, thus, the features of pollutants. Movement can occur under different weather conditions, which affects the perception of the body, however, Thus, passengers can choose the route depending on the busy streets, depending on how they move inside the vehicle and, therefore, adjust microclimatic conditions. Thus, a set of durations affects all levels of exposure. The state of a person is based on the mutual influence of external, internal and social factors. Factors operating in the country can distinguish three main groups. External factors determine the complexity of the route. Social status meansthe place of a person in the society. Internal factors determine the body's response to harmful effects. Human exposure to harmful substances can be determined using direct and indirect methods. Direct methods require detailed personal data. Space methods are less labor intensive and are enclosed in measurements in microenvironment. All people in different microenvironment can communicate with people. In such cases, time and behavior can be used for microenvironment. The main migrations in large urban agglomerations are "pendulum migrations", associated with daily movements to and from work, from suburbs to cities and back, etc.

The social impact of transport and the distributional effects across various segments of society have traditionally been viewed as secondary or even tertiary concerns relative to the economic and environmental impact [7, 8, 9].

Social impact: presence of Infrastructure, presence of parked vehicles, presence of transport facilities, services and activities (accessibility) such as transport facilities; availability and physical access; level of service, etc. Social factors characterize the composition of the population and the characteristics of their life. Environmental factors determine the individual state, elapsed time and qualitative levels of the impact of the polluted environment on the population. Accounting for technical factors provided information allowing to quantify harmful levels of exposure. Table 1 presents indicators that take into account the above factors.

Table 1

Indicators for assessing the harmful effects on the population. Source: Black, W. [10]

Factors	Indicators
social	status (student, working, retired), movement group (gender, age) preferences (sports (physical education), occupation (working conditions)
ecological	condition (complaints of heart, discomfort of movement) bad habits (smoking) exposure time (distance, elapsed time) exposure level (street type, distance, smoking of fellow travellers)
technical	mode of transportation (type of transport) (by car, bus, tram, on foot) car emission characteristic (type, year of manufacture, mileage) admission (ventilation mode, change of ventilation mode, type of movement (on foot or car), frequency of movement, duration of movement)

For example, Hamburg and Göteborg. Hamburg (Germany). Population: 3.4 million inhabitants. HVV land area: 8.7 km^2. Passengers of public transport (2009): 656 million. The city of Hamburg approved an ambitious plan (1998-2021) to reduce emissions of pollutants: more than 300 measures relate to the growth of public transport and the increase of its modal share.

The city of Hamburg was awarded the title "European Green Capital 2011" (Figure 2).

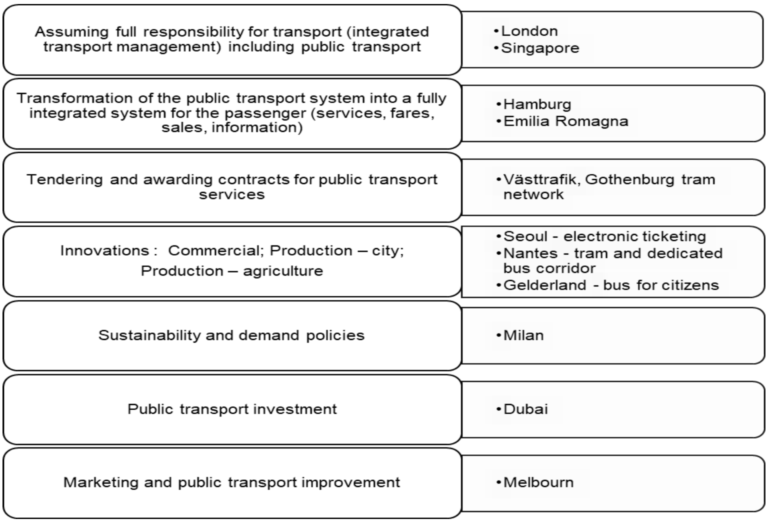

Figure 2

World successful practice in transport planning, Source: Statistical data

Managing Authority: HVV- Authority dei trasporti di Amburgo. Founded in 1965, the HVV is responsible for coordinating and fully integrating the dense urban public transport network (bus, metro, S-Bahn, regional railway and ferry lines. Hamburg includes ten municipalities (one of them is the city of Hamburg), HVV coordinates services 31 carriers (contracts are partially awarded through a public tender and partially - directly).

3 Monitoring and Modelling Air Pollution by Transport

Considering the issue of the formalization of the state of an industrial city atmosphere for effective monitoring, it is possible to take as a basis the "main ecological paradigm", i.e. the concept of an ecosystem [11, 12], hence the recognition of the need for a systems approach [11, 12, 13]. The description of any complex system consists of three components: morphological, functional and informational [11, 12, 13].

