NordFoU: External Influences on Spray Patterns (EPAS)

Report 17: Introduction to the Salt Spreading Simulation software 3-S

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ABSTRACT

Engineering Centre Bygholm has been involved in research projects to understand the processes of salt spreading and to quantify and model some of the most important parameters. Results of the studies are integrated into the software Salt Spreading Simulation (3-S). The aim of the software is to simulate the motion of salt particles that are spread by a spinning spreader disk. The simulations are based on a number of equations for salt particle motion from Newtonian mechanics.

3-S is planned to cover the whole spreading process from the salt tank on the salt truck to the resulting salt distribution on the road. The present version 2 gives a first estimate of the effect on the salt distribution of different key parameters such as particle size, discharge velocity, spreading angle, wind speed and direction, and driving speed of the truck.

A number of assumptions and estimates of parameters are introduced at this stage without appropriate information about their consistency due to lack of experimental data. The simulated distribution curve needs validation as does the models used for the different phases of the salt spreading process. As 3-S is further developed and verified it may hopefully contribute to improved quality of de-icing equipment design and enhanced de-icing management.

ACKNOWLEDGEMENT

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BACKGROUND

Salt is used for winter road maintenance in the Nordic countries to prevent slippery roads. For environmental and economic reasons, the amount of salt should be kept at a minimum without negative consequences for road safety. So far Engineering Centre Bygholm has been involved in two Nordic research projects to provide basic understanding of factors influencing salt distribution on roads.

In the first project, STANsalt (2011-2013), and in the present project, EPAS (2014-2016), the focus has been to understand the processes of salt spreading and to quantify and model some of the most important parameters. Results of the observations, measurements and modelling have been continuously summarized in technical reports 1 – 16 that are available at http://pure.au.dk .

Results of the studies are integrated into the Salt Spreader Simulation software (3-S) that in its current version is developed in Excel. The aim of the software is to simulate the motion of salt particles that are spread by a spinning spreader disk, flying under the influence of gravity, natural wind and air movements created by the truck, bouncing on the road surface and finally settling on the road. 3-S is based on a physical model that consists of a number of equations that predicts the salt-particle motion. It will be used to enhance the understanding of the nature of salt-particle motion through the spreading process. The effects and importance of different parameters on salt-particle motion can be analysed and the parameters to be included in standard performance tests can be defined.

As 3-S is further developed and verified the software may hopefully contribute to improvement of the quality of de-icing equipment design and improved de-icing management.

THE SALT SPREADING PROCESS

As shown in figure 1 the spreading process is subdivided into two major phases:

I) Salt movement on the truck
II) Salt movement after the salt has left the spreader disk.

On the truck the salt is transported in a tank and supplied to the spinning disk by a feeder mechanism. The spinning speed of the disk is determined by a drive mechanism. The amount and velocity of the salt discharged from the spreader disk is dependent on design and control of the components used.

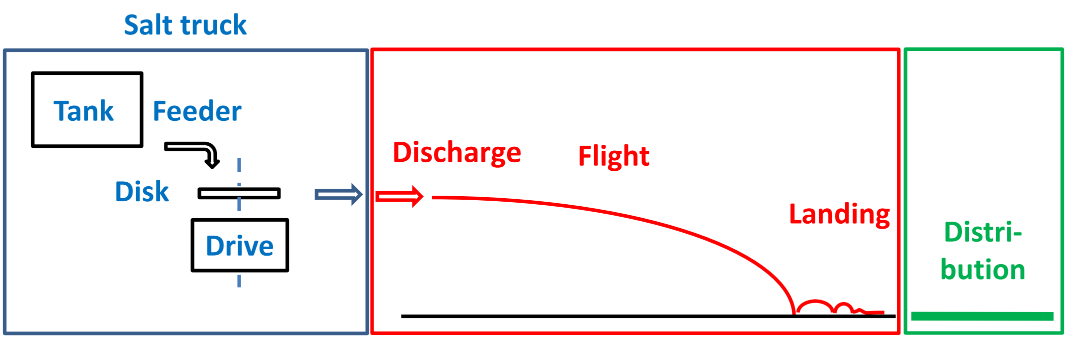

Figure 1. Side view of the 3-S model for salt spreading.

