A new model for a winter index to estimate and evaluate consumption of salt

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ABSTRACT

Episodios de temperaturas muy bajas y precipitaciones intensas durante los inviernos de 2009/10 y 2010/11 llevaron, en algunas partes de Alemania, a consumos muy elevados de fundentes. En algunas ocasiones, incluso, los proveedores de sal fueron incapaces de cubrir la demanda.
Para estimar y valorar mejor la demanda y el consumo de sal en el futuro, el "Bundesanstalt für Straßenwesen" recibió el encargo de desarrollar un nuevo modelo de predicción. Como punto de partida, se utilizaron los datos diarios de más de 500 estaciones de observación del clima pertenecientes al Servicio Alemán de Meteorología (Deutscher Wetterdienst). De los datos climáticos se deriva el tipo de hielo (nieve, congelación del agua de lluvia, condensación y enfriamiento del vapor de agua) y se asigna a un escenario medio de actuación (esparcimiento de fundentes). Por lo tanto, si se conoce la superficie total de las carreteras que rodean a una determinada estación puede calcularse el consumo de fundentes. El uso del modelo ha permitido predecir, también, el consumo de fundentes para espacios de tiempo cortos (días) y diferentes redes de carreteras.

1 INTRODUCTION

In the winter of 2009/10 and in December 2010, Germany experienced unusually intensive winter weather with severe frost and/or much snowfall. At the time, large areas were affected simultaneously and over longer periods. As a consequence, more situations with slippery roads occurred as compared to other winter periods. This resulted in turn in a very high consumption of de-icing salt. Existing salt deposits were soon depleted. Salt suppliers were not able to fully meet the additional demand.
In order to meet the demands of winter service in case of severe and long periods of winter weather in the future a possibility to estimate demand more accurately is to be created. Traditional models for a winter index only result in statements on winter conditions that allow a relative comparison of de-icing salt consumption during the examined periods.
A new model approach is to use meteorological data for the surface areas to be treated so as to make a mass-related estimation of salt consumption.

2 MODEL APPROACH

2.1 BASIC IDEA

The basic idea of the new model approach is to derive possible types of slippery road from extensive weather data. The respective types of slipperiness are assigned an average salting scenario with information of x g/m². These are in turn assigned to the road surfaces to be treated around a meteorological station. The scope of the winter service deployment is differentiated according to road classification.

2.2 WEATHER DATA

The data of the meteorological network of the German Meteorological Service (DWD) are used to assess the weather. The following data are available to do so:

- Daily maximum air temperature
- Daily minimum air temperature
- Relative air humidity at 06:00
- Relative air humidity at 12:00
- Relative air humidity at 18:00
- Height of precipitation per day
- Existing snow height during the day
- Height of new snow per day

The duration of precipitation would have been an essential point. However, this information cannot be provided.

The data are collected from more than 500 measurement and observation stations that are evenly distributed over Germany.

The assessment of a given winter is made on the basis of data from 1 November to 31 March.

2.3 SALTING SCENARIOS

The following daily salting scenarios with regard to the type of slipperiness are assumed on the basis of the meteorological data:

- Packed snow:
  Condition: Snowfall
  Salting scenario: One prophylactic application of 20 g/m², per 2 cm snowfall 20g/m², maximum 7x per day
  20 g/m² + 10 g/m² per cm snowfall, maximum 160 g/m² per day
- Black ice or icy conditions:
  Condition: Minimum air temperature <=0℃, height of precipitation >0 mm (no snowfall)
  Salting scenario: 2x20 g/m² (one prophylactic application, once after precipitation)
  40 g/m² per day
- Slippery frost:
  Condition: Minimum air temperature <=0℃, no precipitation, relative air humidity 90%
  10 g/m² per day

All salting thicknesses are assumed to be of dry matter.

These scenarios must be regarded as rough average values. In case of slippery frost, salting is often not done on the whole network. On the other hand, at lower temperatures it might be necessary to apply a higher salting density, or multiple applications of salting in case of longer periods. Salting in case of snowfall may differ from the assumption made depending on intensity and time of circulation.

The value for black ice or icy conditions is to be considered as a mean value that covers a particularly wide range. Precipitation as rain does not necessarily coincide with temperatures below zero. Salting is not necessary. On the other hand, long lasting rainfall around freezing temperature may require a clearly higher number of deployments.

2.4 SURFACE AREA DATA

For surface area data, the length information from the manual for road and transport “Der Elsner”, issue 2010 was applied. The length information was assigned to the following average widths. This should also include adjacent areas and branches in the estimation:

- Federal motorways: Length x 20 m width

- Federal roads: Length x 8 m width
- State roads: Length x 6 m width
- District roads: Length x 5 m width
- Local roads: Length x 7 m width (including pavements)

For the calculations, the surface data are evenly distributed around the measurement stations included.

2.5 Scope of treatment

There are different treatment times for the individual road categories. For the model, the provisions of the demand level for roads outside built-up areas apply according to the requirements of the Federal Minister for Traffic, Building and Urban Development.
Accordingly, federal motorways are treated around the clock. The treatment scope is therefore 100%.
For all other roads outside built-up areas it is assumed that all surface areas of the roads outside built-up areas are essential for traffic and treated during the time from 6 a.m. to 10 p.m. Compared to motorways, the time scope is less by one third. The treatment scope is therefore assumed to be 67 %.
The estimation for local roads is the most difficult to make. Many roads are not treated or treated very little in the scope of differentiated winter service. There is often a prohibition to use de-icing salt. The treatment scope for such roads is assumed to be 10 %. Due to the high ratio of length of local roads, this assumption receives high weighting and severely influences an estimation of the federal-wide overall consumption.

3 APPLICATION OF THE MODEL

3.1 Estimation of consumption

The model was applied for the first time on the basis of the meteorological data of the winter of 2009/2010 using the assumptions described in section 2. A summarized calculation is shown in table 1. The resulting federal-wide consumption is around 4.2 million t. The table also includes a differentiated list for different road categories according to section 2.4. The estimated values for federal trunk roads are compared with the consumption reported to the federal government by the states. Even when the absence of weather data is considered, the values of the estimation and of the measurements are rather close.

