SYSTEM FOR PROGNOSTIC CALCULATION OF THE OPTIMAL SPREADING DENSITY IN WINTER ROAD CLEARANCE SERVICES

G. Hausmann

KOMMZEPT-Ingenieurbüro Hausmann, Bannewitz, Germany

hausmann@kommzept.com

Research project on behalf of the BASt

(Federal Highway Research Institute)

ABSTRACT

For current winter road maintenance, the determining of the salt dosing (spreading density) is mostly carried out by field personnel on the vehicles. From the evaluation of automated data logging, it is known that personal experience plays a key role in this process. This can be seen from the fact that comparisons of dosing by several employees reveal differences from the average set dosing of up to 100% under comparable boundary conditions. The pilot project “Optimisation of the degree of spreading material – Model to determine the spreading density objectively required in winter road clearance” commissioned by the Bundesanstalt für Straßenwesen (Federal Highway Research Institute), based in Bergisch Gladbach, Germany, set out to minimise the “subjective factors” involved in the application of ice-melting materials.

For this purpose, four motorway maintenance vehicles in Brandenburg and North Rhine-Westphalia were equipped with on-board computers to process short-term weather forecast data (3 hour time horizon), road surface temperature readings and data from the road weather stations located along the route. The on-board computers are linked up with a central server via the GSM network, enabling continual updating of the weather forecast data.

The algorithm software in the on-board computers calculates the optimal amount of spreading material based on liquid quantities forecast on the road surface and the road surface temperatures expected. In addition, the algorithm provides the option of determining increases and reductions for specific sections of the route. In this manner, the experience gained in previous winter service periods is also integrated into the calculation of the optimal spreading density. This can be beneficial on, say, bridges. Thanks to the GPS signal control, the optimal density setting ensues for the restricted section of the bridge crossing in good time without delay.

The use of data from sensors to determine the residual amount of salt and the current water film thickness in the calculation of the optimal spreading density is

set up. To the extent that mobile sensors meeting the requirements are available, then this data can also be integrated into the calculation of the spreading density.

The use of prognostic calculation of the spreading density has revealed a considerable potential for savings in the application of ice-melting material by means of this technology. This is particularly true in the case of preventative spreading operations.

1. Introduction

Determination of the spreading density is carried out on the vehicle by the operating personnel in practice during the actual winter service. From the evaluation of automated data recordings, it is thereby known that personal experience plays a significant role. That indicates that, in comparison to the dosing ratio of several staff under similar general conditions, the average dosing value set deviates by up to 100 %. During spreading journeys, mainly no adjustment of the spreading density is carried out for changed conditions. That is thereby explained because not all relevant data from the vehicle is available. In addition, the influence of different factors are so complex that making a decision without automated processing of the data available is not conceivable.

The objective of the research task is to develop an algorithm that considers all relevant data for the calculation of the required objective spreading density. Based on the continuous updating of the data and evaluated by the on-board computer during the deployment, pilot trials were carried out on four vehicles of the motorway maintenance department in Erkner in Brandenburg and Werl in North Rhine-Westphalia and evaluated. Comprehensive experience was collected during these tests that could provide the basis for the further development of systems for determining the optimum spreading density. Due to the anticipated development of mobile sensors to determine the residual quantity of salt and depth of liquid film on the road, the measurement data of which could be included in the calculation for the optimum spreading density, there is the option for further selection of automated spreading density. Thus, subjective factors for the selection of spreading density are reduced.

2. Influencing factors for ice formation

The formation of ice on traffic surfaces when using de-icing salts is dependent on three primary factors:

1. The road surface temperature (exact temperature of the salt solution on the road)

2. Concentration of the salt solution on the road
3. Type of de-icing salt

These primary factors are dependent on further influences (secondary factors). These are significantly meteorological, road-specific, traffic-dependent and technological factors. The primary factors are listed in **Figure 1** , in conjunction with the secondary factors. The primary factors road temperature and concentration of the de-icing substance are partly influenced by the same secondary factors. For example, the road surface influences the road temperature and concentration of the de-icing substance (e.g. OPA). The forecast for the icing conditions and determination of the optimum spreading density is the result of the numerous influencing factors of a relatively complex initial situation.