3.1 Morphological Description of the State of the Atmosphere of an Industrial City

The morphological description gives a complete picture of the composition of the system, which is described by the four finite sets:

$$S_M = \{ \Sigma, Vr, \sigma, K \} , \qquad (1)$$

where $\Sigma = \{ \Sigma_i \}$ – set of elements and their properties; $Vr = \{ Vr_i \}$ – set of relations; σ – structure; K – composition. The set of elements is a set of subsystems into which the morphological description no longer penetrates. The elemental composition contains the same type and different types of elements of different nature.

3.2 Informational and Functional Description of the Natural and Man-Made System

For each element of the private subsystem and the entire system as a whole, the functionality is defined by a set of morphological description X parameters (including external influences), a numerical functional n_z evaluating the quality of the system, and some mathematical operator of a deterministic or stochastic transformation ψ determining the relationship between the input X state and the state n_z output:

$$n_z = \Psi (X) \qquad (2)$$

As can be seen from the above scheme of principles of complicating behavior, the response function n_z of the subsystem of the upper level depends on the functions describing the internal processes of the subordinate subsystems [1, 3].

It is customary to distinguish from the general theory of modeling physical systems five groups of parameters from the point of view of the method of their use in models:

– input parameters - $V = (v_1,v_2,\ldots,v_k)$, the values of which can be measured, but there is no possibility of impact on them (as applied to the model of the atmospheric air monitoring ecosystem, for example, meteorological conditions);

– control parameters - $U = (u_1,u_2,\ldots,u_r)$, with which it is possible to have a direct impact in accordance with certain requirements, which allows to control the system (these include a number of measures to establish the optimal operation modes of enterprises);

– disturbing (stochastic) effects - $\xi = (\xi_1, \xi_2,\ldots, \xi_l)$, the values of which randomly change over time and which are inaccessible for measurement, creating dispersion of unaccounted conditions or background noise;

– state parameters - $\boldsymbol{X} = (\boldsymbol{x_1}, \boldsymbol{x_2}, \ldots, \boldsymbol{x_n})$ - a set of internal parameters, the instantaneous values of which are determined by the current mode of functioning of the ecosystem and, ultimately, are the result of the total impact of input, control and disturbing factors, and the mutual influence of other intrasystem components;

– output (target or resultant) parameters - $\boldsymbol{n_z} = (\mathbf{z_1}, \mathbf{z_2}, \ldots, \mathbf{z_m})$, $z_k \in Z$, $k=1,n_z$ - some specially selected state parameters (or some functions from them) that are the subject of study (modelling, optimization) and are used as a criterion for the "well-being" of the entire ecosystem.

Disturbing factors can have both external and internal nature. Assuming that ecosystem parameters are related by some functional relations, which in the synthesized model are expressed by a set of equations of different mathematical nature (algebraic, logical, differential, finite difference, matrix, statistical, etc.), the expression can be written as:

$$\boldsymbol{n_z} = \boldsymbol{\Psi}(\boldsymbol{X}, \boldsymbol{U}, \boldsymbol{V}) + \boldsymbol{\xi} \tag{3}$$

Any ecosystem is a dynamic object, therefore, the equation of the static model (3) must be supplemented by a set of points in time $\boldsymbol{T}$, for which the instantaneous values of variables are measured. Since ecosystems also belong to objects with distributed parameters, whose components can change not only in time, but also in space $\boldsymbol{S}$, the general equation of the ecosystem model takes the form:

$$\boldsymbol{n_z} = \boldsymbol{\Psi}(\boldsymbol{X}, \boldsymbol{U}, \boldsymbol{V}, \boldsymbol{T}, \boldsymbol{S}) + \boldsymbol{\xi} \tag{4}$$

3.3 Input Parameters

Climate and meteorological conditions can be attributed to input parameters - $\boldsymbol{V} = (\boldsymbol{v_1}, \boldsymbol{v_2}, \ldots, \boldsymbol{v_k})$: v_1 - time of a year, v_2 - time of a day, v_3 - wind speed, v_4 - wind direction, v_5 - the degree of vertical stability of the atmosphere, v_6 - air temperature, v_7 - relative humidity.

3.4 Control Parameters

Consider the control parameters - $\boldsymbol{U} = (\boldsymbol{u_1}, \boldsymbol{u_2}, \ldots, \boldsymbol{u_r})$ of the ecosystem, which include the choice of operating mode of enterprises that contribute to the formation of the atmospheric air composition. Emissions of harmful substances into the atmosphere during the day can be considered a set of stationary random processes, each of which has its own distribution function f(t) [1, 3]. The stationarity of a random process is a consequence of the homogeneity of the process in time. It is true for a stationary process:

$$w_\xi(x_1;\ldots;x_n;t_1+\tau;\ldots t_n+\tau) = w_\xi(x_1;\ldots;x_n;t_1;\ldots t_n) \tag{5}$$

3.5 Disturbing Effects

As a disturbing (stochastic) effect – $\xi = (\xi_1, \xi_2, \ldots, \xi_n)$ – on the state of the atmospheric air, we consider the influence of motor vehicles. Automotive exhaust gases are a mixture of about 200 chemical elements and compounds. At present, it is considered that the main harmful components of exhaust gases are carbon monoxide, hydrocarbons and nitrogen oxides. The effects on the human body components of exhaust gases are divided into:

- ξ_1 - toxic - carbon oxide, nitrogen oxides, sulfur oxides, hydrocarbons, aldehydes, lead compounds;
- ξ_2 - carcinogenic - benz (a) pyrene;
- ξ_3 - irritant - sulfur oxides, hydrocarbons.

