MODELING OF THE ECOLOGICAL CONDITION OF THE LARGE CITIES ROAD NETWORK

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Abstract

The purpose of current article is to demonstrate the method of mathematical model creation for environmental monitoring at the crossroads. This mathematical model can be used in intelligent transport systems (ITS). The basic parameters for the mathematical model are selected basing on the knowledge structuring in the field of the road network (RN) environmental monitoring. Knowledge structuring about environmental contamination simplifies and demonstrates the choice of the mathematical model basic parameters for RN environmental monitoring. The mathematical model can be implemented by using the cellular automata (CA) theory. The method of creating the RN ecological condition modelling module, which can be used in ITS, is shown on the particular example. The knowledge structuring method in the field of RN state environmental monitoring and its implementation with help of the CA theory are suggested.

Keywords: environmental; monitoring; model; road; traffic

1. Introduction

Recently the extensive growth of the vehicles number in large cities have been observed, which leads to the road network overload. It aggravates issues linked to the organization and safety of traffic, urban ecology and citizens' health. The right ways of solving such problems are not always easy to find due to the fact that there is no single comprehensive approach to the problem of large cities' traffic. The use of vehicles creates controversy – meeting people's needs in vehicles and, at the same time increasing the negative impact of vehicles on the environment.

Great environmental, economic and social losses are caused by the traffic noise, traffic accidents and pollution of air, water and soil and by exhaust fumes. Today the motor transport is one of the largest sources of air pollution, the ratio of which in some cities of Ukraine has achieved (50-90)% of the pollution level and traffic jams in city centers have become a commonplace [3].

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The timeliness of the problem is confirmed by current legislation concerning environmental protection and air. Traffic and environmental safety precautions and constant development of communities require improving of transport and environmental infrastructure.

2. Worldwide experience

Researchers determine the interdependence between the individual emissions and traffic flow parameters (structure, vehicles age and traffic intensity) [7], taking into account the load flow peak [2, 5], and consider the ways of street's pollution reduction [1]. The ways of environmental pollution reduction on pedestrian paths for different traffic scenarios are studied separately [8], and the noise impact caused by the influence of transport on the environment and the possibility of its lowering by the selection of the street area buildings elements parameters [9] are researched as well. The traffic flows organization study using Intelligents Transport Systems [12, 16] is still valid, and the definition of pollution emissions from traffic on the whole country scale as well [19].

The ways of such an improvement underlie in the improvement of the RN and traffic planning and organization of traffic in accordance with sanitary-hygienic standards concerning the public protection from excessive noise exposure and chemical pollution; development of methods of monitoring and control of exhaust emissions and intensity of traffic, especially in large cities. Furthermore, the creation of transport and environmental monitoring is also extremely important.

The development of intelligent transportation system, which combines the latest technology in communication, computer technology, artificial intelligence and simulation techniques is considered as the implementation of this direction [11, 20, 21]. Such system will also allow to use information on the city ecological condition for the benefit of educational activities and promotion of ecological culture of the population.

The creation of ITS-based on local automated traffic management systems, using simulation modeling to resolve specific traffic situations, should be taken as a basis. The development of automated traffic management along with the development of a comprehensive traffic scheme in large cities refers to the set of high priority measures in this direction.

3. Research

To determine the basic input parameters it is necessary to specify the range of options and select those ones that will be used to model the RN ecological condition.

A module of modeling the RN ecological condition can be one of the components of ITS. On the one hand, his module may specialize on monitoring pollution and, on the other hand, it may have the ability to simulate the current condition based on the input parameters, which are changed online.

The module of simulating the RN ecological condition can function on the basis of the method of term-by-term disjunction. The essence of the method of term-by-term disjunction is that a sampling of elements that have common features and properties is transformed on the basis of a specified criterion. The disjunction of two statements is called a new statement, which is true if and only if at least one of these statements is true. From a sampling of objects that may have common features and properties, and in general, combine with each other by a combination of features, you can select those objects that have a common property or a criterion.