		Motorway	Federal roads	State Roads	District roads	Local roads
	km	12.594	40.413	86.607	91.565	457.171
	Width [m]	20	8	6	5	7
	Surface area [m²]	251.880.000	323.304.000	519.642.000	457.825.000	3.200.197.000
	Proportion per station (525)	479.771	615.817	989.794	872.048	6.095.613
Salting applikation density per day	Frequency of salting densities with regard to all stations	Application quantity [t]	Application quantity [t]	Application quantity [t]	Application quantity [t]	Application quantity [t]
10	9990	47.929	61.520	98.880	87.118	608.952
30	3438	49.484	63.515	102.087	89.943	628.702
40	20716	397.558	510.291	820.183	722.614	5.051.069
50	1542	36.990	47.480	76.313	67.235	469.972
60	1031	29.679	38.094	61.229	53.945	377.075
70	818	27.472	35.262	56.676	49.933	349.035
80	560	21.494	27.589	44.343	39.068	273.083
90	355	15.329	19.675	31.624	27.862	194.755
100	301	14.441	18.536	29.793	26.249	183.478
110	162	8.550	10.974	17.638	15.540	108.624
120	218	12.551	16.110	25.893	22.813	159.461
130	97	6.050	7.765	12.481	10.997	76.866
140	95	6.381	8.190	13.164	11.598	81.072
150	42	3.023	3.880	6.236	5.494	38.402
160	286	21.954	28.180	45.293	39.905	278.935
	Total per road type [t]	698.883	897.061	1.441.833	1.270.312	8.879.480
	treatment ratio [%]	100	67	67	67	10
	Total after discount	698.883	601.031	966.028	851.109	887.948
	Overall total [t]					**4.004.999**
	reported consumption	693.900	606.000	With 7% added due to lacking data		4.285.349

Table 1 - Summary of the calculation of salt consumption for the winter of 2009/2010

Table 2 contains a calculation for the road administration in the state North-Rhine Westphalia. Here, exact surface data are available for the treated roads. The captured consumption data are quite compatible with those of the federal trunk roads, Even in case of the few district roads there is only a minor deviation. For state roads, the estimated value is more than 15% above the actual consumption.

	Road category	Motorway	Federal roads	State Roads	District roads
	surface area [m²]	51.420.460	37.526.155	80.308.732	5.749.303
	Proportion per station (45)	1.142.677	833.915	1.784.638	127.762
Salting applikation	Frequency of salting densities with regard to all stations	Application quantity [t]	Application quantity [t]	Application quantity [t]	Application quantity [t]
10	542	6.193	4.520	9.673	692
30	282	9.667	7.055	15.098	1.081
40	1.305	59.648	43.530	93.158	6.669
50	126	7.199	5.254	11.243	805
60	68	4.662	3.402	7.281	521
70	71	5.679	4.145	8.870	635
80	42	3.839	2.802	5.996	429
90	28	2.880	2.101	4.497	322
100	25	2.857	2.085	4.462	319
110	10	1.257	917	1.963	141
120	22	3.017	2.202	4.711	337
130	6	891	650	1.392	100
140	13	2.080	1.518	3.248	233
150	2	343	250	535	38
160	31	5.668	4.136	8.852	634
	Total per road type [t]	115.879	84.567	180.980	12.956
	treatment ratio [%]	100	67	67	67
	Overall total [t]	115.879	56.660	121.257	8.681
	reported consumption	111.170	59.800	102.400	8.600
	Difference between demand and consumption [%]	4,1	-5,5	15,6	0,9

Table 2 - Calculation of the overall consumption for the road administration in the state North-Rhine Westphalia in the winter of 2009/2010

Figure 1 shows a list of the estimated consumptions for all roads for various winter periods. According to this, salt consumption in the winter of 2009/10 is estimated only slightly higher than in the winter of 2005/2006. The consumption in the short period of November and December 2010 exceeds the consumption of the full winter periods of the previous years.