When analyzing the concentrations of impurities from stationary sources, the highest concentrations of the detected impurities are observed in the area of highways with heavy traffic, including - on Nezavisimost Avenue and, especially, at the node at the Palace of Sports. Of the 40 analyzed samples of the ξ_1 group, 68% exceeded the maximum one-time maximum permissible concentration of carbon monoxide, 20% - by suspended particles, 5% - by nitrogen dioxide. Also, the impact of vehicles on air pollution is a disturbing parameter during peak hours to create an unfavorable environmental situation. Determination of the intensity of the motor transport flow on the city's transport network. The study of calculation the amount of pollutants emissions on the nodes and links, on the road network of the city from motor vehicles is based on data on the intensity of the traffic flow. Figure 3 shows a cartogram characterizing the intensity of traffic flows (in cars per hour) on the main streets of Ust-Kamenogorsk city in the East Kazakhstan region.

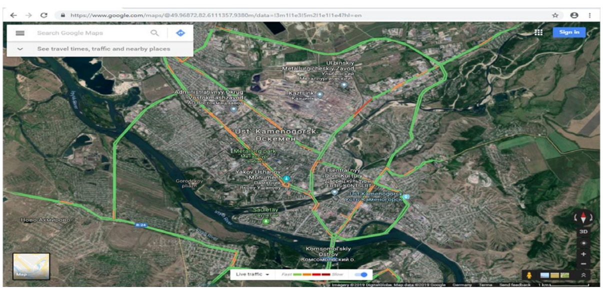

Figure 3
Cartogram of the average daily intensity of traffic flows in the city of Ust-Kamenogorsk, East Kazakhstan region. Source: Google map, Ust-Kamenogorsk

The intensity of the traffic flow (traffic) N_a is the number of vehicles passing through the cross-section of the road per unit of time. Year, month, day, hour and shorter periods of time (minutes, seconds) depending on the task of observation and measuring instruments are taken as the estimated time period for determining the intensity of movement. It is possible to distinguish individual sections and zones on the road network of the city, in which traffic reaches its maximum size, as well as other sections where at the same time it is several times smaller. This spatial unevenness reflects the uneven placement of cargo and passenger-forming points and their places of attraction. The composition of the traffic flow is characterized by the ratio of different types of vehicles in it.

The composition of the traffic flow also affects the loading of streets and roads, which is primarily explained by the significant difference in the overall dimensions of the vehicles. For example, the length of passenger cars is 4-5 m, freight 6-8 m, the length of buses reaches 11 m, road trains - 24 m. Therefore, when driving in traffic, the concept of the dynamic size of a car is important, which depends mainly on the driver's reaction time and brake qualities of vehicles. The dynamic dimension L_∂ of a car in a dense traffic flow (Figure 4) means the road section that is minimally necessary for the safe movement of a car in a traffic flow at a given speed, the length of which includes the length of the car L_a and distance d, called the safety distance.

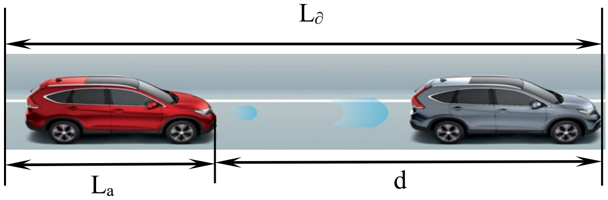

Figure 4

The dynamic dimension of the car in heavy traffic. Source: Pugachev, I. N. [14]

We can take the speed limit permitted in Traffic regulations of the Republic of Kazakhstan in populated areas (60 km/h) for estimation speed for a city highway. The baseline for determining the delay can be taken the normative speed of the message or the normative rate of movement for this type of road, if any. For example, if the estimated speed on the road is v_p = 60 km/h, which corresponds to a driving speed of 60 sec/km without delays, and the actual speed established by experienced testing v_f = 30 km/h (driving speed is 120 sec/km), then the loss of time each car in the stream is 60 sec/km. If the length of the considered section of the highway is, for example, 5 km, then the conditional delay of each car will be 5 minutes. Total loss of time for traffic flow:

$$T_\Delta = N_a t_\Delta T \qquad (6)$$

where t_Δ is the average total delay of one car (seconds); T is the duration of observation (hour), N_a is the number of vehicles passing through the cross-section of the road per unit of time.