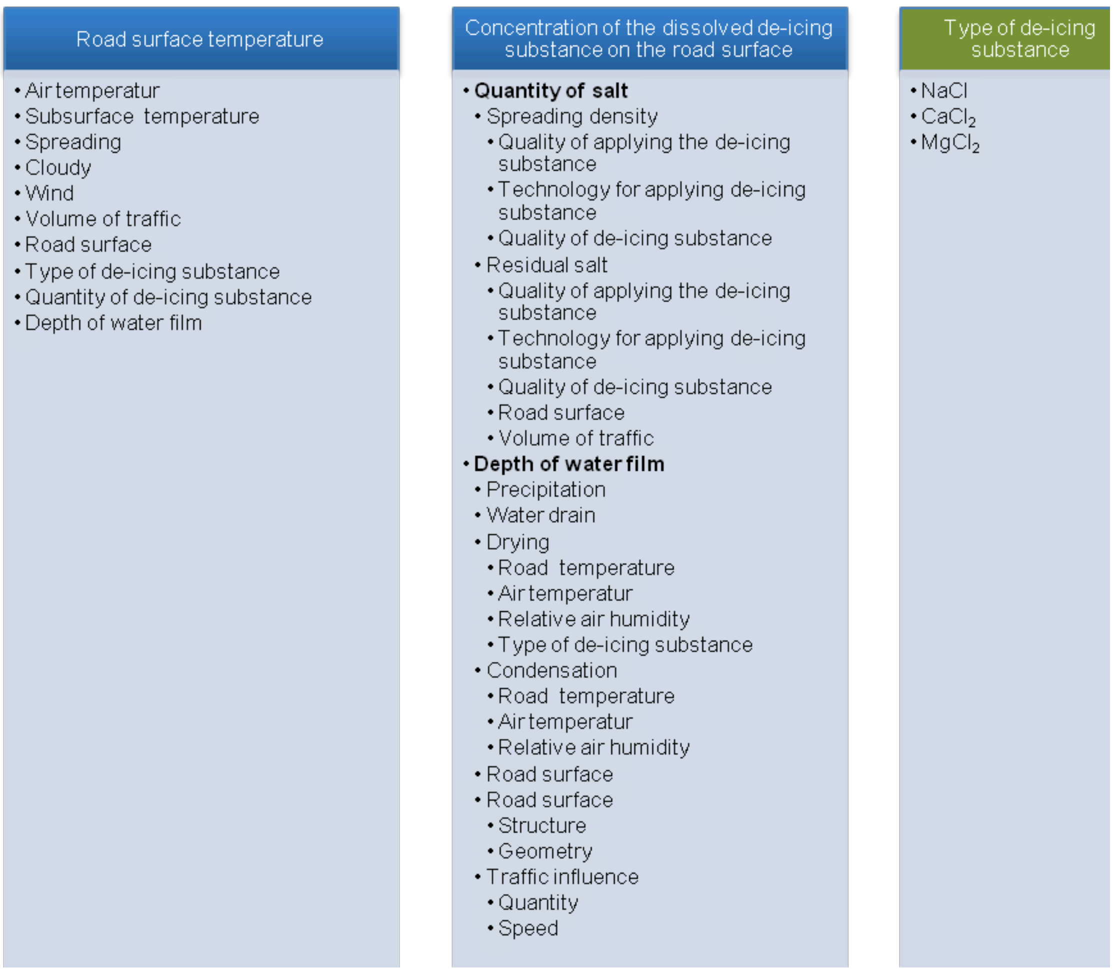

Figure 1: Influencing factors on the icing situation on road surfaces treated with de-icing substances

3. Development of a calculation algorithm for the optimum spreading density

An optimum Spreading Density (SD_{Opt}) is understood to be the minimum quantity of de-icing substance that must be applied per square metre in order to temporarily remove from, or prevent ice forming on traffic surfaces within a technologically required or beneficial plan time period.

