RESIDUAL SALT MODEL FOR DAILY APPLICATION IN WINTER SERVICE MANAGEMENT

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ABSTRACT

In an effort towards a more economic and effective use of salt in winter maintenance, a joint R&D project, MORS (Modelling Residual Salt), has been initiated and financed by the Nordic road authorities and is administered by NordFoU. The purpose is to develop a model for residual salt to be implemented within present and future decision support systems for daily winter service management. The model will be capable of calculating the residual salt in real time or predicting the development of residual salt on the road after spreading. The model predicts the durability of salt application, taking traffic, road and weather parameters into consideration. Implementation of the model will be made possible in a range of different complexity levels including comprehensive algorithms into existing advanced decision support systems. This will also be available for use as printed graphical nomograms, describing the same processes. The model will provide decision makers with a better option of assessing required salt rate on the road surface and planning future operations. It is expected that the model may contribute to a more precise and sound use of salt application rate, without compromising traffic safety and road network accessibility.

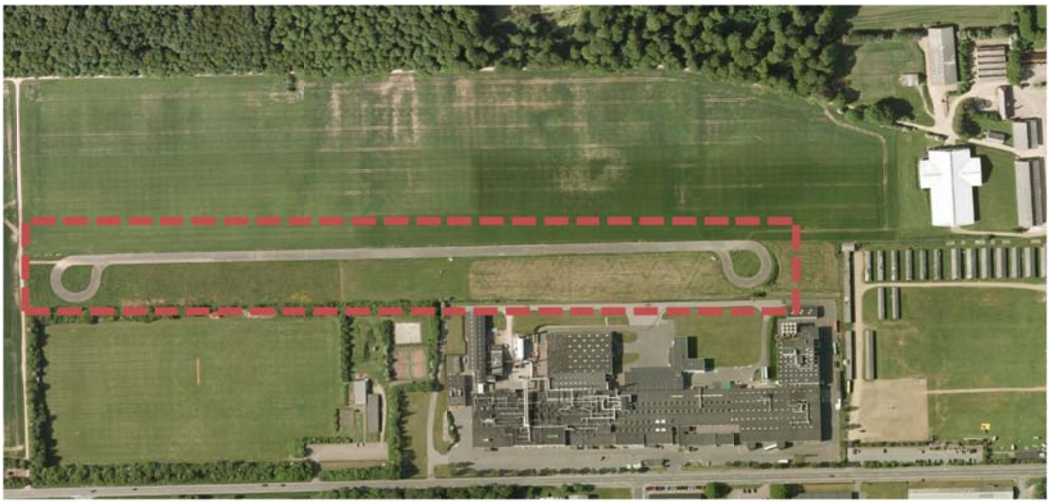
1.0 BACKGROUND

The question about optimising the use of de-icing agents has been an issue for decades among Scandinavian countries and still is a major topic for discussion and further exploration. Thus, through years the authorities have been successful to reduce and optimise the use of salt by applying different approaches in salting methods such as pre-wetted, brine or combi spreading. Sophisticated application rates have been introduced, which was developed based on many years of experience and latest knowledge in relation to chemical properties. However, all these initiatives are initiated before salting action. Our next concern is to discover what actually happens to the salt that is spread out as a result of either call-out as prevent or urgent action due to icy road.

The progress of residual salt is in our view one of the key information to avoid unnecessary actions and to be able to optimise the application rate prior an action. Therefore, this project was initiated under the NordFoU framework, the common platform of the Nordic road administrations for research collaboration. The funding partners for the project, which runs in the period 2011-2013 with extension in the period of 2013-2015, are the road administrations of Denmark, Sweden, Norway and Iceland.

2.0 METHOD DESCRIPTION

In order to monitor residual salt development under controlled conditions, the project team has been carried out field experiments on a test track at Bygholm, Horsens (Denmark). The test track is a close stretch where different salting methods have been applied and then progress of residual salt and key parameters with and without traffic closely monitored and measured.



