DESIGNING AND CONSTRUCTION OF ROADS, AIRFIELDS AND BRIDGES

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PHYSICOSTATISTICAL MODELS FOR ROAD ICE FORMATION FORECAST

The necessity of development of operative management of winter road maintenance is proved. Solution of the problem on the basis of development of the road weather information system is offered. The technique of construction of statistical models for the short-term forecast of ice formation on road surfaces is considered. The project of a "virtual" road meteorological station for realization of received results in practice of the road winter maintenance is offered.

Keywords: highways, short-term forecast on road covering winter slipperiness, road meteorological station.

Introduction

Improvement of road safety during the winter period due to keeping pavement from ice formation is one of the topical problems of ground traffic. Usually slipping on roadway coverings is eliminated by the use of anti-icer and deicer salts. However, the more efficient way is to allow no formation of an ice layer and hence to keep high rideability and road grip of a tyre. The solution of the above problem is possible with the availability of a specialized road ice prediction.

The process of ice formation is very intricate, it is influenced by many weather and road factors and the degree of dependency from these parameters cannot be explained. The problem of road ice prediction is complicated. It cannot be solved by using the conventional research methods. To solve this problem it is necessary to use the method of mathematical modeling and computing experiment.

The mathematical model based upon the calculating analysis of the pavement temperature and the logical modules describing the conditions for ice formation on a road has been developed for the investigation of the process. The model allows one to complete the calculating experiment with the use of a personal computer with the followed data handling. The physicostatistical dependencies for the prediction allowing one to predict the ice formation 3—6 hours prior to its onset have been obtained. The model enables to investigate the dynamic behaviuor of the "road-environment" system during the formation of slipping of various types.

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.

In winter roads can become slippery in a number of ways. There are seven states of road surface.

1. Dry surface.

2. Wet surface.

3. Ice-crusted. This kind of road slippery is formed when water on the surface freezes to a thin coating of ice. It is possible when the surface temperature drops below 0 ^{0}C.

4. Hoar frost. The conditions of its formation are: clear weather, negative radiation balance (radiation loss), high humidity, surface temperature lower than 0 ^{0}C and at the same time lower then the dew point.

5. Freezing rain. It is formed when rain whose temperature is a little above 0 ^{0}C falls onto a cold surface. On contact with the cold surface rain drops are cooled and crystallized to ice.

6. Glaze. This kind of the road slippery is formed when rain is supercooling, that is the temperature of the rain drops is lower then 0 ^{0}C and when they fall onto a surface whose temperature is about 0 ^{0}C or lower they freeze instantaneously to ice.

7. Hard snow. This kind of the road slippery takes place when snow on a highway surface becomes compacted by the action of traffic.

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

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

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.

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	-

Steps 5—7 are to be repeated 96 times daily. 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.

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”.

Linear discriminant functions were calculated to forecast road ice formation. They are used in meteorology to predict the dangerous weather phenomenon [2].

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 Δ^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 and is presented on the Fig. 1.