The technologically required time period is understood to be the timeframe within which repeated spreading could or should be carried out. That can be dependent on the circulation times, shift planning and weather characteristics.

The following considerations are carried out for the deployment "Preventive spreading". That means, the optimum spreading density is calculated for icing conditions that have been forecast for a maximum of 8 hours after the time of spreading. The data for NaCl has been used for the calculations in the following examples. The calculation algorithm is also applicable to other de-icing salts.

According to the dependency on the primary factors, the following general correlation can be formulated for a specific de-icing substance:

$SD_{Opt} = f\ (T_{Fmin}, WFD_{max}, SM_R, SM_{loss})$ (1)

Where:

T_{Fmin} in °C	Lowest road surface temperature to be anticipated within the technologically required period.
WFD_{max} in mm	Maximum quantity of liquid converted to depth of water film present on the road surface within the technologically required period.
SM_R in g/m^2	The quantity of spreading material, from being spread previously, present on the road at the time of the actual spreading.
SM_{loss} in g/m^2	The quantity spread on the road which is anticipated to be lost within the period planned.

A diagram is created derived from the phase limit lines that represent the freezing temperature depending on the quantity of material spread and depth of water film present on the road.

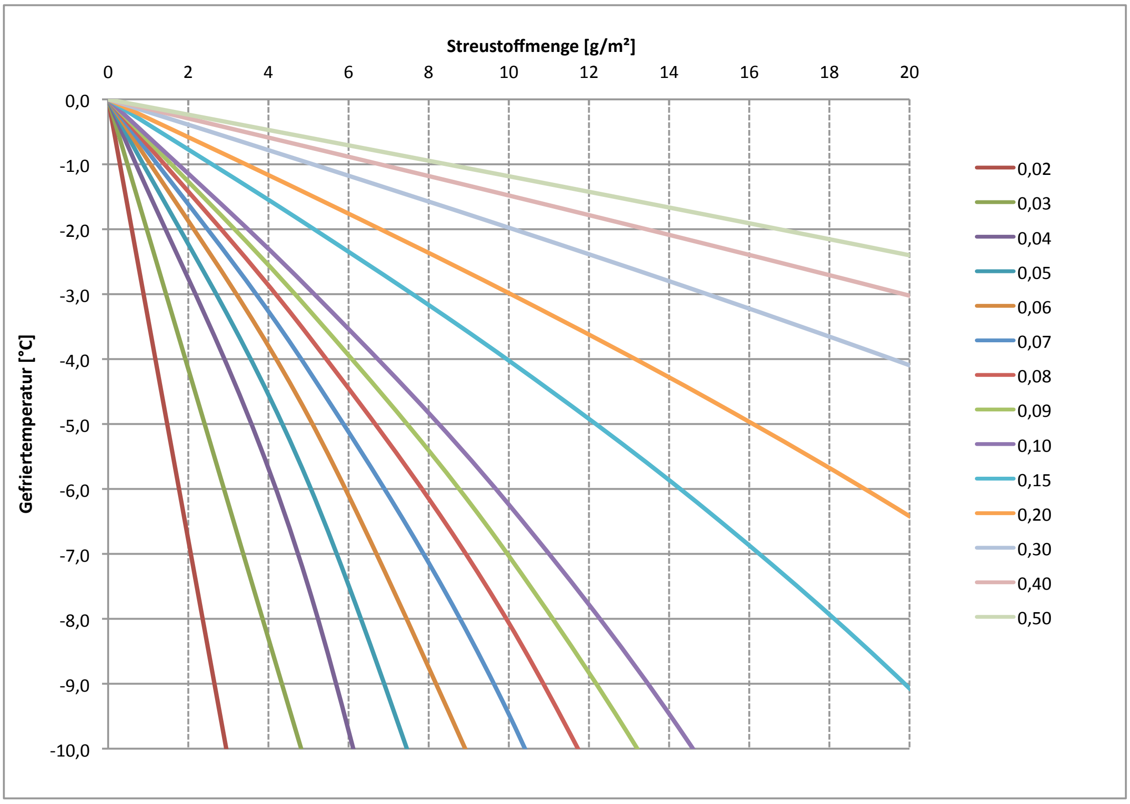

Figure 2: Freezing temperature depending on the quantity of material spread and depth of water film in mm

From the correlations presented in **Figure 2** , the following is easily derivated:

$SD = (T_F \times WFD) / -0.0637$ (2)

SD – Spreading Density in g/m²

T_F - Road temperature

The road temperature T_{FK} calculated can be calculated from a combination of actual measurement of the road temperature (infrared pyrometer) and, e.g. determined from the point forecast of the DWD temperature trend for the time from 0 to 8 hours. The point forecasts of the DWD are transmitted to the service vehicle, updated hourly. According to all present experience, this solution assures great accuracy of the temperature forecast as a procedure, based on the "Thermal Mapping", because the road temperatures measured at the position of the service vehicle are included in the calculation. As a derivative from the practical circulation times that can be realized, a forecast period of maximum 3 hours has been calculated in the field tests. The lowest temperature value T_{PX} forecast within the next three hours is included in the calculation. However, the software is conceived so that other forecast periods can be used at any time for the calculation.