Traffic delays in real conditions can be divided into two main groups: on the nodes of roads and on links. Delays on nodes can be caused by maneuvering or slow-moving vehicles, pedestrian traffic, interference from standing vehicles, including during loading and unloading operations, as well as congestion associated with road glutting vehicles. Thus, we determined the characteristics of the state of traffic, the necessary data characterizing the traffic flow and the city's road network to simulate the spread of emissions of harmful substances from urban vehicles: traffic flow intensity, its composition by vehicle type, traffic density, traffic delays, length and the capacity of main streets and public roads. As the estimated speed for the city highway, we have adopted the allowed speed limit in populated areas: 60 km/h [14-16].

We propose to consider an assessment of the amount of energy and environmental impact of road traffic flows on the street and road network of Ust-Kamenogorsk, East Kazakhstan Region. It is assumed that the entire fleet of vehicles participates in the traffic flows, which is evenly distributed along the road network. Consider the entire city and the city's road network as a graph (crossroads (nodes) are vertexes, links are ribs). The graph edge has the following characteristics: the length, the number of lanes, the speed limit, the load and the presence of traffic lights. There are three categories of roads in one direction in Ust-Kamenogorsk: three-lane (Nezavisimosti Ave., Abay Ave, etc.), two-lane (Potanin St., Burov St., etc.), single-lane (Figure 5).

Figure 5

Map of Ust-Kamenogorsk city presented in the form of vertexes of the graph

It was analysed the state of the city's motor transport flows on the basis of data obtained from the Administrative Police Directorate of the Department of Internal Affairs of the East Kazakhstan region on August 1, 2018 to simulate the process of air pollution by motor transport (Table 2).

Thus, the total number of public transport is 2269 units, the total number of cars in the city of $M_{a.n.}$ = 100,400 units. The total length of the street transport network in the lanes L_d = 820.354 km.

We assume that the composition of automobile park is homogeneous, consisting of cars with gasoline engines, the average length of one car is L_{car} = 5 m (Table 2).

Table 2
Data on registered motor vehicles in Ust-Kamenogorsk (August 01, 2018) Source: Statistical data

Vehicle type	Number of registered vehicles, units		Total
	individuals	legal entities	
Passenger cars	81947	7654	89601
Trucks	3509	5021	8530
Buses	959	1310	2269
Motorcycles	1928	38	1966
Trailers	3809	1510	5319

We assume that the composition of automobile park is homogeneous, consisting of cars with gasoline engines, the average length of one car is L_{car} = 5 m.

Determine that the maximum density of traffic flows on one lane is equal to *Pmax* = 140 auto per km, where l = 5 is the length of one passenger car, d = 2 is the distance between cars. As a justification of this assumption, we note a significant part of the cars that make up the automobile park of Ust-Kamenogorsk city.

We propose to consider the hypothetical possibility that all vehicles of the city move around the city during the day, filling the transport network. Then, the average density of all vehicles of the city on the transport network with a uniform distribution is equal to *p* = 122,386 auto per km.

It is possible to determine the average speed of vehicles in busy and congested areas of the city having a state function. Since the intensity of traffic flows depends on the time of day, week, month and time of year, the time dependence should be considered. According to the calculations of the intensity of motor traffic flows over time during the day at the node "Palace of Sport" of Ust-Kamenogorsk, we determined the number of motor vehicles in the flows by field observation [16, 17].

The calculations carried out by field observation of vehicles at the main nodes of the city showed that the maximum number of motor vehicles exchanges fell on the "rush hour" in the period from 6:00 pm to 7:00 pm: 5,888 vehicles/hour. According to the "Methodological recommendation on the assessment of road capacity", developed by the autonomous non-profit organization "Institute for Movement Safety Problems", Moscow Automobile and Highway State Technical University (MADI), Irkutsk Technical University, Pacific University. "ROSDORNII", LLC "INEMDorTrans", it is recommended when calculating the throughput based on the value of the maximum practical throughput given in Table 3.

In addition, we analysed the data from a satellite interactive map using Google Maps online. On Google maps, the intensity of traffic flows is given in a four-color scheme from 06.00 to 22.00.

Table 3

Maximum practical throughput of traffic Source: Statistical data

Highways	Vehicles / hour
Two-lane	3600 in both directions
Three-lane	4000 in both directions
Four-lane without dividing strip	2100 on one lane
Four-lane with dividing strip	2200 on one lane
Six-lane without dividing strip	2200 on one lane
Six-lane with dividing strip	2300 on one lane
Highways with eight lanes	2300 on one lane

The user can determine by color the approximate number of vehicles. For example, green - traffic flow is free; orange - traffic flow with some interference; red - with slight delays; burgundy - delay. It was normalized four colors in the interval [0; 1] to process the results of data on the intensity of traffic flows on the map of Ust-Kamenogorsk. The example of results obtained on the dynamics of changes in the intensity of the traffic flow during the day on a map of Ust-Kamenogorsk for one day are shown in Figure 6 (a) color data b) approximate numerical data during the day).