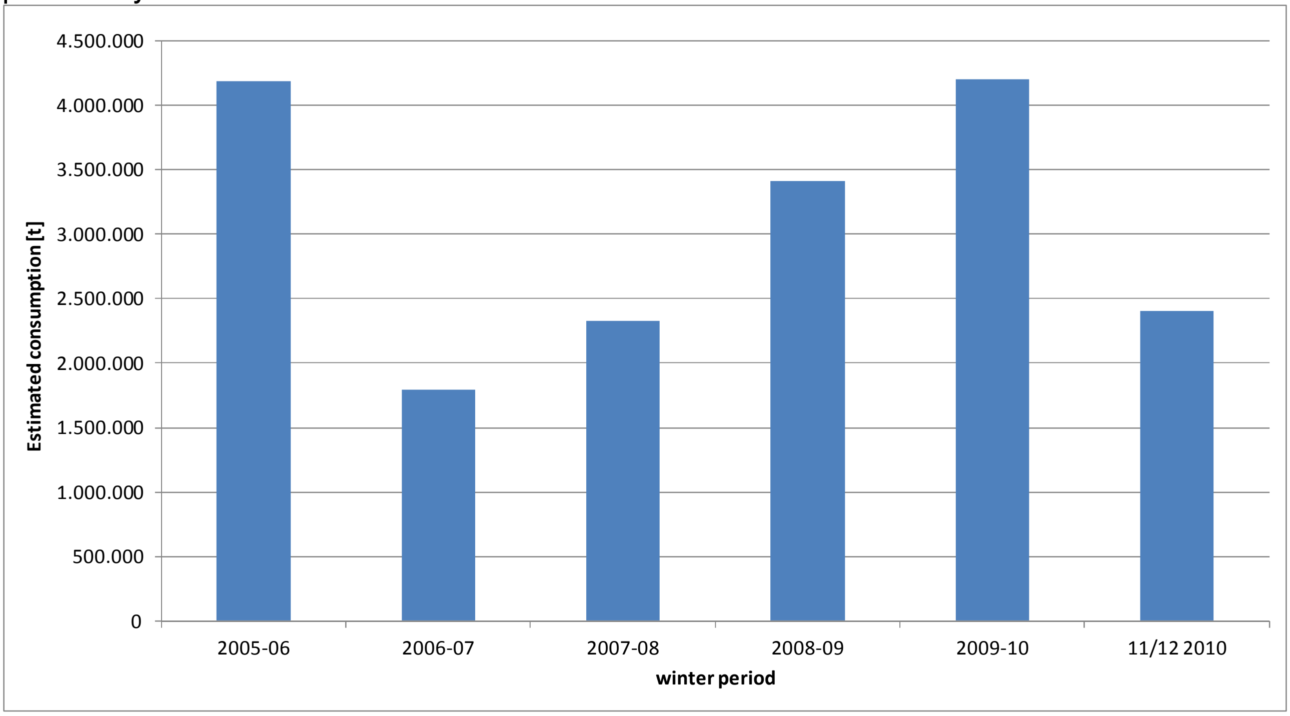

Figure 1 - Estimated consumptions for various winter periods

Reported consumptions are available for federal trunk roads, itemized according to federal motorways and federal roads; these can be compared to the estimated values. Figure 2 shows this comparison. This overview also shows minor differences between reported consumptions for the winters of 2005/06 and 2009/2010.

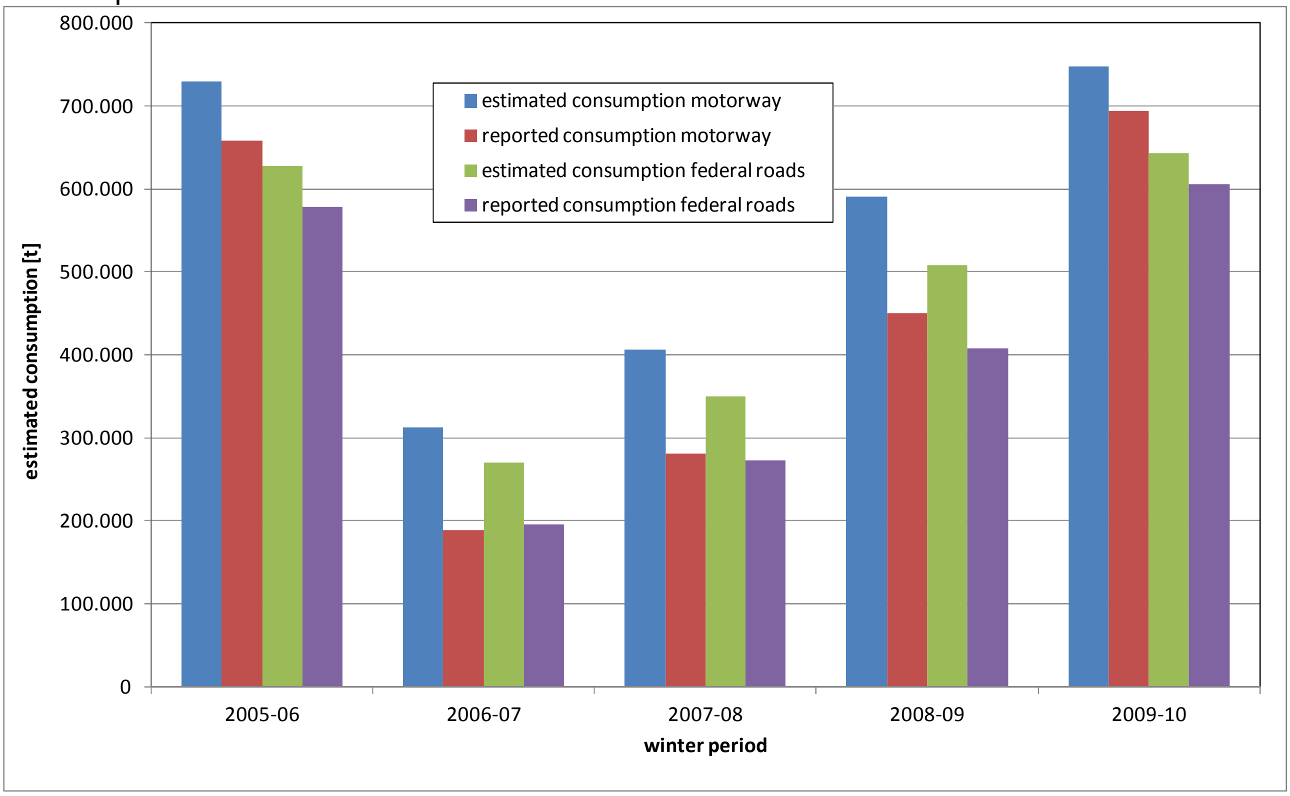

Figure 2 - Estimated and reported consumptions of de-icing salt for various winter periods

In all comparisons, the model estimation states higher values than the totals reported by the states. The differences are values between 6 and 40 %. In all winter periods the difference for federal motorways is higher than that for federal roads. One reason for this may be due to an overrating of the work done at night, or that work is done on federal roads outside the stipulated working times.
The differences increase with decrease of salt consumption per winter (figure 3). Again, there are no exceptions here.