In figure 2 is shown a top view of the spreading process illustrating how the disk discharges the salt in different directions. In the 3-S model the salt distribution on the road is calculated on the basis of forces acting on the particles from leaving the disk till they settle on the road.

The tank, feeder and disk are mounted on the salt truck. In modelling the process, the data has the truck as reference has to be converted to using the road as reference taking the speed of the truck into account.

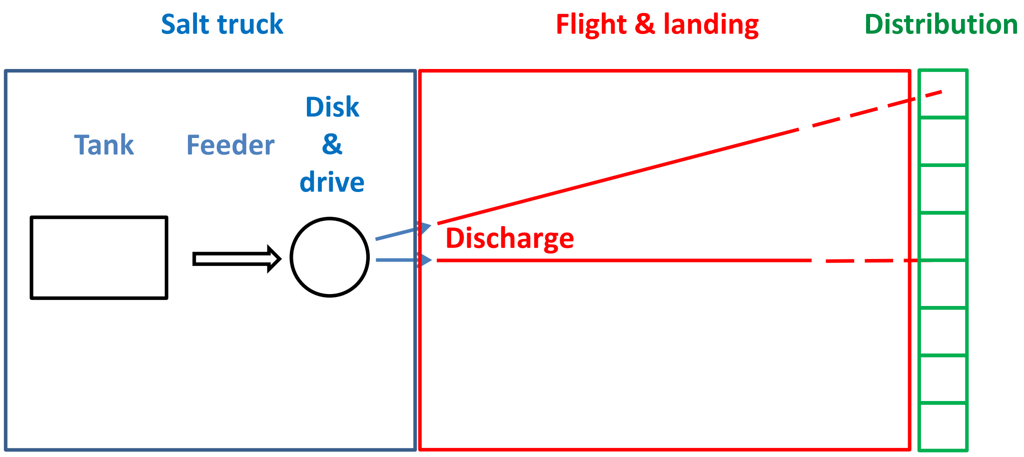

Figure 2. A top view of the 3-S model

The aim of the software is to predict the salt mass distribution across the road after the salt truck has passed.

TANK AND FEEDER

Salt-particles tend to separate in the tank due to truck movement and vibrations. The effect is that larger particles move to the top whereas smaller particles move towards the bottom of the tank.

The separation was observed in an experiment with rock salt in a moving spreader in the spreading hall at Bygholm, report 7. The amount of small particles as percent of the weight deposited on the floor decreased during successive runs while the amount of large particles increased. The number of runs was small, however, and further studies including testing are required to come up with a model for salt separation.

In the present version the size distribution of the salt loaded into the tank is taken as the same as that delivered on the spreader disk. This size distribution may be changed, however, according to actual knowledge. In this report the fictive distribution shown in figure 3 is used.

Size distribution	
Size, mm	**Mass %**
4	**20**
2,8	**20**
2	**20**
1	**20**
0,5	**20**
Sum	**100**

Figure 3. Example of fictive size distribution of salt particles delivered from the feeder mechanism.

SPREADER DISK

The salt particles delivered by the feeder are accelerated on the spinning spreader disk surface. The acceleration is influenced by the geometrical design of the disk and parameters related to the disk drive mechanism. The spinning velocity of the disk and the position of the salt delivered onto the disk are key parameters. These parameters determine the mass flow, the speed and the distribution within the actual spreading angle. In 3-S this is specified in the form of the mass discharged in sectors with the spreading start angle perpendicular to the driving direction, figure 4.