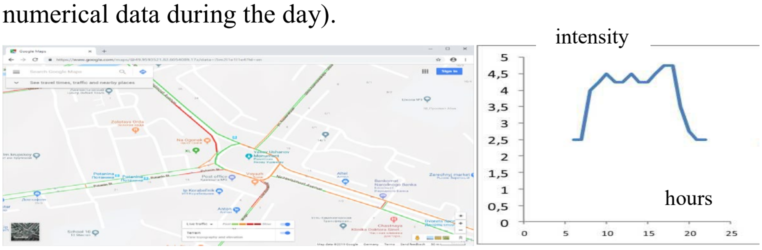

Figure 6

Dynamics of changes in the intensity of the motor traffic during the day on the area Ushanov square, Ust-Kamenogorsk. Source: Based on statistical data and used Google map

It is possible to calculate the total amount of emissions per day and per year given the intensity of vehicles during the day.

Thus, knowing the hourly intensity of traffic and speed of traffic on each route and intersections, it was calculated the power of emission of harmful substances from road transport for the period of the most busy traffic. Thus, an assessment was made of the energy and environmental impact of traffic on the environment of Ust-Kamenogorsk.

The obtained emission functions of harmful substances from several sources and a disturbing parameter form the resulting function F_{rez}:

$$F_{rez}(t) = \sum_{1}^{n} f_i(t) \times \prod\nolimits_{1}^{n} P_i(t) \qquad (7)$$

It is necessary to take into account the probability P(t) of the release value at a certain point in time to find the predicted release value, then the release value of a particular substance from a particular source will be determined by the formula:

$$Q(t) = \int_0^t f(t) \times P(t)\, dt \tag{8}$$

The exhaustive probabilistic description of random processes is the assignment of the distribution laws for any set of samples: the distribution function

$$F_\xi(x_1;\ldots;x_n;t_1;\ldots t_n) = P[\xi(t_1) \le x_1;\ldots\xi(t_n) \le x_n] \tag{9}$$

or an appropriately determined probability density $w_\xi(x_1;\ldots;x_n;t_1;\ldots t_n)$.

Equations 7 and 8 are new and it is our contribution based on principles of mathematical modelling and equation 9 based on the distribution laws for any set of samples.

It is constructed a variation series and find for each hour of observations the number of intervals, step, minimum and maximum values, for example, at 1 a.m. The criterion χ^2 confirms the hypothesis about the normal distribution with the parameters a and σ^2, where $\alpha \in R$, $\sigma > 0$, $\xi \in N_{a,\ \sigma^2}$, ξ has the following distribution density:

$$f_\xi(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-a)^2}{2\sigma^2}}, \quad x \in R \tag{10}$$

The following numerical characteristics are used: mathematical expectation, variance, covariance function, correlation function for an approximate description [18, 19, 20]. In the above calculations, the expectation is calculated by the formula:

$$m_{1\xi}(t) = M[\xi(t)] = \int_{-\infty}^{\infty} x w_\xi(x;t)dx \tag{11}$$

The confidence interval for the mathematical expectation of the general population was calculated with a significance level of 0.05. It is necessary to know the correlation function of a random process [21] to verify the condition of ergodicity, which is the result of the transformation of the research process.

$$K_\xi(t_1;t_2) = M[\overset{\circ}{\xi}(t_1)\overset{\circ}{\xi}(t_2)] = B_\xi(t_1;t_2) - m_{1\xi}(t_1)m_{1\xi}(t_2) \tag{12}$$

3.6 Status Parameters

The parameters of the state - $\boldsymbol{X = (x_1, x_2, \ldots, x_n)}$ - are estimated by changing the concentrations of harmful emissions in the atmospheric air over time, and by such characteristics as the depth and zone of actual contamination with a harmful substance. Let Conc = ($conc_{t1}$, …, $conc_{tk}$) - a set of concentrations of harmful substances, M_{usl} = (mu_{1t}, …, $mu_{ьt}$) - a set of parameters characterizing the meteorological conditions at time t. In general, changes in concentration over time can be written as an autoregressive model as:

$$\hat{Y}_t = const + A_i \times Conc_t + B_j \times M_{usl} + \hat{E}_t \quad (13)$$

where Ai, i = 0, 1…p, k × k is the coefficient matrix depending on the impurity, Bj – k × l is the matrix of weather condition coefficients, Et is the disturbing parameter, const is the vector of constants. It is considered as weather conditions [16, 18, 19, 20, 22]: v - wind speed, vlag - relative humidity and ust - vertical atmospheric stability, measured by the coefficients of M.E. Berlyand model.

3.7 Output Parameters

Pollution parameters are measured during a certain time interval with a given discreteness and are fed to the input of the model, according to which the prediction is carried out. Checking the presence of process deviations from the model is performed by monitoring the deviations of the process indicators from the existing model values: $\Delta_{j} = y_{tj} - y_{tj}^{m}$, where y_{tj} are the coordinates of the vector Y_t at the point t, y_{tj}^{m} are the corresponding values calculated from the model. Any extraordinary event is preceded by any deviations from the normal course of a process. The nature of the development of the event and its consequences are determined by the destabilizing factors of different origin. This may be a natural, anthropogenic, social or other effect that disrupts the functioning of the system.

