Estimation of significance the parameters, influencing on road ice formation (the results of computing experiment)

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INTRODUCTION

Increasing road safety in winter period is one of the important tasks of ground transport. The specialized road short-term forecasts are necessary for its decision.
They make it possible to spray anti-icer salts before ice formation and conserve a high quality of tyre-road contact in unfavorable weather conditions.
The physicostatistical dependencies (linear discriminant functions) for short-term road ice formation forecasts were obtained. The most significant parameters are included into forecast models.
The selection procedure and results obtained are described.

MATHEMATICAL MODELLING OF ROAD ICE FORMATION

The process of road ice formation is very intricate. It is influenced by many weather and road factors and the degree of dependency on these parameters we cannot be explained.
The problem of road ice prediction is complicated. It can't be solved by using the conventional research methods. In Russia we do not have the sufficient statistic of real road slipperiness. To solve this problem we use the method of mathematical modelling and computing experiment.

The mathematical model is based upon the calculating analysis of the pavement temperature and the logical modules describing the conditions for ice formation on a road pavements (1). The road surface temperature was estimated, for this purpose heat conductivity equation with II and III kind boundary conditions was solved.

A detailed study was performed of the ice-crusted, freezing rain and glaze formation. The conditions for this types of road slipperiness formation are presented in Table 1 (2).

Table 1. Conditions of road slipperiness formation

Type of road slipperiness	Conditions of it formation			
	Air temperature	Road surface temperature	Type of precipitation	Road surface condition
Ice-crusted	$< 0\,^0$C	$< 0\,^0$C	Anyone, fall-out for the air temperature more than –3 ^{0}C	Wet
Freezing rain	$> 0\,^0$C	$< 0\,^0$C	Rain precipitation	-
	From -5 ^{0}C to 0 ^{0}C	$< 0\,^0$C	Wet snow (quantity of precipitation Q=0 mm)	-
Glaze	$< 0\,^0$C	$< 0\,^0$C	Rain precipitation or drizzle	-

To simulate the conditions of ice formation on a road surface the meteorological reports of weather station over the 20-years period where used.

The program complex SIGNAL for IBM computer was developed. Algorithm may be presented by 7 steps.

Step 1 . The information about road construction is introduced.
Step 2 . Initial temperature distribution is calculated.
Step 3 . Daily meteorological parameters are introduced.
Step 4 . Meteorological information is interpolated to the nodes of a mesh. The arrays of atmospheric precipitation and surface conditions are formed.
Step 5 . Boundary conditions are calculated. To obtain road surface temperature the difference equation is solved.
Step 6 . The conditions for ice formation in accordance with a table 1 are verified. If the conditions are not carried out then go to step 5.
Step 7 . The information about the date, time and type of ice formation along with road surface temperature and weather conditions on the calculation step as well as the same information for 3, 6, 9, 24 hours before is placed into the database.

Steps 5-7 are to be repeated 96times daily (mesh width on time is 15 minutes). Steps 2-7 are to be repeated for every year of weather observation.

At the first stage of the computing experiment the statistical information of icing risk potential cases over the 20-year period is formed.

SIGNIFICANCE ESTIMATE

Linear discriminant functions were calculated to forecast road ice formation. They are used in meteorology to predict the dangerous weather phenomenon (3, 4). To obtain this models the results of the first stage of computing experiment are used. There are two sets of information. The first named "ice presence" $\{X_1\}$ includes meteorological parameters and road surface temperature in the beginning of the ice formation. The second set $\{X_2\}$, named "ice absence" includes the same parameters the day before.

To raise the forecast reliability the most significant parameters may be included into discriminant functions. To estimate the significance of weather and road parameters "screening" procedure was used. For the selection of the significant parameters the Machalanobis distance D^2 was employed (3)

$$\Delta^2 = (\overline{X}_1 - \overline{X}_2)^T V_m^{-1} (\overline{X}_1 - \overline{X}_2) \qquad (1)$$

where V_m^{-1} is the inverse covariance matrix.

The algorithm of screening procedure consists of several steps (Figure 1).