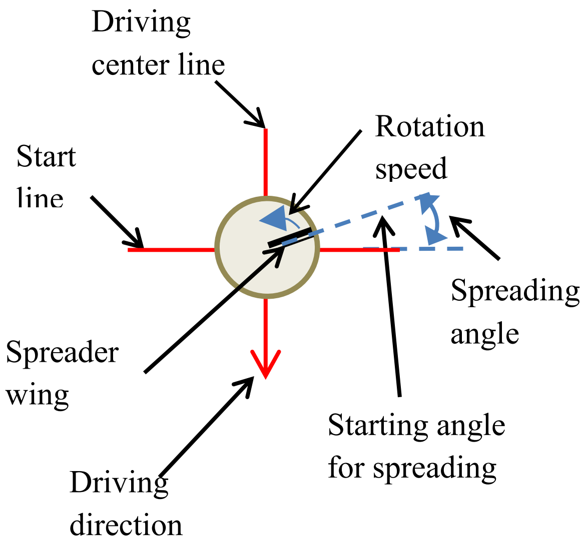

Figure 4. Definition of salt mass ejected in different directions

The variation of salt mass discharged in different sectors, the spread evenness, is specified in 3-S as shown in figure 5. For illustration, in this report the fictive distribution shown in figure 5 is used. It is assumed that the salt is spread evenly through 180° with 90° being opposite the driving direction using 30° sectors as an example.

Spread evenness	
Cast angle	Rel. Value
0	1,00
30	1,00
60	1,00
90	1,00
120	1,00
150	1,00
180	1,00

Figure 5. Specification of the relative spread evenness for spreader disk

The actual spread evenness of different spreader disks needs to be determined by tests. A proper testing method is not available at present. An idea of a test set-up is shown in figure 6 using a number of salt catchers to collect the relative salt mass that leaves the disk within the different sectors.

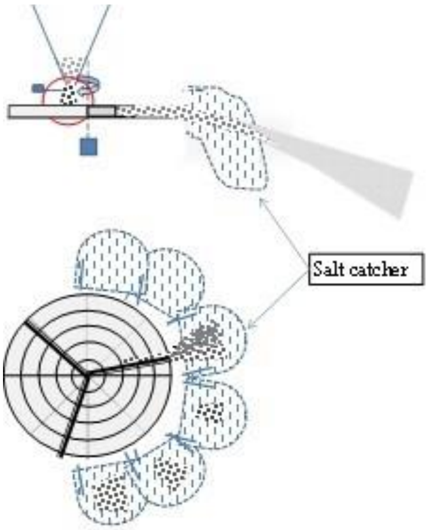

Figure 6. Idea of test set-up to determine spread evenness.

FLIGHT AND LANDING

From the moment the salt particles leave the spreader disk they start a complex path flying through the air. They first pass through the near field region where air movement is dominated by the wake created by the truck. A number of experiments have shown that the air flow centrally behind the truck forms a local upstream and is unstable as described in reports 1, 2, 5, 6, and 9.

Thereafter the salt flies further into the far field zone where air movements are still unstable, but the direction of the average air flow becomes more and more parallel to the driving direction.

Finally, the salt reaches the road surface where it bounces, rolls, slides or sticks under the influence of the near ground air velocities until coming to rest on the road surface

Change of reference point

The tank, feeder and spreader disk are mounted on a salt truck, which naturally is the reference point for position and velocities. The aim of the software is to estimate the salt distribution across the road after the salt truck has passed requiring the reference point to be changed to the road.

At the top of figure 7 is shown the velocity of salt particles discharged from the spreader disk relative to the truck. This is the case when testing a disk in a stationary test rig. When the spreader disk is mounted on a driving truck the salt particle velocities relative to the road becomes as shown below when the driving speed is higher than the velocity of the salt particles discharged from the disk,.

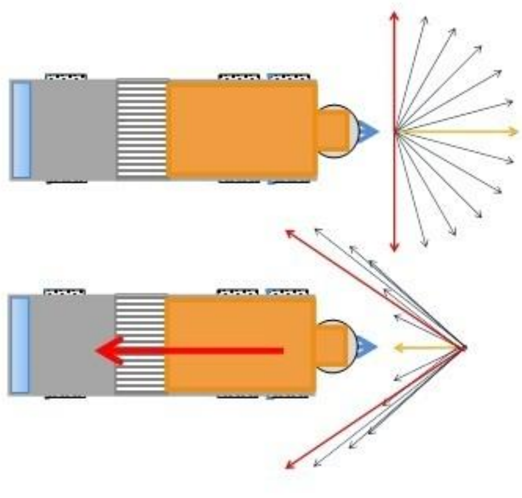

Figure 7. Salt particle velocity relative to the road from a truck at stand still (top) and from a moving truck (bottom).