The forecast for the depth of water film is derived from the road condition forecast. This allocation is an initial conceptual approach that must be checked by practical applications.

Road condition (SZ)	DWD Code	Depth of water film [mm]
dry	0	0,01
moist	1	0,02
wet	2	0,06
frost	3	0,02
snow	4	0,10
ice	5	0,06

Table 1: Allocation of depths of water film (WFD) to road conditions forecast

The forecast values are based on the measurement data from road weather stations on the respective route. One of the test routes was on the motorway A 46, in the vicinity of the motorway maintenance department in Werl. The road weather stations included in the forecast are listed in **Table 2**.

Identifier	GMA-Name	Type of route	Location of route	Surface of route	Width	Length
H459	TB Neheim (Moehne)	2	5	5	51,45000	7,95000
H571	TB Wannebach	2	1	5	51,41667	8,05000
H465	TB Rumbecke	2	1	1	51,39444	8,10042
H462	TB Deitmecke	2	1	1	51,38328	8,13494
H583	Echterberg	1	3	1	51,38381	8,14000
H580	TB Fulmecke	2	1	3	51,35000	8,26667
H582	Graenscheid	1	1	1	51,36092	8,27669

Table 2: Road weather stations on the A 46

Legend:

TB – Bridge over valley

Type of route:	1	level to the environment
	2	bridge
Location of route	1	embankment
	3	across a large river
	5	across a small river
Surface of route	1	Asphalt
	3	concrete construction
	5	box girder bridge

A factor for the period that the substance is already on the road and the residual quantity of salt present at the time of spreading is also included in the calculation for the optimum spreading density.

For the calculation of the substance already on the road, the knowledge gained from the measurements of the substance already on the road about percental losses per time unit is included, as well as practical experience [1], [2], [3]. Measurements carried out during the last three years regarding substance already on the road indicated that by far the greatest loss of de-icing substance is in the first hour after applying the spreading material. Furthermore, the measurements indicated that by applying solutions of de-icing salt, significantly fewer losses of de-icing agent occurred.

