NordFoU: External Influences on Spray Patterns (EPAS)

Report 18: Model for salt spreading simulation software 3S

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ABSTRACT

Engineering Center 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 an interactive Salt Spreader Simulation software (3S). It is based on a physical model that consists of a number of equations simulating the salt-particle motion.

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

A number of assumptions and estimates of parameters are introduced at this stage without ensuring 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 3S is further developed and verified it may hopefully contribute to improved quality of de-icing equipment design and enhanced de-icing management.

INTRODUCTION

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 Center 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 the following 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 that are available on http://pure.au.dk .

Results of the studies are integrated into the Salt Spreader Simulation software (3S) that is an interactive Excel program. 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 and natural wind, bouncing on the road surface and finally being distributed on the road. 3S is based on a physical model that consists of a number of equations simulating the salt-particle motion.

3S is a prototype software being a first step toward covering the whole spreading process from the salt tank on the spreader 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 driving speed of the truck, salt-particle size, initial particle velocity, spreading angle, wind speed and direction. It will be used to determine the importance of different parameters on salt-particle motion and define parameters to be included in standard performance tests.

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

THE SALT SPREADING PROCESS

As shown in figure 1 the spreading process is subdivided into two 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 leaving the spreader disk is dependent on design and control of the components used.

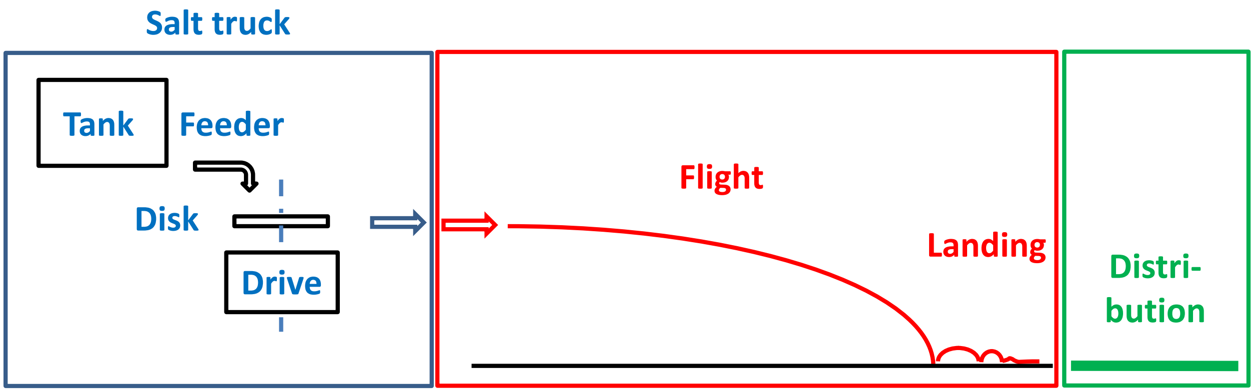

Figure 1. Vertical view of the 3S model for salt spreading from the tank to the road.

In figure 2 is shown a horizontal view of the spreading process illustrating how the disk distribute the salt in different directions. In the 3S model the salt distribution on the road is calculated on the basis of forces acting on the particles from leaving the disk till it rests on the road.

The tank, feeder and disk are mounted on the spreader truck, which naturally is the reference point for position and velocities. In modelling the process from salt being added to the tank to the salt being distributed on the road it important to convert data for the components on the truck to the road taking the speed of the truck into account.

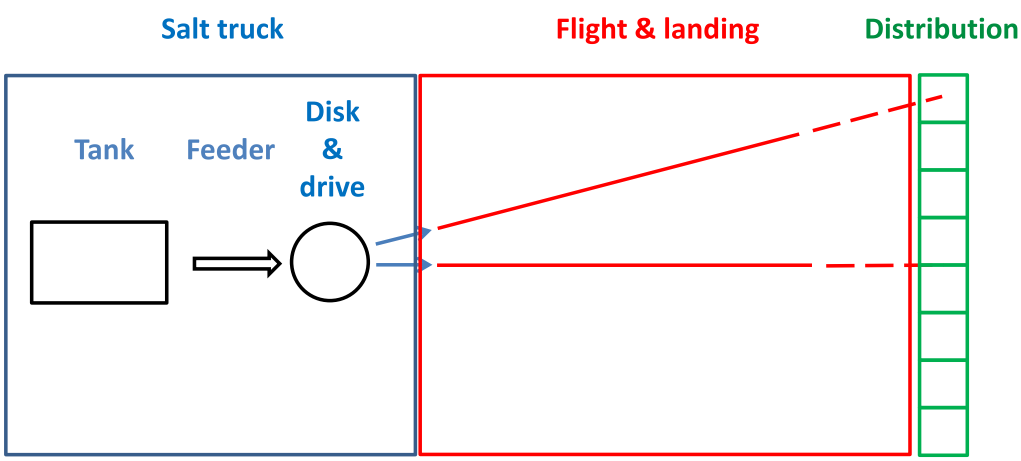

Figure 2. A horizontal view of the 3S model

The aim of the software is to estimate 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 resulting in larger particles moving 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 % of the weight deposited on the floor decreased during successive runs while the amount of large particles increased. The amount of data was small, however, and further studies including testing are required to come up with a model for salt separation.

In the present version 2B 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, figure 3.

N	O	P
Size distribution of salt particles		
Size, mm	**%**	**Basic,%**
6	20	20
4	30	30
2	20	20
1	15	15
0,5	15	15
Sum	**100**	

Figure 3. Example of 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. This 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 outlet mass flow and speed and its distribution within the actual spreading angle. In 3S this is specified in the form of the mass cast in sectors with the spreading start angle perpendicular to the driving direction, figure 4.