The data about type of precipitation and road surface conditions were coded as follows:
OS = 1 for rain precipitation or drizzle, OS = -1 for solid precipitation, OS = 0 if precipitation is absent; RC = 0 for dry road surface, RC = 1 for wet road surface.

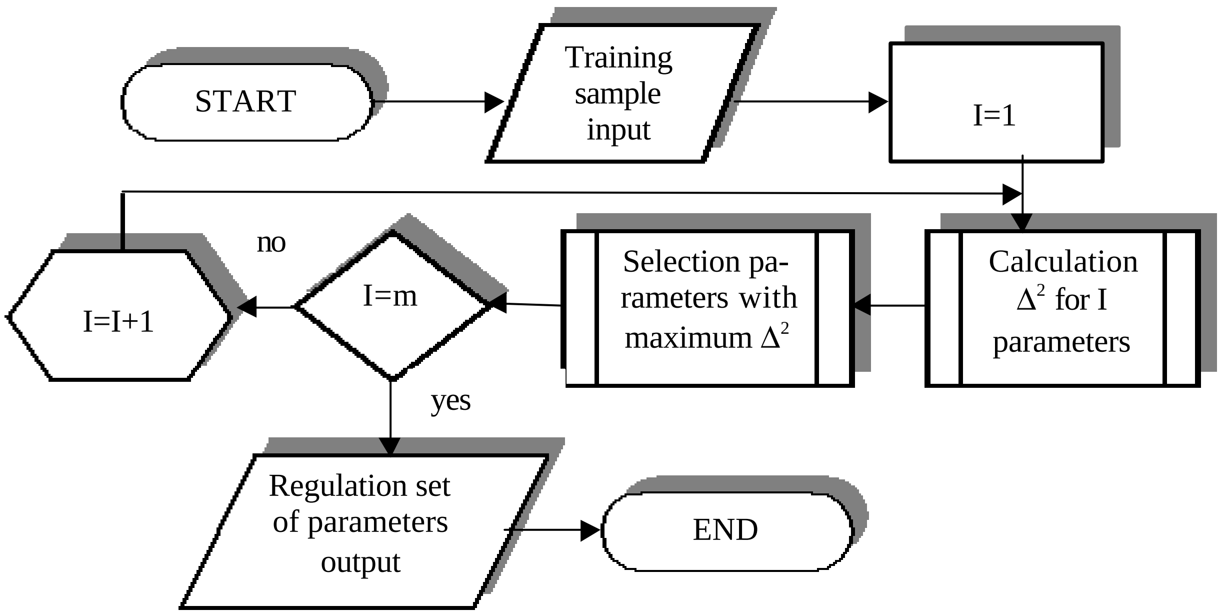

Figure 1. The scheme of algorithm for estimating significance of the parameters, influencing road ice formation

The significance of each parameters was determined with respect to the beginning of ice formation. The list of weather and road parameters is in the Table 2.

Table 2. Weather and Road parameters, influencing on road ice formation

Parameter name	Letter designation	The average value during the ice formation for	
		Ice-crusted	Freezing rain and glaze
Air temperature	T_a	-0,5	-1,6
Road surface temperature	T_s	-0,1	-2,1
Precipitation	OS	0,0	1,0
Wind speed	V	4,2	4,2
Wind direction	RU	W	S
Atmospheric pressure	P	998,5	995,8
Relative humidity of the air	W	85	95
Cloud cover	N	8,5	10
Dew point	T_d	-2,4	-2,0
Road surface condition	RC	1,0	1,0

The results of estimation for ice-crusted formation are in the Table 3.

From the data obtained it might be concluded that for the ice-crusted forecast the most significant parameters are: air temperature (T_a), road surface temperature (T_s) and relative humidity of the air (W).