Ecological monitoring system consists from several blocks: emissions from enterprises, transport and climate conditions. It is very useful for detecting emergency situation in the city. It is necessary to model harmful emissions transfer from transport, in detail, for effective urban land use and trabsport planning.

3.8 Probabilistic-Statistical Modeling of the Harmful Impurities Transfer in the Atmosphere from Motor Vehicles

The atmosphere is a complex dynamic and turbulent system, in which various dynamic and physicochemical processes take place. Random chaotic velocity pulsations in all directions at all points of the flow are characteristic, giving almost all occurring processes a stochastic character for the turbulent flow of the atmosphere. Chaotic pulsation motions result in random, intensive mixing and specific turbulent diffusion, significantly exceeding the molecular, turbulent viscosity of a gas, more uniform distribution than the laminar flow, averaging velocity distribution and its sharp drop in the near-wall area, a sharp increase in friction losses. The impurity particle can move along with the air flow or under the influence of external forces in the atmosphere, and through turbulent diffusion under the influence of turbulent pulsations of the atmosphere. Accordingly, the trajectory of the impurity particles can be considered a total random path: any of its coordinates at any time can be represented as the sum of deterministic and random components:

$$x(t) = \int_0^t u_x(t)dt + x'(t)\,, \qquad (14)$$

where *x(t)* is the projection of deterministic velocity, m/s; *x'(t)* is a random process.

If we consider the motion of an impurity particle as a sequence of spasmodic displacements of length h over short periods of time Δt in one of six possible directions in the orthogonal coordinate system xyz, then the motion path will be three-dimensional broken line, and the direction of motion will be determined at each time point by the corresponding probabilities p_i.

The probabilities of each direction will be P_{+x}, P_{-x}, P_{+z} and P_{-z}. The sum is equal 1. (Figure 7).

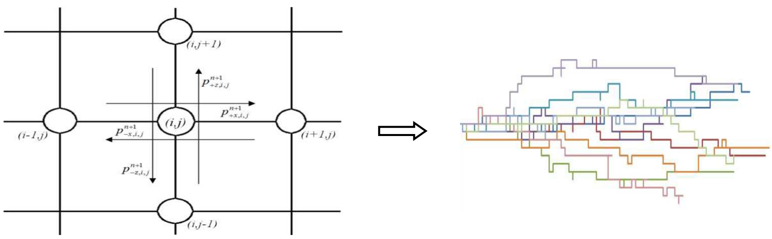

Figure 7

Particle transition schemes and a variant of calculating the possible trajectories of ten particles in a turbulent flow, (10 x 100 steps). Source: A result of modeling

Using the above-described probabilistic statistical model with known values of probabilities d, and a random number generator, respectively, the results of calculating options for possible trajectories of one and ten impurity particles in a turbulent flow are shown).

However, this approach makes it difficult to calculate when there are many sources and volumes of harmful substances. At any time, each particle can be in one of these grid nodes and each of these positions can be considered a possible state of a particle at a time with the corresponding probability *P(i,j,t)* (*i, j* – the number of grid nodes).

Presumably at each time point $t + \Delta t$, in the position (i,j), the probable direction of transition of the particle $P_{l,i,j}{}^{n+1}$ $(l=+x,-x,+z,-z)$ is determined, and accordingly, what flows in is added, and what follows is taken away (Figure 7).

According to Figure 8, the distribution of nitrogen dioxide from a complex node Ushanov Square, is considered with low wind as of 17-00 local time. The areola of impurity distribution are highlighted in different colors, taking into account the concentration.

The composition of attribute and spatial information is the implementation of a grid function on a plane with a constant step Dx horizontally and a constant step Dy vertically. The use of the grid function $q_{ij}=f(x_i,y_j)$ in interpolation procedures is generally accepted and is associated with a number of methodological advantages. It combines the convenience of storing the information received, the possibility of its statistical processing and mathematical transformation of the future map, as well as the ease of implementation of the procedures for constructing isolines (in the form of a broken line) and interval regions according to the values of interpolating functions in the grid nodes (Figure 8).

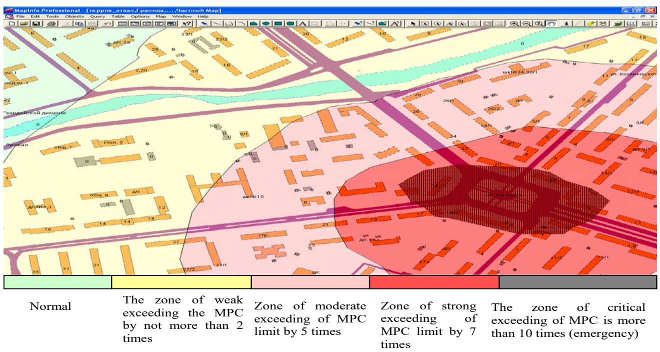

Figure 8

Distribution of nitrogen dioxide from Ushanov Square. Source: A result of modeling