From investigations carried out in the past years and commissioned by the BASt it is known that within a period of up to 24 h after spreading the last time, a quantity of salt of minimum 2 g/m² is present on the rod [1]. After rainfall and at the start of the winter service period, it must be assumed that no residual salt is present on the road. If there is the technical option for mobile measurement of residual salt, the measured value can be included in the calculation for the spreading density.

The value used for the quantity of residual salt must be deducted from the calculated spreading density.

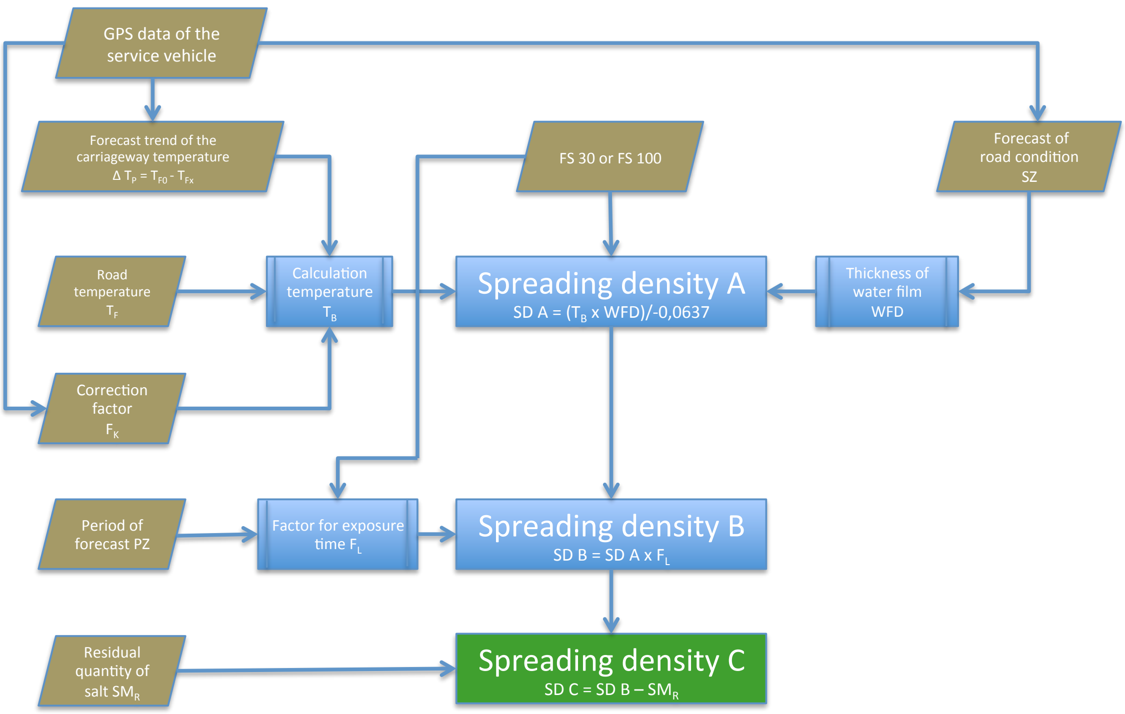

Figure 3: Program sequence plan for calculating the optimum spreading density

For technical implementation of the algorithm in the program, the spreading density must be calculated in three stages (spreading density A, B C). The following general conditions are taken into consideration in the individual stages:

Spreading density A: Calculation value under consideration of the depth of water film and calculation temperature for the road surface, based on the phase limit line (chemical-physical coherences)

Spreading density B: Qualified calculated value under additional consideration of the losses due to the time on the road

Spreading density C: Optimum spreading density under additional consideration of the quantity of residual salt.

The coherences between the input values and staged calculation of the spreading density are represented in a program sequence plan (**Figure 3**).

4. Realization of the System in Service Vehicles

The test systems have been used in two motorway maintenance departments, each on two spreading vehicles in parallel operation. The spreading densities, calculated and set by specialists, have been recorded relating to time and location. Based on this, in an initial step, the plausibility of the calculations were checked under field conditions, in practical application.