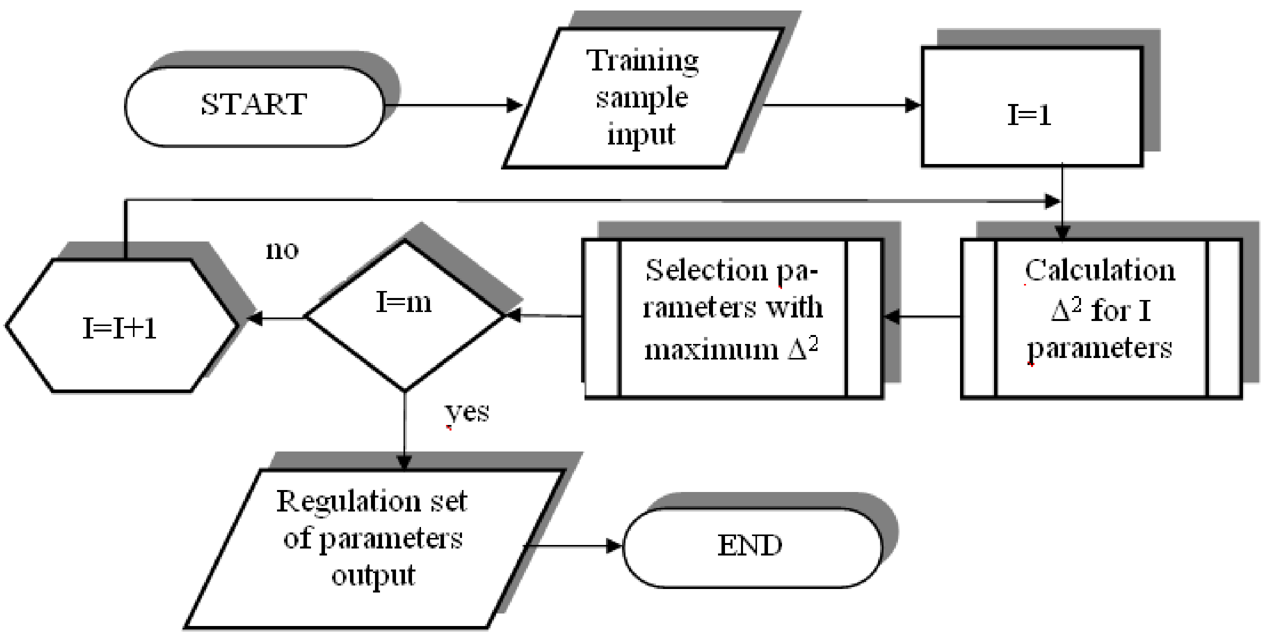

Fig. 1. The scheme of algorithm for estimating significance of the parameters influencing on road ice formation

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.

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

$$D(X) = D(x_1, x_2, \ldots, x_n) = a_1x_1 + a_2x_2 + \ldots + a_mx_m + a_{m+1} = 0, \qquad (2)$$

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

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

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

Coefficients of discriminant functions for ice-crusted, freezing rain and glaze formation forecast are presented in Table 2 and Table 3.

The results obtained enable us to develop the design of “virtual” road weather station presented on Fig. 2.

Table 2

Coefficients of discriminant functions for ice-crusted formation forecast

<table>
<tr><td colspan="7">Meteorological and road parameters</td></tr>
<tr><td>Air temperature</td><td colspan="5">T_a</td><td rowspan="5">a_{m+1}</td></tr>
<tr><td>Road surface temperature</td><td colspan="4">T_s</td><td rowspan="3"></td></tr>
<tr><td>Road surface condition</td><td colspan="3">RC</td><td rowspan="2"></td></tr>
<tr><td>Relative humidity of the air</td><td colspan="2">RH_a</td><td></td></tr>
<tr><td colspan="2">Significance level</td><td>3</td><td>4</td><td>2</td><td>1</td></tr>
<tr><td colspan="2" rowspan="6">Coefficients of discriminant functions</td><td>-</td><td>-</td><td>-</td><td>-0.187</td><td>-0.051</td></tr>
<tr><td>-</td><td>4.102</td><td>-</td><td>-0.528</td><td>2.984</td></tr>
<tr><td>-</td><td>-</td><td>0.057</td><td>-</td><td>0.011</td></tr>
<tr><td>-</td><td>3.594</td><td>-0.265</td><td>-</td><td>-2.591</td></tr>
<tr><td>-0.072</td><td>-</td><td>-</td><td>-</td><td>5.942</td></tr>
<tr><td>-0.086</td><td>3.415</td><td>-</td><td>-</td><td>4.864</td></tr>
</table>

End of Table 2

Meteorological and road parameters					
Coefficients of discriminant functions	-	-	0.895	-1.043	-0.140
	-	3.835	0.787	-1.194	-2.892
	-0.062	-	0.958	-1.021	5.463
	-0.698	3.949	0.754	-1.185	-3.365
	-0.071	-	-	-0.170	5.659
	-0.064	4.086	-	-0.514	-3.812
	-0.068	-	0.077	-	6.037
	-0.079	3.738	-0.236	-	4.504

Table 3

Coefficients of discriminant functions for freezing rain and glaze formation forecast

Meteorological and road parameters					
Air temperature				T_a	a_{m+1}
Road surface temperature			T_s		
Precipitation		OS			
Relative humidity of the air	RH_a				
Significance level	4	1	2	3	
Coefficients of discriminant functions	-	-	-	0.152	0.451
	-	6.634	-	0.031	-2.915
	-	-	0.144	-	0.442
	-	6.679	-0.011	-	-3.070
	0.121	-	-	-	10.759
	0.089	6.580	-	-	-11.402
	-	-	-0.009	0.164	0.454
	-	6.754	-0.302	0.301	-3.072
	0.106	-	-0.061	0.151	-9.260
	0.102	6.696	-0.315	0.259	-12.519
	0.104	-	-	0.092	-9.142
	0.089	6.604	-	-0.028	-11.903
	0.106	-	0.092	-	-9.318
	0.100	6.682	-0.071	-	-12.586