The method of term-by-term disjunction is used to form the characteristics and properties of the RN. This is done on the basis of the initial information about the RN and the peculiarities of its functioning. It is also advisable to use the method of term-by-term disjunction for the formation of the RN structure on the basis of typical elements, which RN usually consists of.

To do it we will write the structure graph of knowledge about such environmental pollution in the RK elements like intersections and parking. The total set of knowledge contains subsets that structure general knowledge due to features.

We mark r_1 = intersection; r_2 = parking. They form the set – "The complex of features" $R = \{r_i\}$. The subset "Features" $U = \{u_i\}$ has 3 items – the values of attributes that are i = 1,... 3, where u_1 = air; u_2 = ground; u_3 = water. The subset "Characteristics of features" $L = \{l_i\}$ has 4 items – values of features' characteristics such as i = 1,... 4 where l_1 = thermal pollution; l_2 = vibration (noise) pollution; l_3 = electromagnetic pollution; l_4 = components of pollution in the environment.

We introduce a sufficiently well-defined set $Q = \{q_i\}$ of knowledge areas q_i, i = 1,... 11 that is:

$$Q=\{qi\}, i=1,...11 \quad (1)$$

In this case it is possible to create a paradigmatic table that reflects the relation between the localization of knowledge q_i and subject variables l, u, r can be built (Table 1).

Tab. 1. Relation between localization of knowledge q_i and subject variables l, u, r

Set of features	Features	Characteristics of feature	Areas of knowledge localization
r_1 (intersection)	u_1 (air)	l_1 (thermal pollution)	$q_1 = r_1 u_1 l_1$
r_1 (intersection)	u_1 (air)	l_2 (noise pollution)	$q_2 = r_1 u_1 l_2$
r_1 (intersection)	u_1 (air)	l_3 (electromagnetic pollution)	$q_3 = r_1 u_1 l_3$
r_1 (intersection)	u_1 (air)	l_4 (components of pollution in the environment)	$q_4 = r_1 u_1 l_4$
r_1 (intersection)	u_2 (soil)	l_2 (noise pollution)	$q_5 = r_1 u_2 l_2$
r_1 (intersection)	u_2 (soil)	l_4 (components of pollution in the environment)	$q_6 = r_1 u_2 l_4$
r_1 (parking)	u_3 (water)	l_4 (components of pollution in the environment)	$q_7 = r_1 u_3 l_4$
r_2 (parking)	u_1 (air)	l_1 (thermal pollution)	$q_8 = r_2 u_3 l_1$
r_2 (parking)	u_1 (air)	l_2 (noise pollution)	$q_9 = r_2 u_1 l_2$
r_2 (parking)	u_1 (air)	l_3 (electromagnetic pollution)	$q_{10} = r_2 u_1 l_3$
r_2 (parking)	u_1 (air)	l_4 (components of pollution in the environment)	$q_{11} = r_2 u_1 l_4$

In this table the area of knowledge localization: thermal pollution of the air at the crossroads $q_1 = r_1 u_1 l_1$. Air pollution by emission components (fumes, dust) at the intersection $q_4 = r_1 u_1 l_4$. Noise pollution of the air at the parking lot – $q_9 = r_2 u_1 l_2$.

The localization of knowledge q is expressed in terms of the value of subject variables r, l, u as follows:

$$\begin{aligned} & r_1 u_1 l_1 = q_1 \; ; \; r_1 u_1 l_2 = q_2 \; ; \; r_1 u_1 l_3 = q_3 ; \; r_1 u_1 l_4 = q_4 ; \\ & r_1 u_2 l_2 = q_5 \; ; \; r_1 u_2 l_4 = q_6 ; \; r_1 u_3 l_4 = q_7 ; \; r_2 u_1 l_1 = q_8 ; \\ & r_2 u_1 l_2 = q_9 \; ; \; q_{10} = r_2 u_1 l_3 \; ; \; r_2 u_1 l_4 = q_{11} ; r_2 u_1 l_2 = q_9 \; . \end{aligned} \tag{2}$$