Using the additional on-board computers installed in the vehicles, all internal and external data received was processed. Using the programmed algorithm, the optimum spreading density (spreading density C) was calculated in the result, in cycles of a second. The source of the external data was the point weather forecast of the DWD (German weather service) and was updated hourly.

Data transfer to the service vehicles was carried out by the DWD via the server of the Fraunhofer-Institut für Verkehrs- und Infrastruktursysteme (IVI) (Fraunhofer-Institute for Traffic and Infrastructure Systems) in Dresden.

The components for forecasting the quantity for spreading are presented schematically in **Figure 4**.

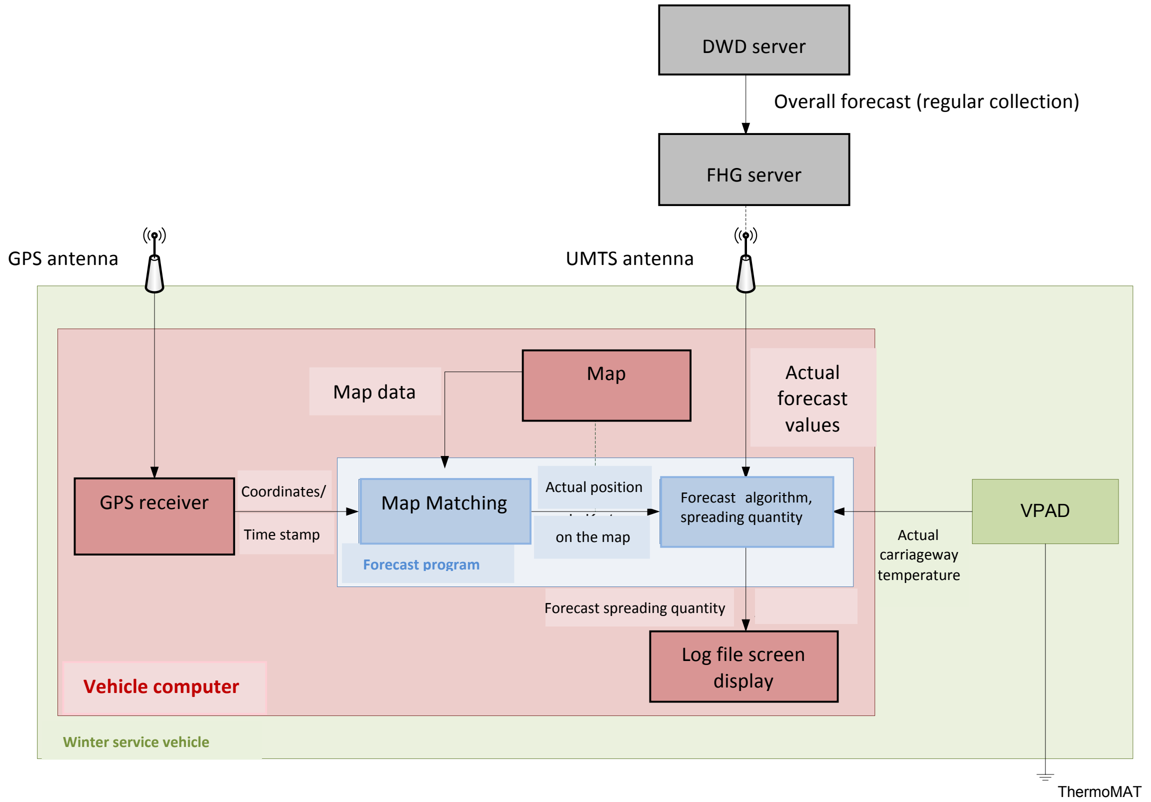

Figure 4: Detailed presentation of the components for forecasting the quantity for spreading

As hardware for the test setup, a Box-PC, Type PICE-V6200-NI with no fan was used for installation in the vehicle. It had a Pineview DualCore processor with 1.66 GHz cycle frequency. In addition, the PC in the vehicle was equipped with a GPS module for determining the position and a GSM/UMTS module for transmitting data between the vehicle and central server. The hardware of the test setup is operated in conjunction with a Vpad and a thermomat system from Küpper-Weisser (**Figure 5**).