When visualizing the simulation results for the construction of a grid in geographic information systems, Delaunay triangulation is used. After the application of isolines of impurity concentrations, it can be noted that there are areas on the map in which the excess concentration of impurities according to the criteria for identifying emergencies described in stage 2 is critical (emergency), despite the general “well-being” of the nature-man-made system state. Based on the results obtained, zones with a critical state of atmospheric air are selected at the boundaries of the critical impurity concentration. The topographic basis for building a map of Ust-Kamenogorsk city is the map obtained on the website of the Brief Research Group http://www.brif.kz/service/geoinformation_system.php. On a topographic map, the zone of possible contamination has the form of a circle, semicircle or sector with a wind speed forecast to be less than 0.5 m/s. 0.6-1 m/s and more than 1 m/s, respectively [16, 18, 19, 20].

After the calculations, a graph of the concentration distribution from the source is plotted, then the data obtained is visualized by plotting the concentration field in accordance with Figure 9.

In Figure 9, a carbon dioxide concentration field is plotted with an indication of the concentration excess values as compared to the MPC in fractions. The distribution of impurities is displayed on the map as concentration circles with centers in emission sources, which facilitates visual perception.

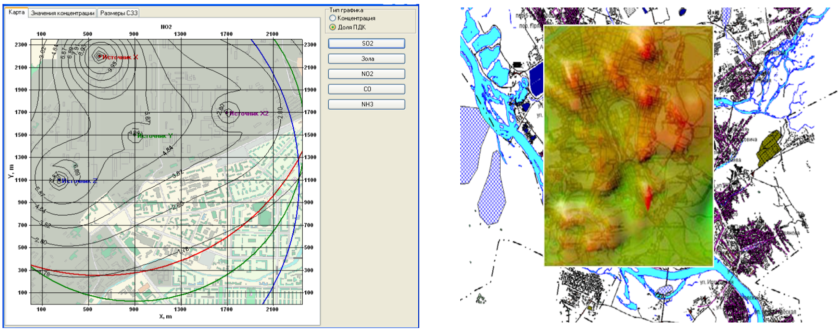

Figure 9

The “Concentration Field” window Three-dimensional map of the impurities distribution from multiple sources. Source: The result of visualization

You can also see the boundary isoline of the influence of each source on the formation of the field of impurity concentrations in the city as a whole [20]. When constructing a concentration field, it is possible to display in fractions of the MPC, which in some cases is more visual. The information presented in Figure 9 in the form of concentration isolines can be displayed by means of GIS technologies in the form of filled polygons, the color of which corresponds to the level of impurity concentration. In the places where impurity polygons overlap from several sources, the concentration level rises. The concentration reaches its highest value in the area of the source of pollution - for example, this is a complex node at peak hours. The negative impact on the public health is discussed in detail in the research [20]. With the help of GIS technology, it can be determined which buildings and institutions fall into an unfavorable zone at certain hours or are permanently in it. This information can be especially relevant for children's and health-improving institutions, such as kindergartens, schools, hospitals. GIS technologies make it possible to build three-dimensional maps of the distribution of impurities according to Figure 9.

After modelling and finding the places with harmful impact on people it is possible to prepare recommendations for effective land use including transport planning.

Common recommendations [22-26] are included in the strategy of sustainable development Ust-Kamenogorsk city of the Republic of Kazakhstan:

- Remove kindergartens, schools, hospitals and other official buildings in so-called good ecological zones.
- Reorganize and rebuild ecological-emergency areas.
- Decrease the negative impact of industry.
- Organize sustainable city transport system.

Kazakhstan residents, like most residents of modern cities, need more mobility and convenience from public transport in order to carry out daily door-to-door movement in the city with maximum comfort. Integration and an integrated approach should become the cornerstone of the transport life of the city, first of all, when a passenger uses different types of transport (inter-modality). As the research shows, the development of bicycle infrastructure can significantly change the transport habits of Kazakhstan residents in favor of increasing the share of sustainable transport and reducing the number of personal cars on the roads.

Conclusions

We can indicate following results of the work.

It was estimated the current condition of information technology use for solving environmental monitoring problems.

It was formalized the natural-man-made system and its conditions from the position of describing complex systems. We presented our own formalization on the bases of morphological, informational and functional description.

We proposed our own model for the classification of conditions for the environmental sustainability of the transport system to identify the critical - the condition of an emergency situation.

It was provided visualization of evaluation results using GIS (software was developed), as well as issuing recommendations of land use taking into account environmental safety for a particular condition.