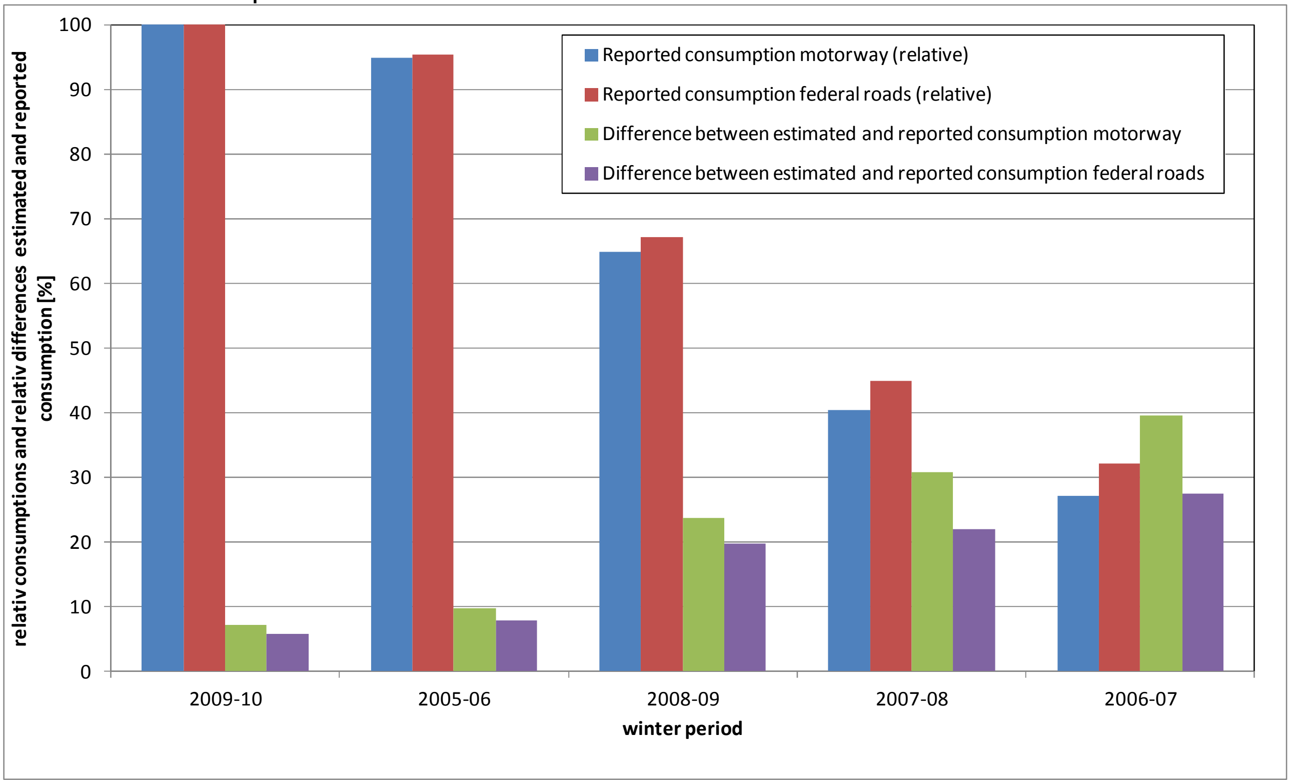

Figure 3 - Differences between estimated and reported consumptions depending on consumption (all values are relative, only for motorways and federal roads)

The itemization of the total for a winter in daily consumption allows a valid comparison of consumption and supplied quantity, which may be very useful for planning of storage capacities and supplied quantities. The first example is shown in figure 4 for the winter of 2009/2010. Each column represents consumption on one day for all roads in Germany. The highest consumption on one day in that winter was slightly over 100,000t.
The resulting line in the diagram describes the available stock of de-icing salt. The initial quantity is assumed here to be 1.9 million tons. Of this, 1.2 million tons are stored with the road construction administrations and 0.7 million tons are stored with salt suppliers. The available stock in this example is ideally replenished immediately.
Deliveries are not made on weekends an public holidays. The maximum quantity delivered daily in this example is 30,000 tons. Initially, less than the maximum quantity delivered is used up. Production of de-icing salt is limited when warehouses are full at the beginning of winter. From mid-December, consumption on most days is higher than what can be delivered. Stock decreases continuously. By mid-March stock is used up. The line shown of stock below zero tons symbolizes shortage.

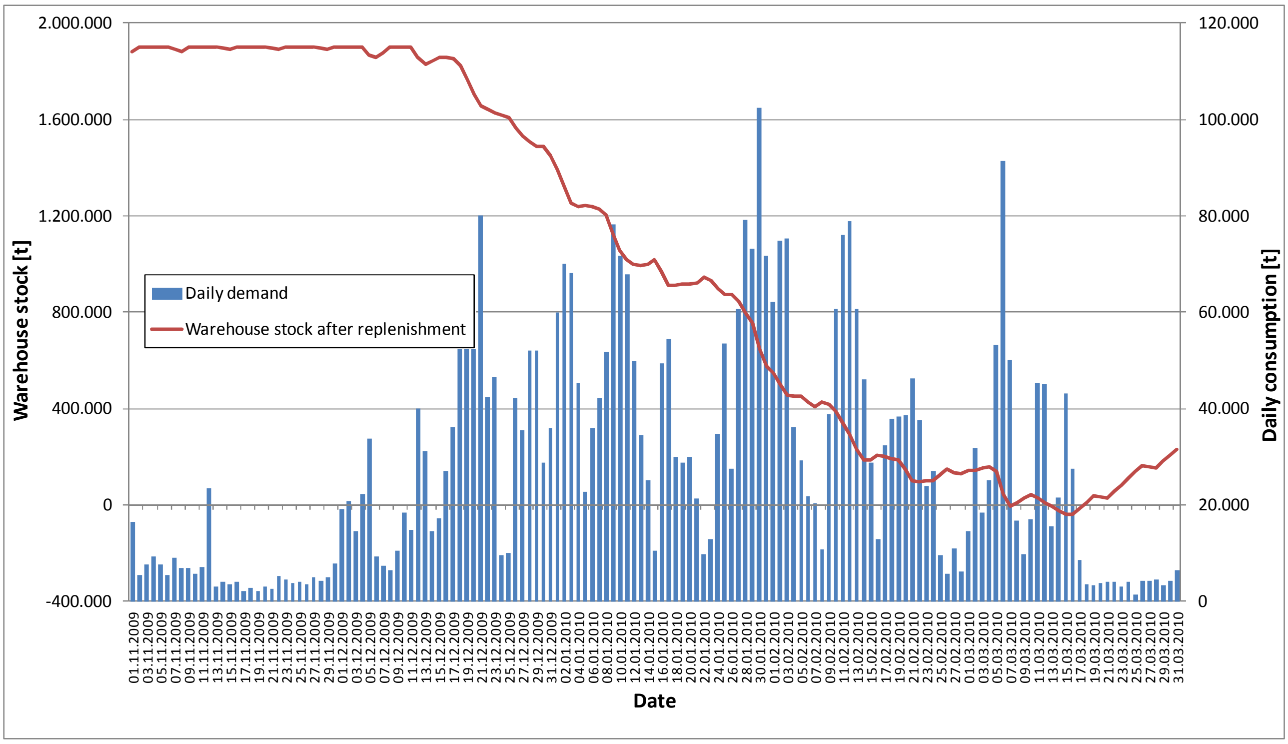

Figure 4 - Estimated daily consumption of de-icing salt in Germany in the winter of 2009/2010 with the development of warehouse stock assuming ideal re-supplies of up to 30,000 tons daily.