3-S calculates the particles initial velocities relative to the truck. For this purpose, the spreader disk radius/ blade length and the spreader disk's spinning speed are used.
The particle's velocity relative to the road is calculated knowing the driving speed of the truck. The needed information is specified as shown in figure 8. In this report only the effect of driving speed and disk rotation speed is illustrated.

Change red-numbers in yelow cells			
Driving speed	1,4 m/s	5	km/h
Salt particle initial velocity	16,4 m/s	59	km/h
Spreader disc rotation speed (Range: 80 to 215 rpm)		100	
Spread disc radius / Blade length (Range: 0.25 to 0.3 m)		0,3	m

Figure 8. Specification of driving speed, spreader disk spinning speed and radius/blade length.

Flight
During flight the salt particles are exposed to gravity and drag forces. The drag forces are a function of the particle velocity relative to the surrounding air. The surrounding air will normally also have a velocity relative to the road, and information of the wind is given as average wind velocity and wind angle as shown in figure 9.

In this report the effect of 8 m/s crosswind from the right is shown as an example.

Wind velocity	**8,0**	m/s	28,8	km/h
Wind angle to the start line	**0**	degree		
Spreading-start angle to the start line	**0**	degree		
Setting A = 1, B = -1	**1**			

Figure 9. Specification of average wind velocity and direction.

The result of simulation the flight phase is the velocity and position of the salt particle reaching the road surface from the spreader disk placed at a height of 40 cm above road.

Bouncing
Bouncing behaviour is described in report 13. When the salt particles are impacting the road surface it was observed that the particles combine bouncing, sliding and rolling. All of these three impact types are further dependent on the irregular geometry of both the salt particles and the road surface.

In figure 10 is shown a side view of how the particles bounce off scattered at a spread angle ± 20° when they impact at an angle of 20°.

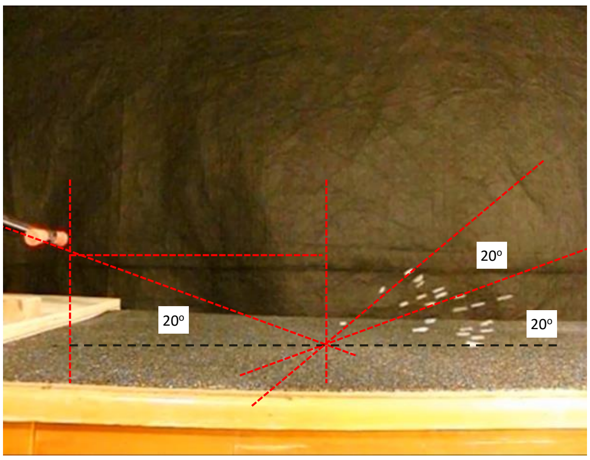

Figure 10. Side view of dry salt particles bouncing on a horizontal surface

A top view of how the particles bounce off is shown in figure 11. The salt particles were 4 mm rock salt that were observed to bounce off scattered within a spread angle of ± 36 °. This value is included in the simulation of the first bouncing.

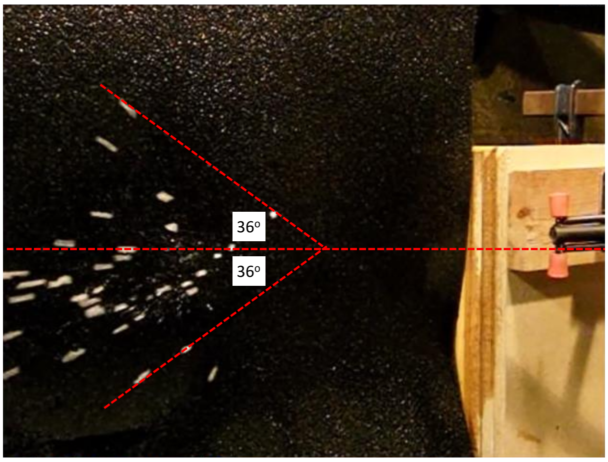

Figure 11. Top view of dry salt particles' first bouncing on a surface

SIMULATED SALT DISTRIBUTION

Low truck speed

The result of the salt spreading simulation inside in a spreading hall is shown in figure 12 using the characteristics for the fictive spreader salt and spreader disk defined above. Inside the hall the maximum driving speed is limited to allow for truck acceleration, sufficient length for measurements and truck breaking.