Figuer 1 - Test site in Bygholm, Denmark.

The equipment's that were used to take the measurements included both manual equipment's such as Sobo 20, refractometer, Wet dust sampler etc. and automatic measurements with road sensors connected to Vaisala Rosa system. During completion of field tests, the project faced some challenges. The original asphalt covered on the test track was rough, had a lot of cracks and missing cross fall. Therefore, the road had to be resurfaced. After resurfacing has been done, it showed that the texture of the road surface was too small and not representative for ordinary roads. Based on field tests, it was also discovered that installation of road sensors was crucial for measuring quality. After the second field experiments some parts of the road sensors were also reinstalled.

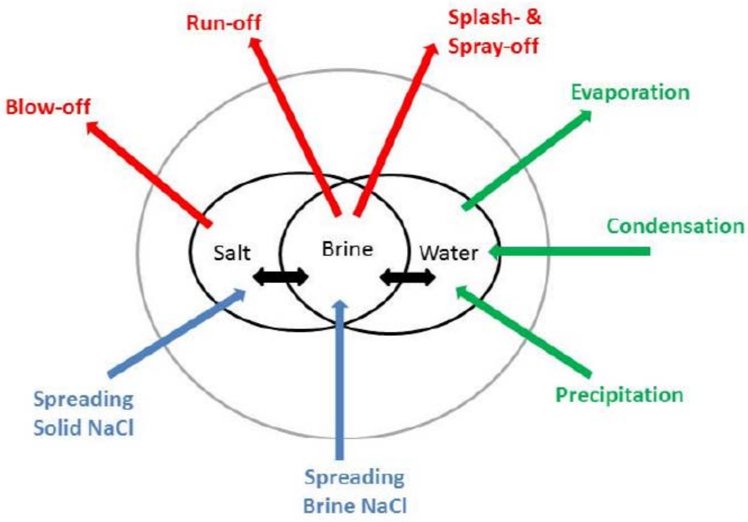
More details of method description of this project will be discussed in another paper amid topic 5 by Göran Blomqvist under the title: Measurements of residual salt on a test track under controlled conditions.

3.0 DEFINING THE CONCEPTUAL MODEL

The model assumes that there might be mass in the form of three *elements* on road:

1. Water
2. Brine
3. Undissolved salt

Figure 2 shows a principal sketch of a model which shows the processes that is believed to affect the amount of salt on the roadway.



Processes that bring mass in and out of the system:

1. Spreading of dry salt
2. Spreading of brine
3. Blow-off (dry salt/salt crystals that are lost because of the road traffic)
4. Run-off (drainage of fluid / salt solution from the road surface)
5. Splash + spray-off (liquid / salt solution that is lost because of the road traffic)
6. Evaporation of liquid from the road surface
7. Condensation of atmospheric moisture on the road surface
8. Precipitation in the form of rain or snow

Figure 2 - MORS - Model concept

In addition, we have identified two processes which change the mass of the different elements within the system, i.e. the water, brine or undissolved salt:

1. Solution
2. Crystallization

Once the salt is spread on a road, the salt is exposed to a number of *factors* and *processes* that occur during normal traffic and meteorological conditions. For instance, when the salt is spread out, the salt can be subjected to additional water in the form of precipitation which results that the salt gets dissolved and carried away from the road surface by run-off. But the opposite can just as well happen to dissolved salt which can dry out by evaporation and wind thus easily blows off of the road. Traffic has a huge impact on residual salt. Depending on the salt consistency and the road condition, traffic contributes by various processes to the reduction of salt. For example, when a road is wet or moist (dissolved salt), vehicles will splash and spray salt as brine off the road, both are two different processes but occurs at same time and therefore are quantified with same equipment. In the case of undissolved salt being present on the road surface it is exposed to blow off. Both of these processes have the same driving force, namely traffic. Both for spray/splash-off and blow-off the driving force will be the mechanical action of vehicles' tires and the turbulence created by vehicles. The turbulence level depends on type of vehicle. Turbulence level is dependent on the vehicle aerodynamics design. It is about how air flows around a fixed object. Vehicles are constantly exposed to air resistance. The air flows over the car roof, and suddenly breaks down on the trunk. This creates turbulence and pressure in the area between the rear window and trunk. Trucks have a large flat front face, rather than a rounded shape. Therefore, they also create more turbulence thus contributing to greater blow off than ordinary passenger cars.