On the background of daily consumptions of the winter of 2009/2010, figure 5 shows a different scenario. Here, different courses of warehouse stock and consumption are shown. Suppliers' warehouse stock and stock in the depots of road construction administrations are represented with two lines (black and blue). The red line shows cumulative consumption. The initial warehouse stock in the depots of road construction administrations and suppliers combined with ongoing production is marked by the green line.

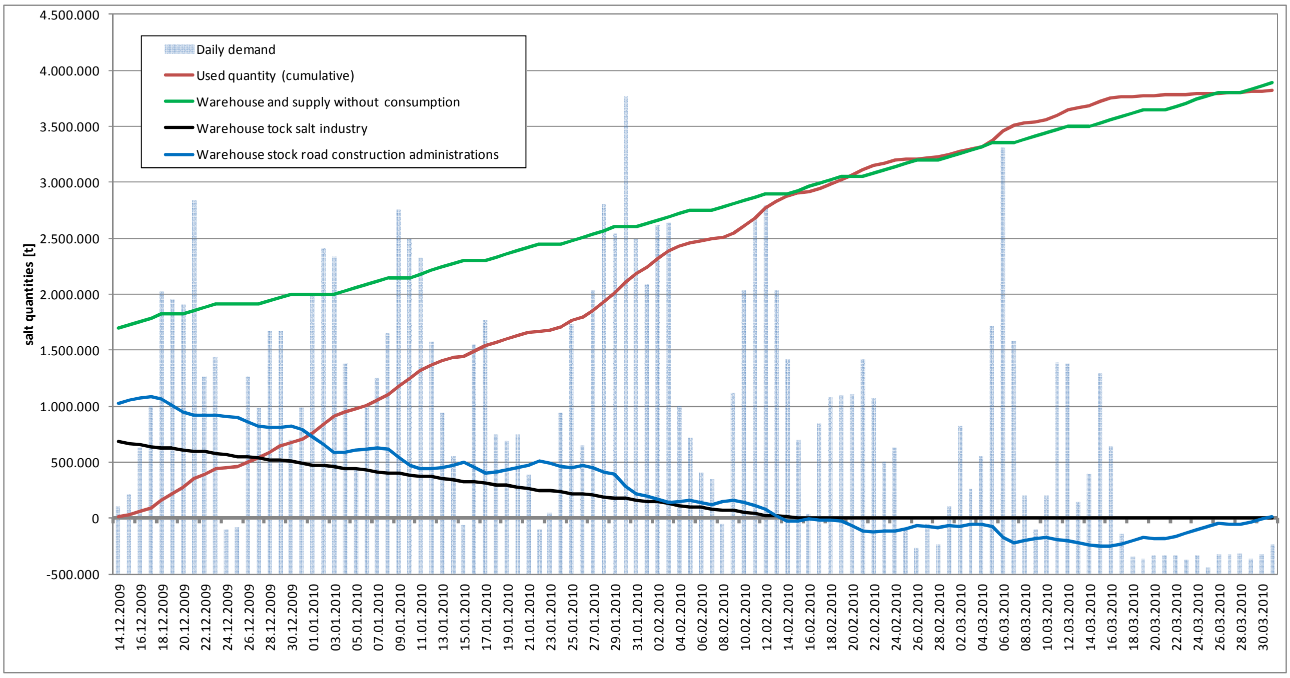

Figure 5 - Estimated daily consumption of de-icing salt in Germany in the winter of 2009/2010 with the development of warehouse stock assuming ideal re-supplies of up to 30,000 tons daily

For supplied quantities, a distinction is made between quantities from production and quantities from suppliers' warehouses. The course only starts mid-December, because there was hardly any consumption before that time. The low quantity used was not replenished by that time. The initial stock was therefore slightly less than assumed in figure 4. Again, daily production is assumed at 30,000 t. In addition, 15,000 t can be delivered from the suppliers' warehouses. However, this is only possible until the end of January 2010. At that point, the warehouses are depleted. The re-supplied quantity then equals the production quantity. In case of similar consumption, depots of the road construction administrations are depleted sooner.
Calculations with the same approach were made for the period from 22 November to 31 December 2010. In total, the estimated consumption during that period was about 2.3 million tons of de-icing salt for all German roads. On 25 December 2010, a daily consumption of 130,000 t was estimated, which is more than a quarter above the daily peak estimated for the winter of 2009/2010.
Figure 6 shows the estimate of daily consumptions in that period for federal trunk roads. From an estimated initial stock of 270,000 t in the depots of the road construction administration, two lines to represent the course are shown. The red line shows the course in case of a daily supply of 10,000 t. The course of warehouse stock assuming a daily re-supply of 15,000 t is represented by the green line. In case of the lower supplied quantity, de-icing salts available would already be used up before Christmas; re-supplies would not have been sufficient. In case of a supplied quantity of 15,000 t daily, problem would not have occurred.