In our example the truck speed is set at 5 m/s. Disk rotational speed is initially set at 100 rpm and increased to 120 rpm. The wind is set at 0 m/s.

The distance from the start line to final position of the salt is shown by the upper curves indicating that the larger particles travel further than the smaller ones before settling.

The lower curve shows the accumulated percent of settled salt mass at different distances from the driving center line. In this case the distribution is fairly constant within ±3m with maximum spreading width of 7m to the sides.

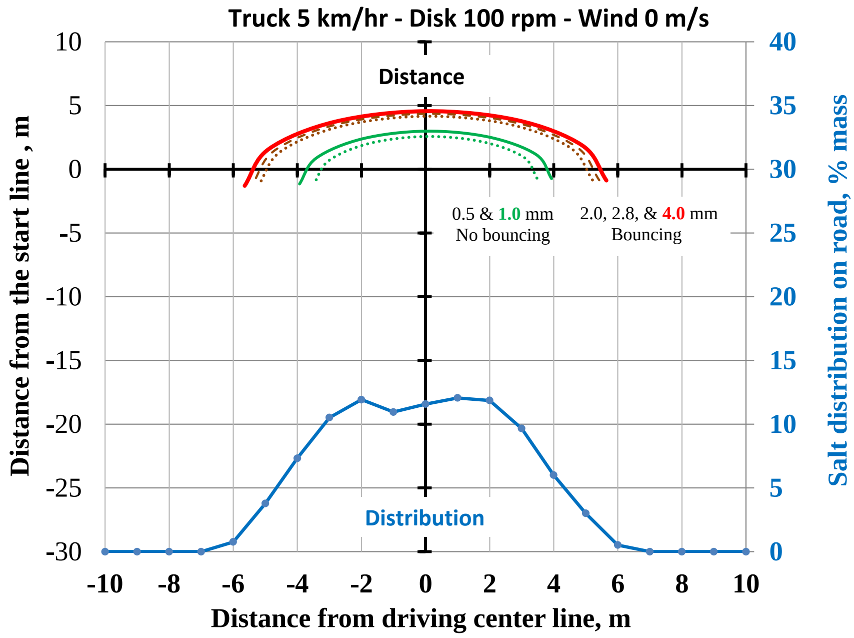

Figure 12. Results of simulated salt distribution at low truck speeds.

In figure 13 the simulation results of increasing the speed to 120 rpm is shown for the fictive salt and spreader. The effect is seen to increase the spreading distance.

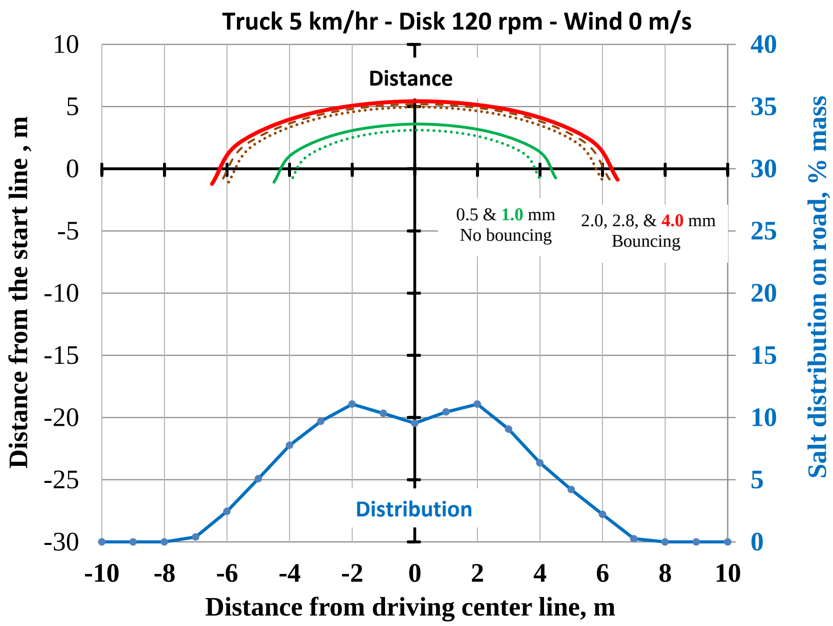

Figure 13. Effect of increased disk speed on simulated salt distribution at low truck speeds.