Figure 5: Hardware components of the system in laboratory arrangement

5. Results

The practical tests were carried out during the winter service periods 2011/12 and 2012/13 [4]. Installation of the on-board computer and GPS antennae was very easy and quick on all vehicles. The conceived principle of function was implemented in practice without significant modifications and fundamentally fulfilled the stipulated expectations.

From the comparison of the spreading densities, it can be seen that for the road condition forecast "dry" or "moist", there is always a lower spreading density calculated than actually set in practice by the operating personnel. For snowfall, due to the algorithm, a higher spreading density is calculated than actually applied in practice.

With the present options, the calculation for the optimum spreading density, using an algorithm under consideration of measurement and forecast values, exploits a potential in saving unused up to present for reducing the quantity of salt, foremost by deployment for preventative spreading.

In conjunction with the hardware installed in the vehicle, the dosing algorithm can reduce the heavily distinctive subjective factor for the selection of spreading density for winter service spreading. In this respect, there is the option to exploit a large potential in saving using such assistance systems for the application of salt. The asset of the system, in comparison to the infrared pyrometer system, lies in the better consideration of the quantities of liquid to be anticipated on the road. That increases the surety of the driving personnel when selecting the spreading density in the event of preventative spreading. The function capability of the system has been verified. For practical implementation, the function of the system must be stabilized. Subsequently, the algorithm can be immediately used for setting the spreading density on the spreading machines. Ideally, the system should be configured so that it is compatible with spreading machines of the established manufacturers. The prerequisites for this are present.

From the experiences gained from the tests, two suggestions can be derived that can be realized in the short-term, also independent of the introduction of the system.

1. Equipping spreading machines with a "Residual salt button". By operating this, due to the knowledge of spreading carried out, during application of the spreading material the assumed quantity of residual salt can be taken into consideration during dosing by using a fixed value (e.g. 2 g/m^2).
2. GPS-controlled temperature correction approx. 100 m before large bridges, in order to adapt the dosing to compensate for delays due to the system. The temperature correction could again be switched off after a few metres on the bridge if the system can immediately implement the actual temperature measured into the optimum spreading density. This action could increase confidence in the temperature-dependent dosing.

With the objective of introducing such systems practically into the winter service, the following steps should be taken:

1. Modification of the algorithm in evaluation of the practical tests and under consideration of the specialist discussions.
2. Adaptation of the system to the spreading machines of other manufacturers.
3. Carrying out monitored practical applications with direct transmission of the calculated spreading density to the control unit of the spreading machines.
4. Inclusion of a mobile measurement of the quantity of residual salt, as soon as the technical possibilities are available.

REFERENCES

[1] Hausmann, G., (2009). Verteilung von Tausalzen auf der Fahrbahn, Berichte der BASt, Heft V 180, Bergisch Gladbach

[2] Hausmann, G. (2012). Empfehlungen zum richtigen Aufbringen von Tausalzlösungen, Berichte der BASt, Heft V 218, Bergisch Gladbach

[3] Badelt, H., Hausmann, G. (2012). MaÎtrise du dosage en fondant routier / Distribution of the de-icing salts on the road surface; Routes-Roads, Paris, № 345, 1st Quarter

[4] HAUSMANN, G. (2013). Optimierung der Streustoffausbringung, Modell der objektiv notwendigen Streudichten im Straßenwinterdienst, unveröffentlichter Forschungsbericht im Auftrag der BASt

KEYWORDS

WINTER MAINTENANCE / SPREADING MACHINES / SPREADING DOSAGE / DE-ICING AGENT