International Journal of Engineering & Technology, 7 (4.36) (2018) 88-91

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

An Approach to Emergency Situation Forecasting in the Field of Road Maintenance Based on Big data Analysis

E.M. Mikliaev[1], I.I. Antonova[2], V.V. Nikonov[3], S.G. Magomedov[4]

[1]*MIREA - Russian Technological University,Russia*
[2]*MIREA - Russian Technological University,Russia*
[3]*MIREA - Russian Technological University,Russia*
[4]*MIREA - Russian Technological University,Russia*

Abstract

The article considers the approach to forecasting emergency situations in the field of road maintenance by the example of bituminous concrete pavement, the wear of bituminous concrete pavement is calculated, dependences on temperature and humidity are determined, a mathematical model and algorithm are proposed, and an information system for forecasting emergency situations is developed.

Keywords: *pavement, mathematical model, proposed, information system, algorithm*

1. Introduction

A modern city comprises not only houses, offices, streets and its inhabitants but also a great amount of data and information objects. The latest trend in metropolis development is the “SmartCity” paradigm. An integral part of the information supply of the “SmartCity” is represented by the concept of “BigData”, which includes predictive analytics as one of its methods.
Emergency situation (ES) is an event in a series of similar events which are classified as normal. An event can be defined as an element of a time series assigned with a sequence of parameters, a sequence of factors*(k)* influencing the parameters, and a sequence of contiguous events. Accordingly, ES can be defined as an event which has one of its parameters exceeding critical value. The parameters can change according to the influence of factors.
According to the above definitions of ES, the problem of emergency situation forecasting in general is reduced to finding all functions depending on damaging factors which completely describe all types of changes in the sequence of parameters and determination of the time series of events based on these functions as the event parameters tend to critical value.
A well-known approach is to describe the change in the technical state of an object by such polynomial constraints[1] as uniformly increasing linear or exponential dependencies. In the first case, uniform wear is described, and in the second case, wear with the intensity increasing with time is described.
Linear and exponential dependencies are represented by functions with value depending both on the values of the variables, which in our case are the damaging factors, and on the coefficients. The further solution of the prediction problem with this description of the process is reduced to a linear approximation for finding the coefficients of the functions and subsequently finding the values by formulas according to the calculated coefficients.
The most common ES met during road maintenance is the destruction of bituminous concrete pavement caused by natural wear and tear which occurs under the influence of damaging factors. The wear of objects in most cases is negative, thus the function describing the effect of damaging factors is strictly monotonically increasing[2].

2. Research Methods

To determine the wear of each individual element, a generalized characteristic is used - the share of resource depletion or the share of the residual resource β, which determines which part of the individual resource of the element is consumed at the time of the survey[3] - $\beta(e11)$, $\beta(e12)$,…, $\beta(e1m)$, and this characteristic is equal to the sum of all the damaging factors: l_1, l_2,…,l_k,, influencing the element in the course of time:

$$\beta(e) = \sum_{k=1}^{l} f(l_k) \tag{1}$$

The main features of Big Data are Volume, Velocity and Variety[4]. Dependence of these characteristics on previously adopted designations, describing the wear of objects:

- The volume of data is directly proportional to the number of changing objects and elements (n and m) and depends on the number of damaging factors (*k*);
- The velocity with which the final data is changing depends on the function f(l) and the number of damaging factors k. It shall be mentioned that the period in which all the elements are changing and the number of elements changing over a short period of time are of great importance;
- The variety of data is provided solely by the number of damaging factors (k).

To determine the need to use the methods of Big Data analysis, it is suggested to perform a preliminary estimation of the resources necessary for calculations[5]. In the task of emergency situation forecasting the damaging factors falling under the described criteria include meteorological conditions, such as temperature (k_1) and humidity (k_2).

When calculating the wear of bituminous concrete pavement, the process is described by a linear function *f(t)* emerging from the origin of coordinates, since at the initial moment of time the probability of occurrence of an ES is zero, and the time *t*, when the maximum service period has been exhausted and the bituminous concrete pavement has to be replaced.

3. Results and Analysis

In order to solve the problem of emergency situation forecasting during road maintenance, it is necessary to determine the time period for reaching the possible state of the object6 by analyzing the discrete set of states in which the object can exist with the transition function from one state to another. To do this, a mathematical model was created in which the surface was represented by a set of measurements of deviations from the zero value, an enlarged table of weather conditions was introduced, and a dependence was described. On the model, an algorithm was tested that predicts wear in different periods.