Table 3. The results of significance the parameters, influencing ice-crusted formation

The significance of parameters (in decreasing order)					
3 hours before ice formation	average values	6 hours before ice formation	average values	24 hours before ice formation	average values
T_a	0,5	T_a	1,1	RU	S
T_s	0,7	T_s	-0,6	W	90
W	88	W	91	T_a	0,1
RC	1,0	T_d	0,9	RC	0,4
OS	-0,1	N	9,5	T_s	-0,2
P	997,9	RC	0,9	OS	-0,1
N	9,3	P	997,6	P	999,2
V	4,0	V	4,2	N	9,5
T_d	-1,2	RU	WSW	T_d	-1,4
RU	WSW	OS	0,2	V	3,5

Freezing rain and glaze have the same conditions of formation. They were joined in one set for estimation. The results of estimation for these types of road icing are in the Table 4.

Table 4. The results of significance the parameters, influencing freezing rain and glaze formation

The significance of parameters (in decreasing order)					
3 hours before ice formation	average values	6 hours before ice formation	average values	24 hours before ice formation	average values
OS	-0,3	OS	-0,3	OS	-0,1
W	93	W	91	W	87
T_a	-2,4	T_a	-3,0	T_a	-5,1
T_s	-2,8	T_s	-3,3	T_s	-5,4
RC	0,5	RU	SSW	N	8,6
P	996,6	V	4,5	P	1001,1
V	4,6	P	997,5	RU	SSE
RU	SSE	T_d	-4,3	V	3,7
T_d	-3,3	RC	0,3	RC	0,1
N	9,9	N	9,8	T_d	-6,6

From the data obtained it might be concluded that for the freezing rain and glaze formation forecast the most significant parameters are: precipitation (OS), relative humidity of the air (W). air temperature (T_a) and road surface temperature (T_s).

Thus, the most significant parameters may be included into forecast models. Standard computer programs of discriminant analysis were used.

MODELS FOR ROAD ICE FORMATION FORECAST AND THEIR RELIABILITY ESTIMATION

Linear discriminant functions where calculated to forecast road ice formation. . The form of the discriminant function is:

$$D(x) = a_1x_1+a_2x_2+...a_mx_m+a_{m+1} \quad (2)$$

where coefficients a_i are calculated from the condition of maximum difference of these sets:

$$\Phi = \left(\frac{\overline{X}_1 - \overline{X}_2}{S_x}\right)^2 \rightarrow \max \quad (3)$$

where X_i is the vector of average values, S_x is the mean square deviation.

The statistical information formed on the first stage of the computing experiment was divided into two non-intersecting and independent sets. The first set was used for “training” and the second set was used for “examination”.

The linear discriminant functions were calculated for the most significant parameters and their combinations. The results of reliability estimation for ice-crusted formation are presented on the Figure 2 and for freezing rain and glaze – on the Figure 3.