Let us perform the operation of term-by-term disjunction of possibly greater number of related equations [22]. So we get the local knowledge area. Such areas may include more than one calculated limited number of features and subject areas of researching:

$$\begin{aligned} & r_1 u_1 (l_1 \vee l_2 \vee l_3 \vee l_4) = q_1 \vee q_2 \vee q_3 \vee q_4 ; \\ & r_1 u_2 (l_2 \vee l_4) = q_5 \vee q_6 , \; r_1 u_3 l_4 = q_7 ; \\ & r_2 u_1 (l_1 \vee l_2 \vee l_3 \vee l_4) = q_8 \vee q_9 \vee q_{10} \vee q_{11} . \end{aligned} \tag{3}$$

Function from the object domain of knowledge q to local area of the expert's studies m:

$$\begin{aligned} & q_1 \vee q_2 \vee q_3 \vee q_4 \vee q_8 \vee q_9 \vee q_{10} \vee q_{11} = m_1 ; \\ & q_5 \vee q_6 \vee q_7 = m_2 \; . \end{aligned} \tag{4}$$

The local area of the expert's studies has no clear algorithm on which it is formed. It depends on the subjective approach and general trends in the development and modification of knowledge in this field.

Taking into account the dependence of subject areas of knowledge q on subject variables r, l, u (2) and the relation between the subject areas of knowledge q and local areas of the expert's research m (4), dependences of local areas m on subject variables r, l, u have the following form:

$$\begin{aligned} & m_1 = r_1 u_1 (l_1 \vee l_2 \vee l_3 \vee l_4) \vee r_2 u_1 (l_1 \vee l_2 \vee l_3 \vee l_4) ; \\ & m_2 = r_1 u_2 (l_2 \vee l_4) \vee r_1 u_3 l_4 \; . \end{aligned} \tag{5}$$

The predicate $P(r, l, u, m)$ or system of the expert's local areas research interdependence m and subject variables r, l, u is as follows:

$$\begin{aligned} & P(r, l, u, m) = \\ & = m_1 r_1 u_1 (l_1 \vee l_2 \vee l_3 \vee l_4) \vee m_1 r_2 u_1 (l_1 \vee l_2 \vee l_3 \vee l_4) \vee \\ & \vee m_2 r_1 u_2 (l_2 \vee l_4) \vee m_2 r_1 u_3 l_4 \end{aligned} \tag{6}$$

Predicate P can be graphically represented by a logical network (Figure 1). Predicate describes local areas of research, where much attention is paid to the research in two directions m_1 and m_2. The direction m_1 focuses on the study of the ecological condition at intersections and parking. Another direction m_2 is to study the contamination of water and soil particles by vibration and waste items of vehicles. At this time the study of the exhaust particles emission l_4 is dominant.

Figure 1 shows that research m_1 in the direction of the influence of component l_1 – l_4 on the air is more extensive. In accordance to this fact these studies should be taken to form the basic input parameters for modeling the ecological condition at crossroads module.

The simulation should be carried on with a help of effective mathematical models of traffic flows that can adequately predict the condition of the road network. To solve this problem it is advisable to use a new class of traffic flows models based on a microscopic approach – cellular automata [6, 14, 17]. The program, recorded in the environment of MatLab, provides an opportunity to present the interaction of vehicles in traffic flow in more detail. The use of a random number generator for the emergence of new cellular automaton is a distinctive feature of the program. Consequently after repeated simulation of motion on the selected road section the statistical picture of the workload of its separate parts can be defined.

The assessment of the overall impact of vehicles on mesoclimate of urbanized areas can be made on the basis of the formula [4, 13, 18]:

$$Q = Q_s \, G (1 - \eta) \, S \tag{7}$$

where:

Q – heat provided by vehicle motor, (kg m^3)/c^3;

Q_s – the average heat value of fuel combustion, MJ/m^3;

G – fuel consumption, L/100 km;

η – performance coefficient;

S – transport flow normed intensity, veh/h.

The vehicle noise at even movement in a straight transfer on a straight stretch of road can be described by the formula [10]:

$$L = 10 \lg N + 13{,}3 \lg V + 8{,}4 \lg \rho + 7 \tag{8}$$

where:

L – is the sound level, dBA;

N – the total vehicles number in the two directions of traffic for 1 hour, veh/h;

V – the traffic flow speed, m/s;

ρ – the proportion of trucks and public transport vehicles in the total flow, %.