The project team has identified all the factors and are well known with all the processes occurring on road surface. An advantage that created a targeted research plan executed by establishing tests campaigns in Bygholm, laboratory tests, physical prototypes, international exchange of knowledge and assisting PhD students with specific measurements that have contributed great knowledge for model development.

3.1 Assumptions and simplifications

The model contains of ten different *processes* that affect the amount of salt on the road after salt spreading. The processes are then affected by number of *factors*. A complete model is very difficult to achieve and certain simplifications and assumptions are therefore necessary. The aim of the model development has been to focus on the processes with greatest impact on residual salt reduction.

The model in its current shape takes processes such as outflow (run off) and removal (splash + spray off) into consideration. Additionally a sub-model which is currently under development describes the evaporating/condensing time which affects the amount of water on road and thereby also salt concentration in brine.

The following assumptions have been made:

- Assuming the spreading is either with salt solution or that all the salt is dissolved. The model does not consider the process the solution of salt, i.e., the model assumes spreading with brine or the salt is dissolved
- Assuming no initial loss. The model does not take into account that the actual spreading of the salt may have a direct loss, meaning that a certain percentage of the salt never ends up on the roadway. Initial loss may be due to turbulence from spreaders, wind or spreading dry salt or humidified salt where the salt grains "bounce" off the road or due to inaccuracy of spreaders capability to secure the salt on road surface.
- Snow precipitation. The model does not take into account the addition of mass of snow and a possible melting of this.
- Snow removal. The model does not include the impact of snow clearing on the amount of salt

3.2 Model Development

The project group has with its knowledge developed a practical model which forms the basis for entire development phase. The model describes the behaviour of residual salt due to spreading action. We will first experience an initial salt loss to road edge during spreading hence to inaccuracy of spreaders capability to secure the salt on road surface. Consequently a certain amount will remain on the road surface. The exact amount depends on type of spreaders and salting method, a quantity that project group hope to gain from another NordFoU project namely Stansalt. The remaining salt on road surface can depends on type of salting method, be measured with sensors if it is dissolved.

Obviously, more water on the road results in more salt being dissolved, and therefore the salt amount can be registered with the various measuring equipment’s. The processes that occur on road surface due to traffic influence and road wetness are highlighted earlier in this section although their influences in decrease of residual salt are illustrated with the practical model. The project group has also reached the conclusion that road wetness has a great influence on quantity of residual salt. The rate of salt loss can be very fast when it rains, the salt flows away from the road with water.

However, the residual amount of salt on a dry road and how it decreases over time is an interesting situation, a situation that will also be carefully monitored during MORS II.

Working with road sensors as the main source to data has also made clear to the project group that a few facts need to be ensured before considering the use of road sensors for residual salt:

1. There must be water present either in the form of rime or precipitation etc.
2. Proper installation of the sensors is crucial for detection of residual salt
3. Sensors must be attended once a year to ensure that point 2 is met

In order to be able to get reasonable data from sensors, we need minimum 0.02-0.03 mm water layer thickness on the surface. The true amount of salt is obtained app. 20-30 min. after spreading.

3.2.1 Run off model

Description of the model obtained from Warren Viessman, Jr., Gary L. Lewis and John W. Knapp, 1989: Introduction to Hydrology, Third Edition. A fuller description can be found in the original publication; N. H Crawford and R. K Linsley, Jr.., "Digital Simulation in Hydrology: Stanford Watershed Model IV", Department of Civil Engineering, Stanford University, Tech Rep. No. 39, July 1966.
The model takes into account precipitation, and the first to be calculated is the equilibrium quantity of liquid at a given rainfall intensity. This is calculated for each time sequence (every 5 minutes in our model), regardless of how long rainfall lasts.