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References

[1] Scholz M., Hedmark A., Hartley W.: Recent advances in sustainable multifunctional land and urban management in Europe: a review. J. Environ. Plann. Manag., 55, 2012, pp. 833-854

[2] Li X. B.: Core of global environmental change research: frontier in land use and coverage change, Acta Geog. Sin. 51, 1996, pp. 553-558

[3] Vitousek P. M., Mooney H. A., Lubchenco J., Melillo J. M.: Human Domination of Earth's Ecosystems. In: Marzluff J. M. et al. (eds) Urban Ecology, 2008, Springer, Boston, MA, pp. 3-13, https://doi.org/10.1007/978-0-387-73412-5_1

[4] McHarg I.: Design with Nature, Natural History Press, New York, 1969

[5] Steinitz C.: A framework for theory and practice in landscape planning, GIS Eur., 1993, pp. 42-45

[6] Aljoufie M.: Toward an effective analysis of public transportation demand factors in car-dependent cities: case of Makkah City, Saudi Arabia, Urban, Planning and Transport Research, An Open Access Journal, Volume 9, 2021, Issue 1, pp. 258-276

[7] Geurs K.: Social Impacts of Transport: Literature Review and the State of the Practice of Transport Appraisal in the Netherlands and the United Kingdom Transport, Reviews 29(1), January 2009, DOI: 10.1080/01441640802130490

[8] Schiefelbusch M.: Rational planning for emotional mobility? The case of public transport development, Planning Theory, Technische Universität Berlin, 2010

[9] Theis T.: What is Sustainability? In T. Theis, & J. Tompkins, Sustainability: A Comprehensive Foundation. Houston: Connexions. Retrieved October 1, 2012, from http://cnx.org/content/m41188/1.7/

[10] Black W.: Sustainable Transportation: Problems and Solutions. New York: Guilford Press, 2010

[11] Bernstein J., Szuster B. W.: The new environmental paradigm scale: Reassessing the operationalization of contemporary environmentalism, The Journal of Environmental Education, Volume 50, 2019, Issue 2, pp. 73-83, https://doi.org/10.1080/00958964.2018.1512946

[12] Fedorov V. D.: Notes on the paradigm in general and the environmental paradigm in particular, Vestnik MSU, biological series, № 3, Moscow, 1977, pp. 8-22

[13] Khailov K. M.: "Life" and "Life on Earth": two scientifical paradigms, General biology journal, T. 59, № 2, Russia, 1998, pp. 137-151

[14] Pugachev I., Kulikov Y., Cheglov V.: Features of traffic organization and traffic safety in cities, Transportation Research Procedia, Volume 50, 2020, pp. 766-772, ISSN 2352-1465, https://doi.org/10.1016/j.trpro.2020.10.089

[15] Rajczyk P., Evtiukov S. New technological solutions in improving road safety, Transportation Research Procedia, 36, 2018, pp. 649-653, DOI: 10.1016/j.trpro.2018.12.133

[16] Repin S., Evtiukov S., Maksimov S. A method for quantitative assessment of vehicle reliability impact on road safety, Transportation Research Procedia, 36, 2018, pp. 661-668, DOI: 10.1016/j.trpro.2018.12.128

[17] Lukanin V. N. Buslaev A. P., Yashina M. V.: Road traffic and the environment, International journal of vehicle design, № 3, Interscience online Journal, 1998

[18] Berlyand, M. E.: Prediction and Regulation of Air Pollution, Springer, 1991, Volume 14, 312 p.

[19] Genrikhovich E.: Air Pollution Modeling and Its Application XII, Springer, 1998, 723 p., DOI: 10.1007/978-1-4757-9128-0_84

[20] Shvets O., Bugubayeva A., Rakhmetullina S., Wojcik W.: Development of intelligent information system of assessing the negative impact of industrial emissions on the public health, Journal of Theoretical and Applied Information Technology, Vol. 99 (15), August 2021, pp. 3737-3752, http://www.jatit.org/volumes/ninetynine15.php

[21] Matveev Yu. L.: Function and density distribution of pollutants and air temperature, Optics of the atmosphere and the ocean, T. 7, № 2, Russia, 1994, pp. 244-249

[22] Helmut E.: Landsberg. City climate, Hydrometeoizdat, Leningrad, 1983, 248 p.

[23] Low N.: Is Urban Transport Sustainable? In Making Urban Transport Sustainable, New York: Palgrave Macmillian, 2003, pp. 1-22

[24] Lee S., Lee M., Chun Y., Griffith D: Uncertainty in the effects of the modifiable areal unit problem under different levels of spatial autocorrelation: A simulation study, International Journal of Geographical Information Science, 33(6), pp. 1135-1154, https://doi.org/10.1080/13658816.2018.1542699

[25] Chen Y., Bouferguene A., Li H., Liu H., Shen Y., & Al-Hussein M.: Spatial gaps in urban public transport supply and demand from the perspective of sustainability, Journal of Cleaner Production, 195, pp. 1237-1248, https://doi.org/10.1016/j.jclepro.2018.06.021

[26] Chamseddine Z., Asmaa Ait Boubkr: Exploring the place of social impacts in urban transport planning: the case of Casablanca City, Urban, Planning and Transport Research, Volume 8, 2020, Issue 1, pp. 138-157, https://doi.org/10.1080/21650020.2020.1752793