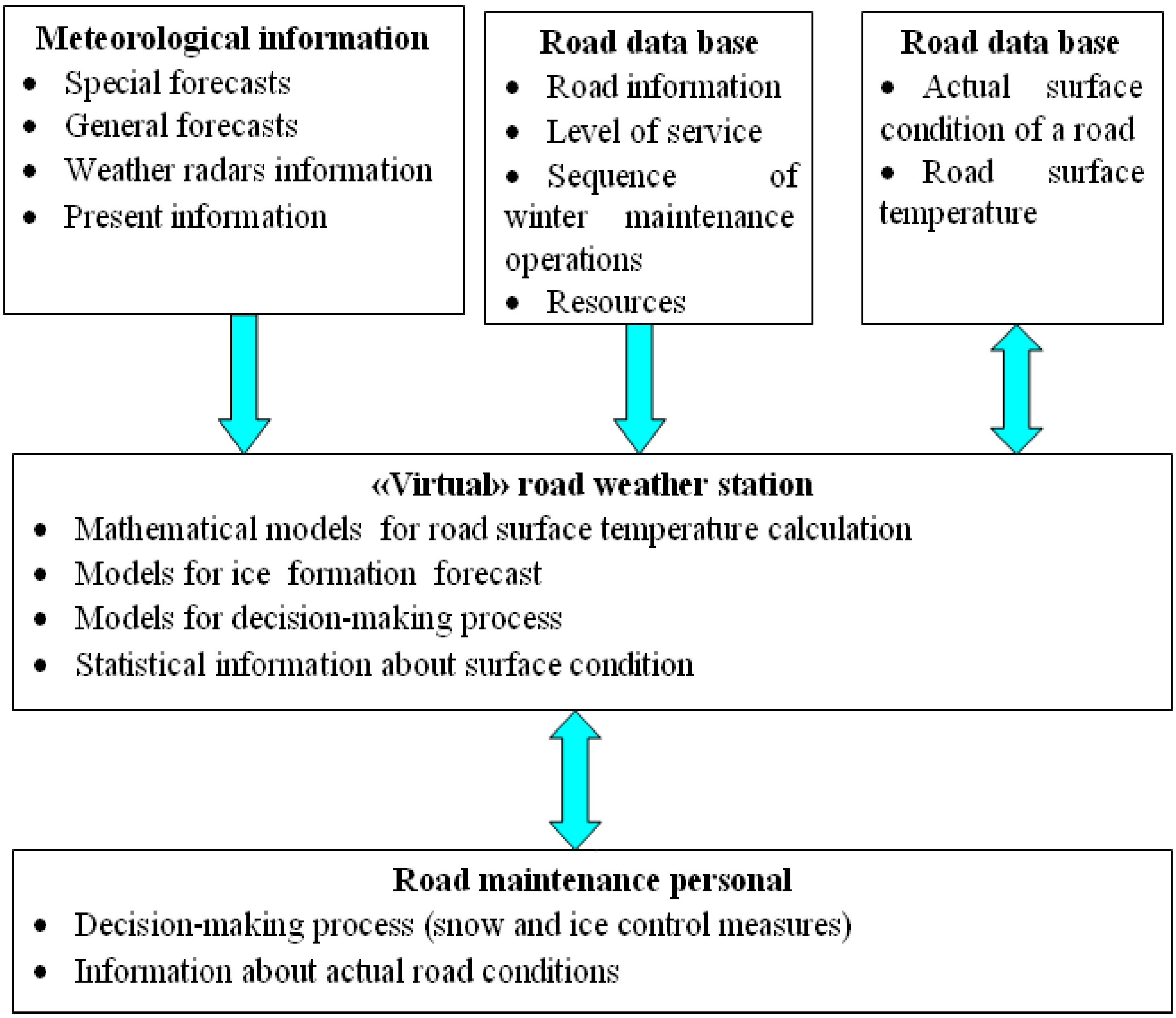

Fig. 2. The scheme of "virtual" road weather station

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

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