3.2.2 Splash and spray off model

The traffic impact on salt reduction from the road is calculated within the MORS project, engineered empirical model where salt deposition in a profile across the road and out on each lane is related to the three measurable quantities amount of liquid on the road surface, salt concentration and crosswind (the road at right angles to wind component). It includes both splash and spray mechanisms and the model will not distinguish between the loss of dissolved salt (spray-off) and undissolved salt (blow-off), even if it is developed based on measurement campaign in May 2012, when only brine was used in the experiments

3.2.3 Combined model: Run off, splash and spray off

Reductions of salt according subsidiary models described above are based on the time passed after salting and number of vehicles. The model must have initial data on fluid amount and salt content on the road, and then the concentration is calculated. The following definitions apply:

Liquid = water + salt

Salt = liquid x concentration = (water + salt) x concentration

Liquid flow, salt quantity and concentration are related to the equations. With two of the three variables known (water, salt, concentration), the third can always be calculated. Availability of monitoring data for water, salt and concentration may vary between different locations where the model is likely to be used, but to start the calculations we must always two of the three variables measured or determined by other means.

Calculated loss of liquid acc. Run off model includes loss of water and salt, in which the loss of salt is calculated using initial concentration. Precipitation will increase the amount of water on the road surface, and reduce levels accordingly. The Splash and spray model calculates the loss of salt amount, parallel to loss of water is calculated using concentration. The figure below shows the measured and calculated flow on roadway during field campaigns on 3. December 2012.