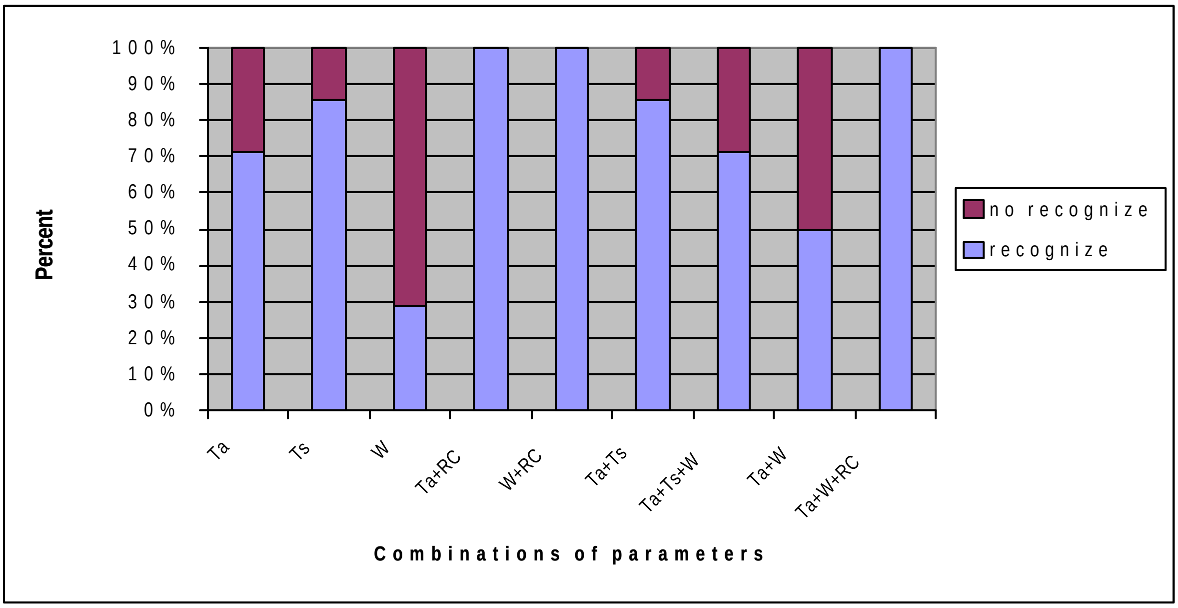

Figure 2. The results of reliability of estimation for ice-crusted formation

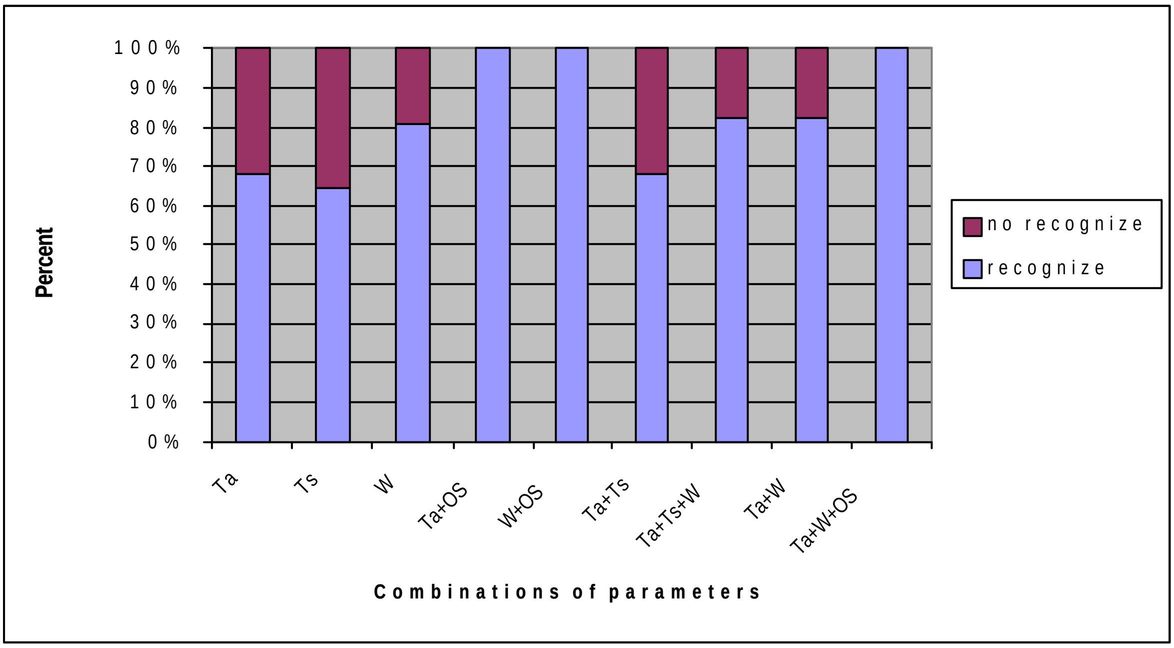

Figure 3. The results of reliability of estimation for freezing rain and glaze formation

CONCLUSIONS

The linear discriminant models which have the air temperature as a parameter, as well as the models which have the road surface temperature as a parameter have approximately equal reliability for the analyzed types of road slipperiness.

Precise information about road surface conditions (for ice-crusted formation) and about precipitation (for freezing rain and glaze formation) raise the forecast reliability.

The models for short-term road ice formation forecast were be tested during two winter seasons in the Ice Warning System in Moskow region. Practical experiments with models confirmed sufficient forecasts reliability (nearly 85 %).

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