The following designations are introduced:

- U - wear of the road pavement;
- U_z - wear of the road pavement at the time of measurement;
- $U(w)$ - wear as a function of humidity;
- $U(c)$ - wear as a function of temperature;
- t_0 - the initial point in time;
- t_z- time of measurements;
- c - temperature;
- w - humidity.

At the initial point in time, after capital repairs or road pavement replacement, wear at any point is zero:

$$U_{t_0} = 0$$

After the start of service, the ambient temperature and humidity begin to affect the road objects, and from the formula (1) the total wear at a given point is the sum of the wear as a function of humidity and temperature:

$$U = U(w) + U(c)$$

Wear at any time can be represented as a sum of wear:

$$U = \lim_{n\to\infty} \sum_{i=0}^{n} U_{t_i}$$

where *i* is the number of measurements.

Dependence of bituminous concrete pavement wear on humidity Uw is expressed by the formula:

$$U_w = a \cdot e^{bw} \tag{2}$$

where *w* is the humidity of bituminous concrete pavement in percentages, *a*=0,38÷0,79, *b* = 0,32÷0,079, depending on the type of bituminous concrete pavement, and the correlation coefficient is defined within K =0,97-0,99.

Dependence of bituminous concrete pavement wear on temperature Uc is expressed by the formula:

$$U_c = g + dc \tag{3}$$

where *c* is the temperature of bituminous concrete pavement in degrees Celsius, *g = 0,39÷0,70, d = 0,2*˙*10-2 ÷0,08*˙*10-2*.

The primary coefficients were calculated from the experimental data of M.F. Jalilov7, obtained for mixed traffic flows observed in the period 2000-2001, the unit wear is 1.3 to 1.72. For macadam-mastic bituminous concrete pavement and a conditional mixed transport stream, the spread of the wear indicator was 2.15 to 3.16, an average of 2.73, the data was derived in accordance with the work of E.V. Kalenova and S.S. Lugov8.

Having data on temperature and humidity, the wear of the bituminous concrete pavement at a given point can be calculated for any point in time:

$$U = \lim_{n\to\infty} \sum_{i=0}^{n} (U_{t_i}(w) + U_{t_i}(c)) = \lim_{n\to\infty} \sum_{i=0}^{n} (a \cdot e^{bc_i} + c + dc_i)$$

the correlation coefficients between wear as a function of temperature and wear as a function of humidity at the current time of measurement can be calculated:

$$r = \frac{U_{t_i}(c)}{U_{t_i}(w)}$$

and the correlation coefficients depending on the measurement time can be calculated:

$$k = \frac{U_{t_n}}{U_{t_i}}$$

However, the reliability of such data will be low. To increase the reliability of data and to obtain information on a specific object, it is proposed to perform a diagnostic examination at a time t_i and obtain the factual wear value. Having data on humidity and temperature for any period of time in n samples and the factual wear *U*, it is possible to calculate the factual coefficients *a, b, g, d*.

Having data on temperature and understanding that the wear behaves like a linear function of temperature, it is possible to approximate these data by a linear formula (3), i.e. to find coefficients g and d for which

$$F(g,c) = \sum_{i=1}^{n} (U_i - (gc_i + d))^2 \to \min$$

The solution is to find the coefficients according to the formulas

$$g_z = \frac{n\sum_{i=1}^{n} U_i c_i - \sum_{i=1}^{n} U_i \sum_{i=1}^{n} c_i}{n\sum_{i=1}^{n} c_i^2 - (\sum_{i=1}^{n} c_i)^2}$$

$$d_z = \frac{\sum_{i=1}^{n} c_i^2 \sum_{i=1}^{n} U_i - \sum_{i=1}^{n} U_i c_i \sum_{i=1}^{n} c_i}{n\sum_{i=1}^{n} c_i^2 - (\sum_{i=1}^{n} c_i)^2}$$