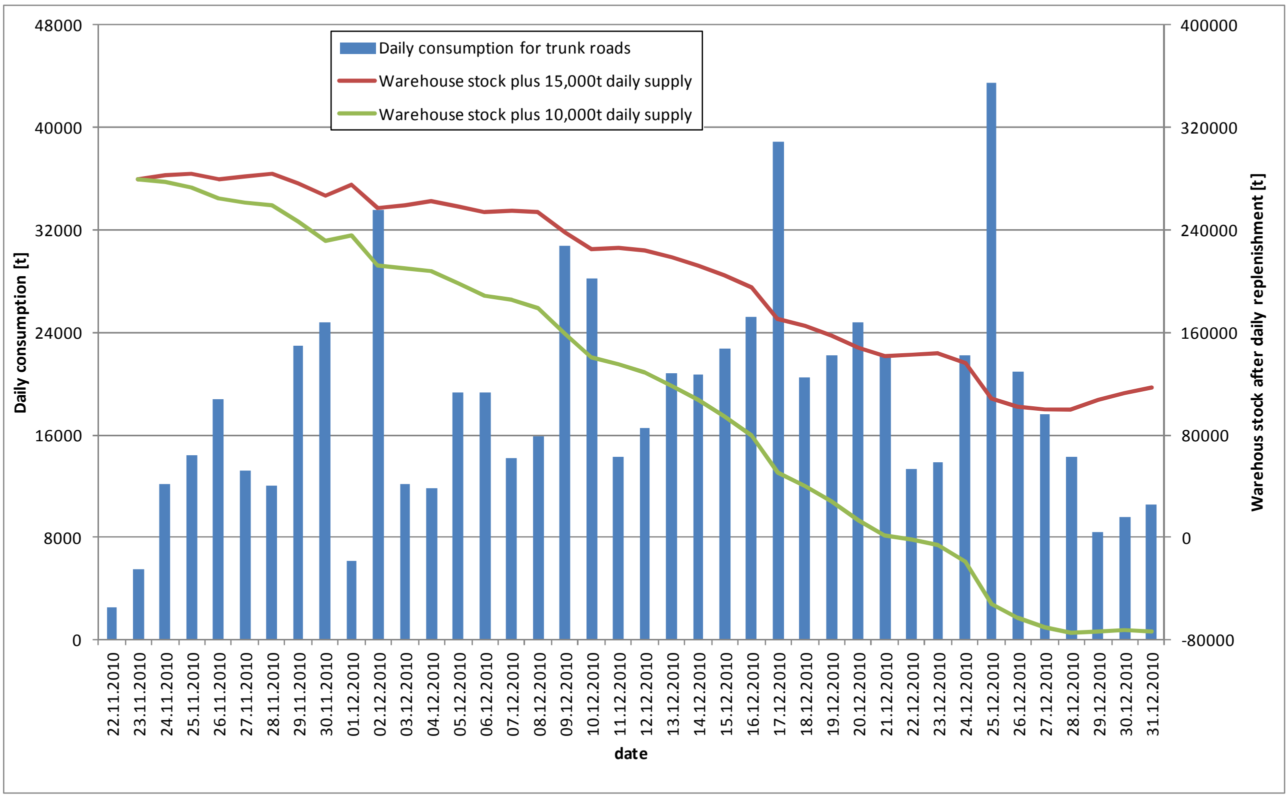

Figure 6 - Daily consumptions in the period 22 November – 31 December 2010

All representations of the course of warehouse stocks show ideal conditions of re-supplies for federal-wide average consumptions.
Smaller networks may be burdened with extreme consumptions over longer periods, which may result in supply problems. For this case, results from the model estimation are currently not available, but that can be calculated using the model approach.
In practice, many road construction administrations place orders and many suppliers deliver quantities. They are not coordinated with each other and will not be in the future. To avoid major supply shortfalls of salt supplies in the future, it is useful to replenish local

minor shortages as soon as possible. This is the only way to avoid a situation where major simultaneous requests for supply occur that cannot be fulfilled by salt suppliers.

3.2 REPRESENTATION OF POTENTIAL SAVINGS

The model approach may be used for pure estimation of quantity as well as for an assessment of changed measures taken by winter service. This is shown in the two examples below. For an estimation of saved quantities, the approach for de-icing salt scenarios in section 2.3 is modified.

The first example (table 3) refers to application of de-icing salt solutions. In case of slippery frost, only 6 g/m² of de-icing salt are used instead of the average quantity of 10 g/m². For packed snow and icy conditions/black ice 12g/m² are applied in the first – prophylactic treatment instead of 20g/m². Table 3 shows the same calculation as table 1 (here only for federal trunk roads) with the reduced application densities per day. Due to the high number of days with only one or two deployments daily the consumption of de-icing salt is reduced by 20%. The saved de-icing salt can is sufficient for an additional 5 days with intensive winter service. The costs for federal trunk roads would be reduced by almost 20 million Euros. However, this calculation should be balanced by corresponding costs for investment for using de-icing salt solutions.

Salting application densities per day [g/m²]	Number of deployment days	Total number of deployment	Salt quantities federal motorways [t]	Salt quanitiies federal roads (67% scope of treatment) [t]	Total federal trunk roads [t]
6	9.990	9.990	28.757	24.731	53.489
22	3.438	6.876	36.288	31.207	67.495
32	20.716	41.432	318.046	273.516	591.562
42	1.542	4.626	31.072	26.721	57.793
52	1.031	4.124	25.721	22.120	47.842
62	818	4.090	24.332	20.925	45.257
72	560	3.360	19.344	16.636	35.980
82	355	2.485	13.966	12.011	25.977
92	301	2.408	13.286	11.426	24.711
102	162	1.458	7.928	6.818	14.745
112	218	2.180	11.714	10.074	21.788
122	97	1.067	5.678	4.883	10.560
132	95	1.140	6.016	5.174	11.190
142	42	546	2.861	2.461	5.322
152	286	4.004	20.857	17.936	38.793
Total [t]	39.651	89.786	565.867	486.639	1.052.506
Proportionate percentage of deployment with solution:	44%	Consumptions without use of solutions (information from table 1)	698.883	601.031	1.299.914
				Savings de-icing salt:	247.408
			Cost savings of pur salt (80€/t):		19.792.665 €

Table 3 - Estimation of savings of de-icing salt due to use of de-icing salt solutions for the winter of 2009/2010

The other example (table 4) shows an estimation of the savings potential in case of lower application densities during snowfall. According to observations made in Austria, only low application densities of de-icing salt is considered necessary to keep snow in a condition fit for clearing. These are to be included in a new information sheet of the FGSV (Research Society for Roads and Traffic in Germany). In the model for the estimation the de-icing salt scenario for snowfall is changed. Instead of 10 g/m² per centimetre of new snow, only 7.5 g/m² are assumed as mean application density. This is valid for all applications except for prophylactic application and the last deployment after snowfall has finished.