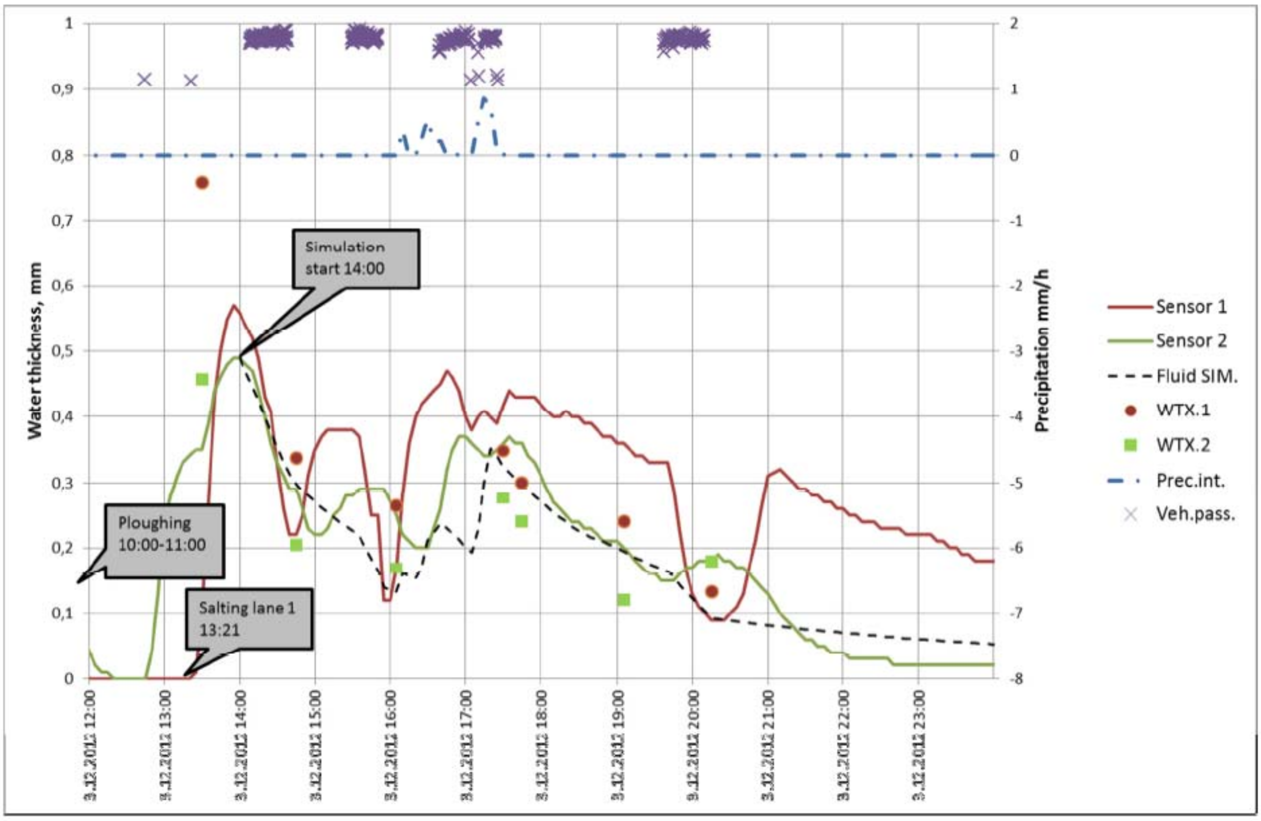


Figure 3 - Measured and simulated values of water flow of the road. The figure clearly shows that in periods without traffic, surface runoff is predominant for change in surface wetness. Sensor 1 is located in the right wheel track but sensor 2 is between the wheel tracks. The simulated water volumes are preliminary to interpret as a kind of average volume across the road.

Using the model, the traffic forecast for the next few hours must be available. This data can e.g. be examined in advance using traffic counts; it is possible to create a table for each day of the week based on the analysis of traffic through an entire season.
The following table illustrates how the timing in the model calculations appears when the calculations start at. 5:50 when the initial conditions are introduced in the model:

Table 1 - Elapsed time in the model calculations

Time		Traffic		Water		Salt		Concentration	
Time	Passage	Total	Passage	Start	End	Start	End	Start	End
05:45	-	98	-	-	-	-	-	-	-
05:50	0	112	0	-	220.0	16.4	16.4	6.9%	-
05:55	5	120	8	220.0	218.6	16.4	16.3	6.9%	6.9%
06:00	10	136	16	218.6	215.7	16.3	16.1	6.9%	6.9%

Here the calculated values for water and salt are a sum of the scores from the runoff model and from the splash model, where the initial estimates based on the elapsed time (5 minutes each calculation step), and the other based on the number of vehicles passing in that 5 minutes interval acc. traffic forecast.

As the model development progress during MORS II, a better physical description lie behind the modelling of respectively water and salt on the road. An example of this trend is the evaporation of water and condensation from the atmosphere and better traffic data such as percentage of heavy vehicles and variable speed.

4.0 CONCLUSION

Calculating Residual Salt Amount is a useful parameter in the context of it to provide us with the information about the amount of residual salt that is left on the road after being spread, is enough to slow the freezing process, by lowering the freezing point temperature thus weakening the ice to form. Applications are therefore considerably great as the winter crew can, by knowing the residual salt amount, use the parameter in order to select a salt rate associated with salt call-out. The crew will then decide whether to use full rate at the given road temperature, or whether to use a reduced rate because they now know that there is some residual salt back on the road to compensate for the full rate. One can also imagine that they occasionally find out that there is sufficient residual salt to weaken the ice to form, and therefore decide to completely avoid salt call-out.

4.1 Benefits of residual salt model

When the researchers succeed in finding a solid model with a reasonable approximation of residual salt amount after a given time or traffic flow, the possibilities are considerable excessive.
The possibilities include everything from reducing pollution along the road to financial gain and an effective workflow for winter crew.

4.2 Environmental conditions

A total Salt Stop for winter road maintenance is not realistic, because salt is, besides being very cheap compared to other de-icers, very fast-acting. Also at low temperature, is the rate relatively small and can be spread with high vehicle speed.