Similarly, it is possible to calculate the coefficients a and b, the dependences for which are expressed by formula (2), approximating these data by an exponential curve. In order to reduce these data to the linear case, a logarithm of the function can be taken and the logarithm properties can be used accordingly:

$$\ln U(w) = \ln(a \cdot e^{bw}) = \ln a + \ln e^{bw} = bw + \ln a$$

and the coefficients a and b can be found for which

$$F(a,b) = \sum_{i=1}^{n} (\ln U_i(w) - (bw + \ln a))^2 \to \min$$

The solution is to find the coefficients according to the formulas

$$a_z = \frac{n\sum_{i=1}^{n} \ln U_i w_i - \sum_{i=1}^{n} \ln U_i \sum_{i=1}^{n} w_i}{n\sum_{i=1}^{n} w_i^2 - (\sum_{i=1}^{n} w_i)^2}$$

$$\ln b_z = \frac{\sum_{i=1}^{n} \ln U_i \sum_{i=1}^{n} w_i^2 - \sum_{i=1}^{n} \ln U_i w_i \sum_{i=1}^{n} w_i}{\sum_{i=1}^{n} w_i^2 - (\sum_{i=1}^{n} w_i)^2}$$

$$b_z = e^{\ln b_z}$$

Thus, formulas are obtained for calculating the coefficients az, bz, gz, dz based on which the wear at a given point can be calculated:

$$U = U_z + U = U_z + \lim_{n\to\infty}\sum_{i=0}^{n}(U_{t_i}(w) + U_{t_i}(c)) == U_z + \lim_{n\to\infty}\sum_{i=0}^{n}(a_z \cdot e^{b_z c_i} + g_z + d_z c_i)$$

The wear of the bituminous concrete pavement along the entire road is a wear matrix where the number of rows is determined by the number of measurements along the road, and the number of columns is determined by the number of measurements across the road:

$$U = \begin{pmatrix} U_{11} & \cdots & U_{1m} \\ \cdots & \cdots & \cdots \\ U_{n1} & \cdots & U_{nm} \end{pmatrix}$$

Based on the analysis of the matrix of values, it is possible to predict the change in the surface pattern with the frequency of the measurements (Fig. 1).

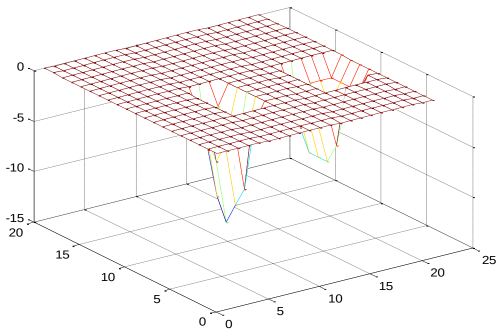

Fig. 1. Prediction of road surface pattern in the moment t_i

The following task is to develop an algorithm for calculating the matrix predicting the wear of the bituminous concrete pavement. At the start of service at the time t0 the wear of the coating is U = 0. Prior to obtaining the factual wear data, an array describing the wear is calculated on the basis of experimental data obtained in earlier studies. To calculate the wear matrix, it is proposed to use a system consisting of 2 nested cycles.

After the transfer of the parameter representing the period of fault-free service, a separate schedule is formed for the repair works on this object.

The algorithm includes the following factual entities:

1. Road surface, represented as a measurement surface
2. Damaging effect, represented in the form of a set of formulas describing the dependence of the amount of damage
3. Periodic work on repair of bituminous concrete surface, expressed by equating the values of item 1 of this list to 0. Note that it is necessary to carry out such work periodically, the period between repairs being determined by the magnitude of the damaging effect from item 2 of this list.

For the approbation of the model and the algorithm conducted on the basis of the road-maintenance enterprise, an information system was developed. The implemented system performs the following functions:

1. Obtaining data from the database on:
1.1. Objects of road facilities, including area characteristics, the length of road objects and information on repairs carried out.
1.2. Incidents detected at road facilities.
1.3. Weather conditions from 2015, including temperature characteristics and humidity.
2. Upload of data on road facilities, incidents and weather conditions to the database from formatted files.
3. Predicting wear and calculation of expected dates of emergency situation occurrences based on the data entered.
4. Forming a work schedule for repairs.

Data necessary for the operation of the information system are stored in a database on road facilities, weather, incidents, title lists for repairs and works.

This information system enables keeping track of road facilities, their measurements, incidents, titles for work and weather conditions. Based on Big Data, which includes changes in weather conditions and measurement arrays stored in the database, the system calculates wear and tear and predicts the occurrence of ES - destruction of bituminous concrete pavement - forming the expected date of ES occurrence and informing the repair services ahead of time about the occurrence of the incident.

For the experiment the streets of Moscow repaired in 2016 were chosen, and their wear and tear was calculated based on the data obtained in earlier studies. To calculate the reliability of the forecast made by the information system the forecast values of the number of emergency situations for 2017 and the real values of identified emergency situations for objects repaired in 2016 were compared.