The estimated value of the exhaust gases toxic components at the tested area was determined [11, 15]:

$$M_i^p = \sum_{j=1}^{k} M_{ij}^{pn} + \sum_{j=1}^{l} M_{ij}^{нn} + \sum_{j=1}^{r} M_{ij}^{b}, \tag{9}$$

where:

$\sum_{j=1}^{k} M_{ij}^{pn}$, $\sum_{j=1}^{l} M_{ij}^{нn}$, $\sum_{j=1}^{r} M_{ij}^{b}$ – accordingly massive emissions of exhaust gases at regulated, unregulated intersections and streets intersection;

$k,\ l,\ r$ determine the number of regulated and unregulated intersections and streets between the intersections.

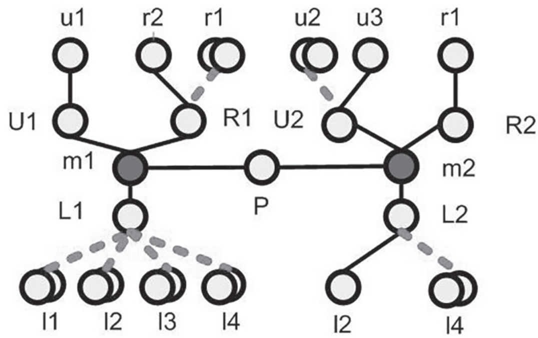
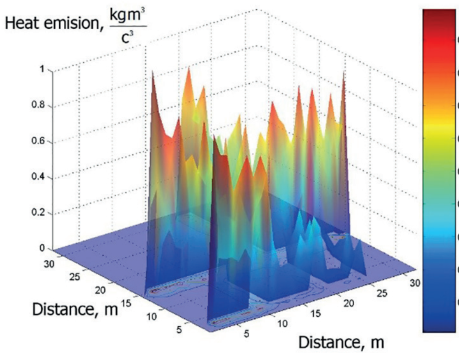
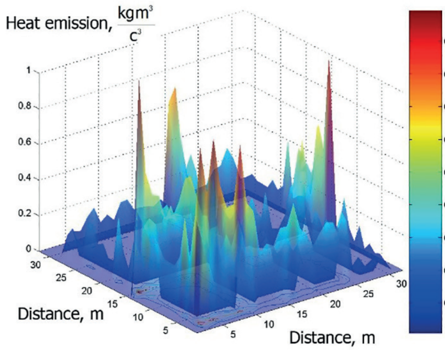


Fig. 1. Predicate of the relation values variable *m* of expert's local areas research and subject variable *r, u, l* of knowledge domains *q*

As an example, the environmental map visually represented in Figures 2-4, was formed due to the multiple traffic flow modeling based on the cellular automata use and determination of transport impact on the environment, namely: the heat equivalent level, the noise equivalent level, gas concentration equivalent level for the selected intersection. The RN is represented on the map in the horizontal plane. The chart shows the value of a parameter under examination at each point of the RN. An additional restrictive plane indicates that the parameter under examination exceeds the specified conditions. Such visualization allows you to quickly and accurately conduct the analysis of the investigated parameter and make correct conclusions.



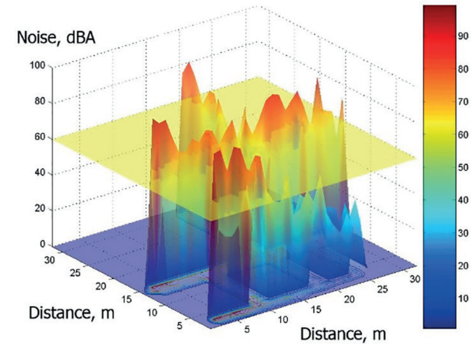
a) The equivalent level of heat emission (parent version) at the flow density 0.9