Table 2 - Annual salt consumption in the Nordic countries - Source: Winter service in the Nordic countries in 2011.

Tons/season	Finland	Sweden	Danmark	Norway	Faroe Islands	Iceland
2003/04	86.700	280.700	93.700	123.000	960	8.000
2004/05	101.000	293.100	142.000	140.100	899	13.600
2005/06	78.700	311.400	189.400	166.700	875	13.500
2006/07	70.050	183.000	73.700	137.100	1.315	14.160
2007/08	93.000	183.800	35.500	159.700	1.600	14.000
2008/09	87.300	225.500	49.700	200.000	1.103	15.500
2009/10	62.890	238.250	100.840	201.000	1.916	14.089
2010/11	78.053	253.900	107.000	238.000	1.148	15.746

In season 2010/11, the salt consumption on the Nordic roads was over 690.000 tons. The amount will of course vary depending on winter's harshness. However, the average consumption over the last 8 years was approx. 610.000 tons.
Previous environmental assessments conducted by road and environmental authorities have concluded that large quantities of the scattered salt ends up directly in verges, and those that remains on the road to a large extent also ends in verges. It just happens more

slowly and over time. However, part of the salt adheres to vehicles and surrounding structures such as bridges. The study has also pointed out that road salt is very harmful to the environment, damages vegetation and lakes along the road. Furthermore, road salt cause increased chloride concentration in groundwater.

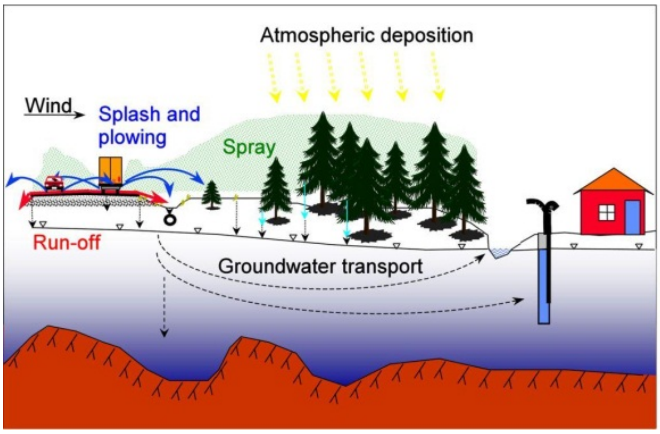


Figure 4 - Road salts cycle in nature along the road network. (Source: VTI)

The same studies, which are also confirmed by the transport sector, indicate that road salt is very aggressively against constructions, and in particular, corrosive safety features of vehicles such as the braking system.

Knowledge of the "residual salt" will help winter crew to salt only where it is needed. This creates a viable situation on the road network and therefore wastage is reduced significantly, in the bottom line it will relieve the environment and reduce Vehicle Operating Cost VOC.

4.3 Economic benefits

Road salt is traded today to a market of approx. 55-65 €/tons [source: Danish Road Directorate]. The price is virtually the same on the Nordic market. If we look at a Nordic average consumption for the last 8 years at 610.000 tons Table 2 using the Nordic road authorities somewhere between 34-40 M€/year on the purchase of road salt. In addition, there are also costs associated with the salting of roads. An earlier estimate by the Danish Road Directorate reveals that a callout for preventive salting on Danish roads consisting of both municipal and state roads will cost road authorities about 533 K€. Alone in Denmark, the average call-outs/year is about 100 call-outs in connection with salting. Multiply with the cost of salting, this summing up to 53 M€/year nationwide. The amount is in addition to costs associated with operation and maintenance of trucks, the cost of winter crew, administration and development.
It is obvious that if the parameter "residual salt amount" can help winter crew to prevent even one single salting, thus the society has saved 533 K€. The amount is in addition to the salt saved for the omitted salting, also an economic benefit that environmental pollution is reduced.

5.0 REFERENCES

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