In the winter of 2009/2010 with large amounts of snow, about 45,000 t of salt could have been saved if this approach had been applied. This saved quantity would have been sufficient for an additional peak day or two average days. Except for staff training, this measure would not require any other investments.

Salting application densities per day [g/m²]	Number of deployment days	Total number of deployment	Salt quantities federal motorways [t]	Salt quanitiies federal roads (67% scope of treatment) [t]	Total federal trunk roads [t]
10	9.990	9.990	47.929	41.218	89.148
30	3.438	6.876	49.484	42.555	92.039
40	20.716	41.432	397.557	341.895	739.452
47,5	1.542	4.626	35.141	30.221	65.362
55	1.031	4.124	27.205	23.396	50.602
62,5	818	4.090	24.528	21.094	45.622
70	560	3.360	18.807	16.174	34.981
77,5	355	2.485	13.200	11.352	24.551
85	301	2.408	12.275	10.556	22.831
92,5	162	1.458	7.189	6.183	13.372
100	218	2.180	10.459	8.995	19.454
107,5	97	1.067	5.003	4.302	9.305
115	95	1.140	5.241	4.508	9.749
122,5	42	546	2.468	2.123	4.591
130	286	4.004	17.838	15.340	33.178
Gesamt	39.651	89.786	674.325	579.912	1.254.237
		Comsumptions without reduced salting application desity during periods of snowfall (information from table 1)	698.883	601.031	1.299.914
				Savings de-icing salt:	45.677
				Cost savings of pur salt (80€/t):	3.654.147 €

Table 4 - Estimation of savings of de-icing salt due to reduced application during times of snowfall for the winter of 2009/2010

4 FURTHER DEVELOPMENT OF THE MODEL

Since the selected model approach was still considered a rough draft, it has been further developed. The further development includes a differentiated examination of the meteorological data. Figure 7 shows the calculation course. Differentiation results from examination of the precipitation quantity and relative air humidity. Using the difference between minimum and maximum temperature for air, a distinction is made between short and long periods of precipitation with various applications. The model also provides a differentiation of application densities depending on relative air humidity.

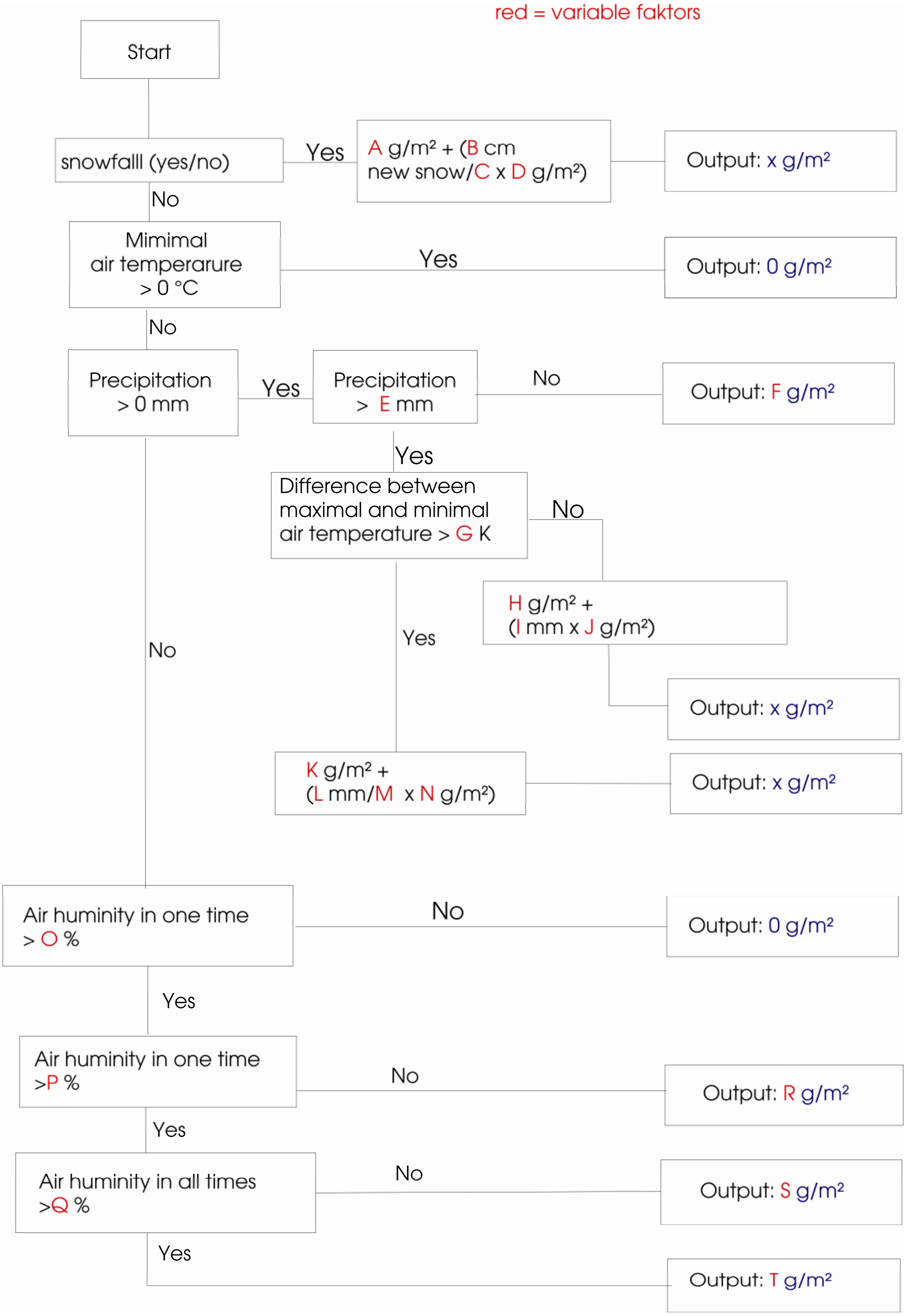

Figure 7 - Calculation model

For further adjustment of the calculation approach, BASt has developed a special program. It can be used to make quick calculations with changeable parameters. Calculations are possible German-wide and for all individual states. The input screen for the calculations is shown in figure 8.