To evaluate the difference between predicted and factual data, the Student t-criterion for independent samples was calculated. The data were summarized in a table:

Table 1. Number of incidents on the streets repaired in 2016.

Number of objects	2017 factual	2017 predicted
681	205	218

Then the distribution was checked for normality and the arithmetic mean, standard deviation and the number of objects in each group were calculated.

Table 2. Comparison of arithmetic mean, standard deviation and the number of objects.

		2017 factual	2017 predicted
Arithmetic mean	$M_x = \frac{\sum X_i}{n}$	M_1=159,5	M_2=169
Standard deviation	$\delta_x = \sqrt{D_x} = \sqrt{\frac{\sum(x_i - M_i)^2}{n-1}}$	δ_1=1	δ_2=1
Number of objects	N_i	N_1 =2	N_2 = 2

The empirical values according to the formula of Student t-criterion[9] were calculated for independent samples:

$$t_e = \frac{|M_1 - M_2|}{\sqrt{\frac{\delta_1^2}{N_1} + \frac{\delta_2^2}{N_2}}} = \frac{|159,5 - 169|}{\sqrt{\frac{1}{2} + \frac{1}{2}}} = 9,5$$

The degrees of freedom were calculated:

$$df = 2 + 2 - 2 = 2$$

The significance level was determined according to the table of critical values of t-Student[10]. The value 9.5 is less than the value 9.925, therefore, the significance level is greater than 0.05. Since the significance level is greater than 0.05, it can be concluded that there are no differences between the groups, which in this case proves a sufficient level of prediction reliability.

4. Conclusion

The information system developed for emergency situation forecasting based on the mathematical model using linear approximation of the wear functions of bituminous concrete pavement caused by such damaging factors as weather conditions ensures the reliability of the forecast over 95%. Given the high reliability of the system it can be recommended for use in organizations that carry out technical maintenance of road facilities and road transport infrastructure. This work was partially supported by motivational payments system faculty MIREA[11].

The proposed mathematical model and algorithms can be used in many areas of the urban complex, not only in information systems for road maintenance, but also in the operation of housing facilities or energy facilities and resource-supply organizations.

Gratitued for Financial Support

The work was financially supported by the Ministry of Education and Science of the Russian Federation (State Contract No. 03.G25.31.0280, May 30, 2017).

References

[1] Milovanov S N Forecasting methods usage in innovative management Izvestia: Herzen University Journal of Humanities & Science. 2007. 17/43-1: 219-22

[2] Shelupanov A A, Iskhakov S Y, Yevsyutin O O, Akimov D A, Nikonov V V Security of heterogeneous objects based on multilevel modeling and preemptive incident forecasting (Tomsk). 2014. p 90

[3] Mitushov A A Simulation of Thermal Power Equipment Elements Wear Vestnik IGEU. 2010. 3:77-81

[4] Magomedov Sh. Organization of secured data transfer in computers using sign-value notation//ITM Web of Conferences. 2017. T. 10 DOI: 10.1051/itmconf/20171004004

[5] Nikonov V V, Mikliaev E M Assessment of the necessity to use Big Data methods in city management systems Scientific Perspective. 2017. 1/6:68-72

[6] Voit A, Stankus A, Magomedov S, Ivanova I Big Data Processing for Full-Text Search and Visualization with Elasticsearch Int. J. of Adv. Comp. Science and App. (DOI: 10.14569/IJACSA.2017.081211). 2017. 8/12:76-83

[7] Jalilov M F Accounting for the abrasive action of car wheels for predicting wear on bituminous concrete pavements (Moscow: MADI Press) 2004. p 246

[8] Kalenova E V, Lugov S S Technique and results of measurements of bituminous concrete pavement wear on a wheeled bench Online magazine: Naukovedenie 2 (URL: www.naukovedenie.ru/PDF/34TVN214.pdf), 2014.

[9] Suleimanov S L, Oshovskaya E V, Isaenko V V Search for a function describing the technical condition of equipment Progr. Tech. and Sys. of Mech. Eng. 2002. 23:147-51

[10] Gaponova S A, Porshnev A V Statistical methods in psychological study: tutorial (N.Novgorod: N.Novgorod Press). 2010. p 93

[11] Pankov V. The effectiveness of incentive mechanism, and the potential level of satisfaction of the needs of the employee. Russian Technological Journal. 2015. № 4 (9), V. 1, p. 288-291.