Normal truck speed

The simulated effect of increasing the driving speed to road level is shown in figure 14. The distance from the start line to final position on the road has increased 5 -10 m in the driving direction dependent on salt particle but the distance from the driving centre line has only increased slightly.

According to 3-S version 2 the effect on salt distribution of increasing driving speed from 5 to 40 km/hr is insignificant.

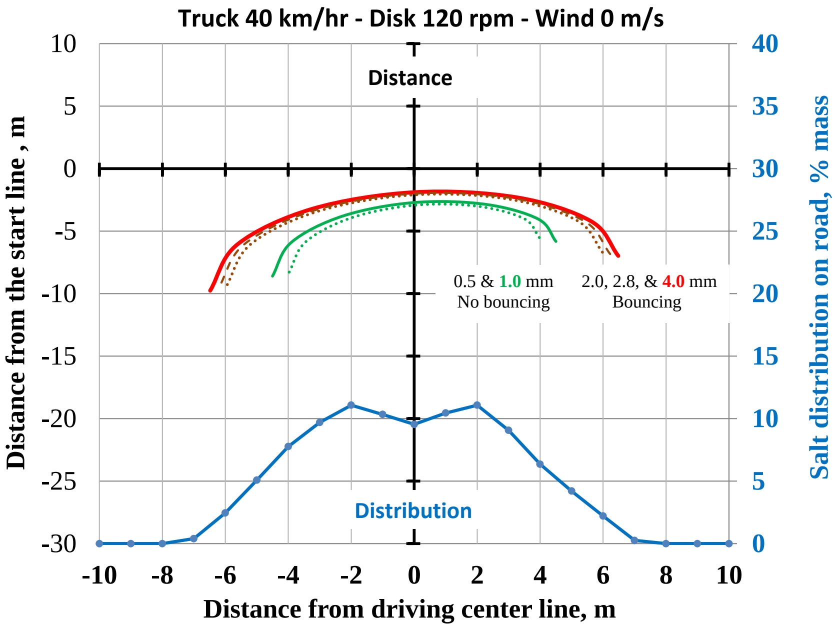

Figure 14. Effect of increased truck velocity on simulated salt distribution.

The simulated effect of 8 m/s crosswind from the right side is shown in figure 15. The effect on the spreading distribution is dramatic. The distribution pattern is being slightly slanted and moved some 4 m to the left. The changes seem to be due to the larger particles being more sensitive to the crosswind.

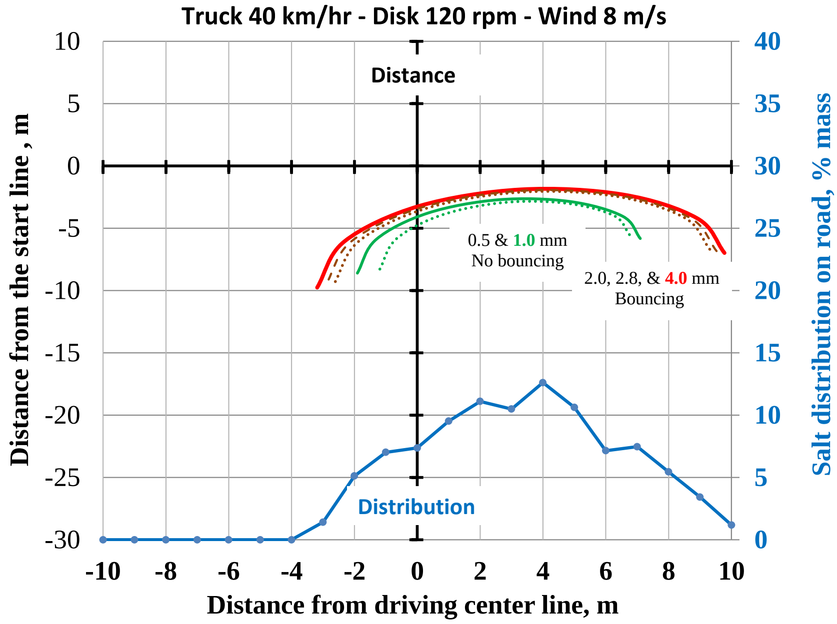

Figure 15. Effect of crosswind on simulated salt distribution.