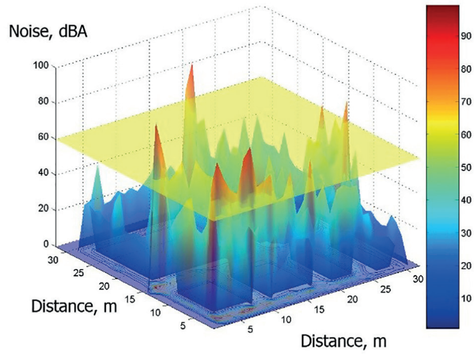
b) The equivalent level of heat emission (final version) at the flow density 0.9

Fig. 2. The equivalent level of heat emission caused by the car engines running at the crossroads. The latitude and longitude coordinates of crossroads is represented on the map in the horizontal plane:

a) before the improvement of the traffic scheme; b) after the introduction of the bypass road

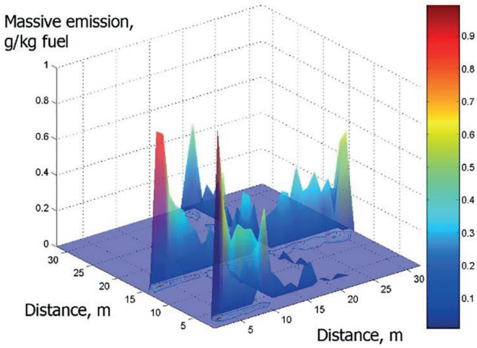


a) The equivalent level of noise (parent version) at the flow density 0.8

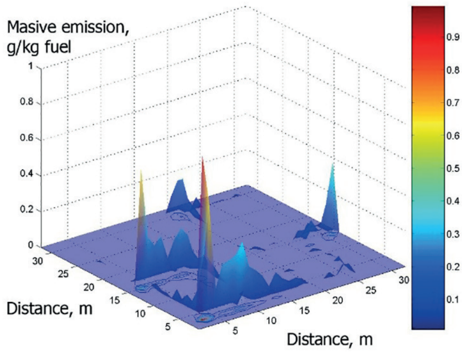


b) The equivalent level of noise (final version) at the flow density 0.8

Fig. 3. The equivalent noise level produced by vehicles at the crossroads. The latitude and longitude coordinates of crossroads is represented on the map in the horizontal plane: a) before the improvement of the traffic scheme; b) after the introduction of the bypass road



a) The equivalent level of gas pollution (parent version) at the flow density 0.9



b) The equivalent level of gas pollution (final version) at the flow density 0.9

Fig. 4. The equivalent level of gas pollution caused by cars at the crossroads. The latitude and longitude coordinates of crossroads is represented on the map in the horizontal plane: a) before the improvement of the traffic scheme; b) after the introduction of the bypass road

4. Recapitulation and conclusions

The proposed method of knowledge structuring in the area of the ecological RN condition study allows to organize and bring forth interrelations between network features, as well as select key parameters that will be examined in mathematic models.

A new class of traffic models based on a microscopic approach – cellular automata are proposed to use in order to simulate the ecological condition of the road network of big cities. Such models can be taken as the basis for the environmental monitoring of RN module. Ecological state changes of road network intersection according to the results of bypass road introduction is given as an example.

Knowledge structuring about environmental contamination simplifies and demonstrates the choice of the mathematical model basic parameters for RN environmental monitoring. The mathematical model can be implemented by using the cellular automata theory.

In case of creation of the intelligent transportation system (ITS), the module of simulation the RN ecological condition can function on the basis of the method of term-by-term disjunction. The method of term-by-term disjunction is used to form the characteristics and properties of the RN. This is done on the basis of the initial information about the RN and the peculiarities of its functioning. It is also advisable to use the method of term-by-term disjunction for the formation of the RN structure on the basis of typical elements, which the RN usually consists of.

By conducting a multiple traffic simulation based on the use of cellular automata, it is possible to create an environmental RD map and to do this with the account of non-standard situations: road reducing, road blocking, using additional routes, reversing the movement, etc.

5. Nomenclature

CA – the cellular automata theory

ITS – the intelligent transport systems

RD – the environmental map

RK – the elements of environmental pollution

RN – the road network

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