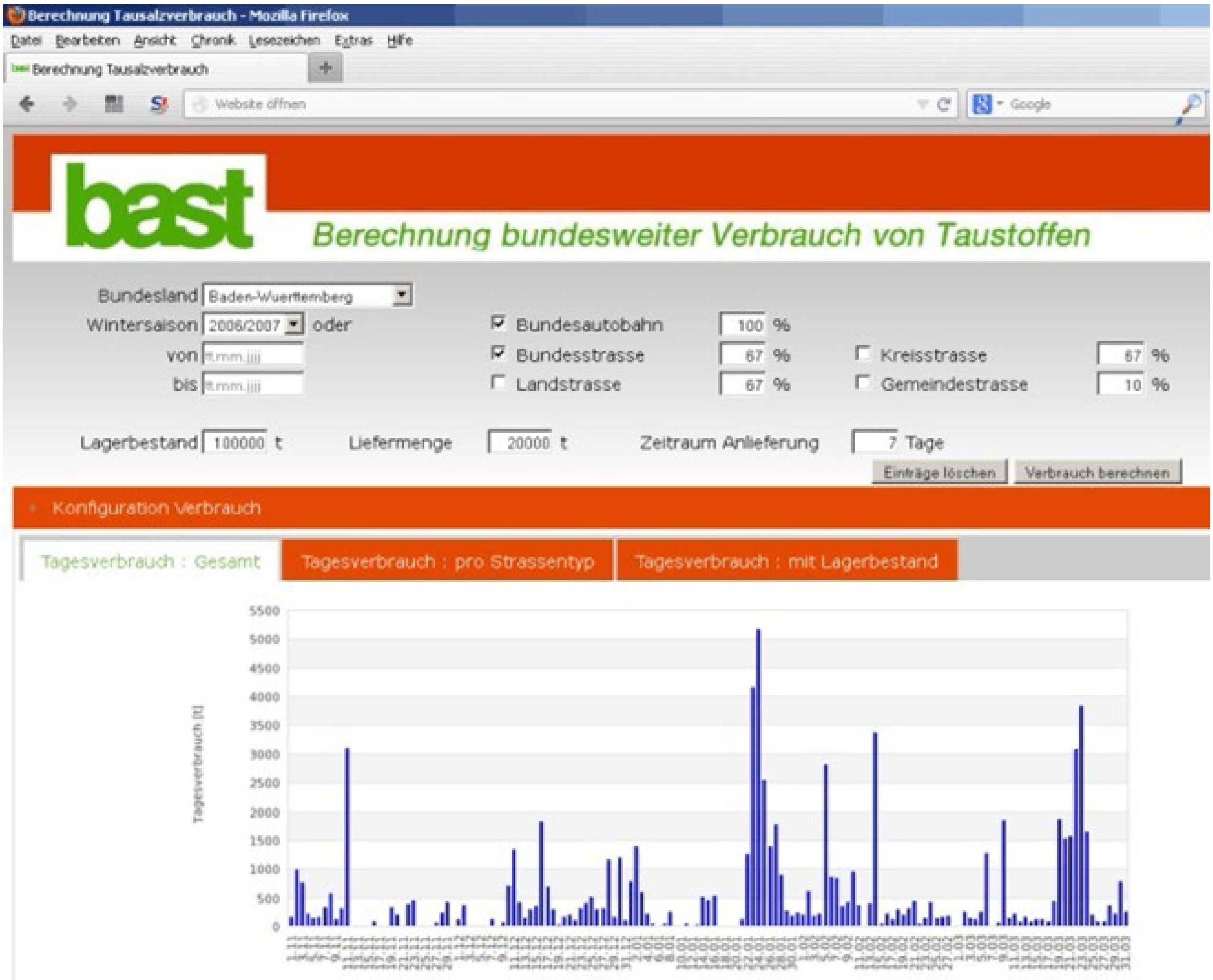

Figure 8 - Input screen

Up to now, only little experience with the application is available.

5 SUMMARY AND OUTLOOK

Applications of the model show varied congruence of the estimations of the model and the reported consumptions. The more severe the winter, the smaller the difference is between the two values.
An exact estimation requires exact initial values. The meteorological data are regarded to be quite precise. However, due to their lack of density (sometimes only one value per day), it is not possible to assess the development of slipperiness exactly. The ca. 500 measurement points are not regarded as sufficient for exact small-scale assessment. An important further development of the model is seen in use of signalling systems for slipperiness. There are a larger number of these. The provide data every 15 minutes. Their use is expected to provide a more precise exact retroactive reflection of the weather and of road conditions than is currently possible by using meteorological data. However, availability of the data will have been improved. Furthermore, it must be checked whether they are exact.
Also, information about the surfaces is decisive for the estimations. For calculations concerning federal motorways, the surface data from the database "bisstra" (German data base of motorways and federal roads) are to be included in the future.
The software tool developed by the Federal Highway Research Institute provides for calculation of various scenarios. Mainly, it simplifies calculations of daily consumption that

previously required much effort. Calculations are also possible for individual states.
Apart from retroactive assessments, we are planning to develop a forecast for estimating consumption. This may be very useful in case of a foreseeable shortage of de-icing salt in order to initial emergency measures or for better disposition of transport capacities of existing salt stock to the maintenance depots.