DISCUSSION

The development of the simulation model is still at its first stage. A number of assumptions and estimates of parameters are introduced without ensuring appropriate information about their consistency due to lack of experimental data. Parameters like irregular bouncing, particle spinning, swarm transport and road surface condition are not included.

When the specific parameters of the salt quality and the spreader are known it is possible to validate the simulation software in the spreading hall at low driving speeds. This is also the case with the effect of disk speed.

The 3-S Simulation software does not include the effect of the turbulence created by the truck, which may have a considerable effect on the salt spreading pattern, especially on the smaller particles. At low truck speeds permissible inside in a test hall the effect is expected to be small, but at normal driving speeds on roads it is expected to become important. The wake velocities have been studied for scale models in the wind tunnel (report 1, 2, 4 and 5) and for full scale trucks in the spreading hall (report 6) and on the test road (report 9). So far the observations and measurements have not resulted in a model for the velocities in the wake field that could be integrated into the 3-S software.

In 3-S the effect of fluctuating wind velocities has not been included for the same reason.

Further studies are required to bring these parameters to a level, where they can be modelled and included in the software. Linking the particle trajectory model with a model simulating the turbulent airflows in the wake and in the wind is important to develop an intelligent control of the salt spreading process

CONCLUSION

3-S is a prototype software covering the whole spreading process from the salt tank on the salt truck to the resulting salt distribution on the road. It gives a first estimate of the effect on the salt distribution of different key parameters such as salt-particle size, initial particle velocity, spreading angle, wind speed and direction and driving speed of the truck.

Verification of the simulated distribution curve need validation as does the models used for the different phases of the salt spreading process.

LITERATURE

Jan S. Strøm[1)] & Hisamitsu Takai[1)], 2011. **Report 1**: Velocity distribution and stability around a scale model salt spreader. http://pure.au.dk/portal/da/publications/velocity-distribution-and-stability(cea9f6f3-65bc-47cf-aaed-31579ac46d14).html

Jan S. Strøm [1)], 2011. **Report 2**: Visualization of the airflow patterns around two model salt spreaders. http://pure.au.dk/portal/da/publications/visualization-of-airflow-patterns(3a66157f-23b7-4aed-86e5-455134109218).html

Jan S. Strøm[1)] & Hisamitsu Takai[1)], 2011. **Report 4**: Effect of driving speeds. http://pure.au.dk/portal/da/publications/effect-of-driving-speeds(9e3bb440-cba3-4bdf-9344-8ed76ab680ca).html

Hisamitsu Takai[1)] & Jan S. Strøm[1)], 2011. **Report 5**: Three-dimensional velocity and its components. http://pure.au.dk/portal/da/publications/three-dimensional-velocity-and-its-components(53f6da42-2b23-4c32-8e49-9fc5822f34c4).html

Hisamitsu Takai[1)] & Jan S. Strøm[1)], 2011. **Report 6**: Three dimensional velocities generated by a full scale salt truck http://pure.au.dk/portal/da/publications/three-dimensional-velocities-generated-by-a-full-scale-salt-truck(ee6fe582-a013-42dd-836d-a38ccab24b5e).html

Jan S. Strøm[1)], 2012. **Report 7**: Effect of crosswind on salt distribution. http://pure.au.dk/portal/da/publications/effect-of-crosswind-on-salt-distribution(bcf97949-fdc9-48a4-b6d8-557ab03360dd).html

Jan S. Strøm[1)], 2012. **Report 9**: Visualization of airflow patterns behind a full scale salt truck. http://pure.au.dk/portal/da/publications/visualization-of-airflow-patterns-behind-a-full-scale-salt-truck(25f21938-67dc-4338-ac90-92352cacea46).html

Hisamitsu Takai[1)], Torben Brøchner [2)] & Jan S. Strøm[1)], 2015.

Report 13: Experimental determination of key parameters for the Salt Spreading Simulation Software 3-S:

http://pure.au.dk/portal/files/94083095/Report_13_Parameters_for_3_S_06nov2015.pdf