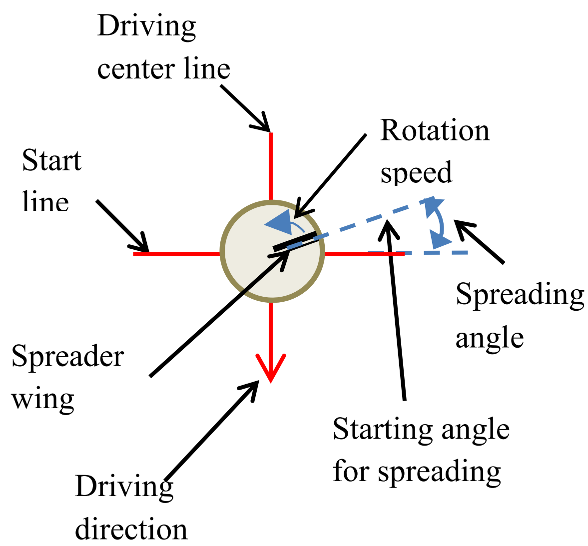

Figure 4. Definition of salt mass cast in different directions

The variation of salt mass cast in different sectors, the spread evenness, is specified in 3S as shown in figure 5. Until more data are available it is assumed that the salt is spread evenly through 180° with 90° being opposite the driving direction.

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

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

The 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.

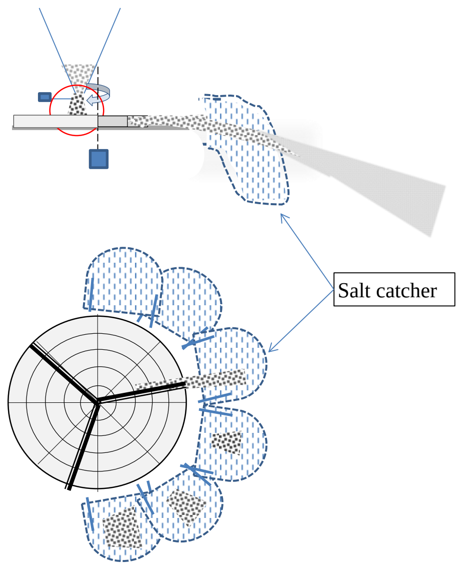

Figure 6. Idea of test set-up to determine spread evenness.

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 (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 spreader 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. When a particle has left the disk the reference point need to be changed to the road.

At the top of figure 6 is shown the velocity of salt particles leaving 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 leaving the disk,.

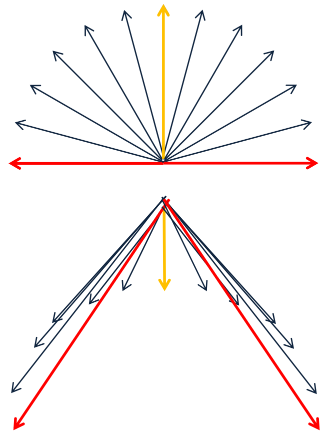

Figure 6. Salt particle velocity relative to the road from a truck at stand still (top) and from a truck moving (bottom).

3S 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 may be calculated knowing the driving speed of the truck. The needed information is specified as shown in figure 7.

	A	B	C	D	E
2	Change red-numbers in yelow cells				
3	**Driving speed**	16,7	m/s	60	km/h
4	**Wing rotation speed adjustment*, %**	0	**%**		
5	**Salt particle initial velocity**	16,7	m/s	60	km/h
6	**Spreader disc rotation speed (Range: 80 to 215 rpm)**			102	
7	Ref. Technial report 19				

G	H	I	J	K
Wind velocity	0,0	m/s	0	km/h
Wind angle to the start line	0	degree		
Spreading-start angle to the start line	0	degree		
Spread disc radius / Blade length (Range: 0.25 to 0.3 m)	0,3	m		

Figure 7. 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.

In 3S the effect of fluctuating wind velocities has not been included. The wake velocities created by the truck has 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 3S software.

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 8 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°.

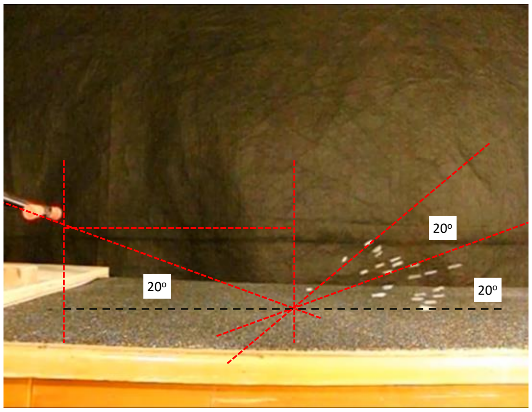

Figure 8. Side view of dry salt particles bouncing of a horizontal surface

A horizontal view of how the particles bounce off is shown in figure 9. The salt particles were observed to bounce off scattered within a spread angle of ± 20°. This value is included in the 3S software.

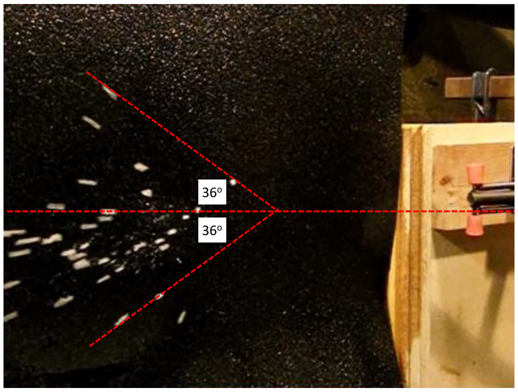

Figure 9. Horizontal view of dry salt particles bouncing of a surface

The result of the first bouncing for symmetric spreading of 4mm rock salt is shown in figure 10 for a stationary truck at top and a moving truck at bottom.

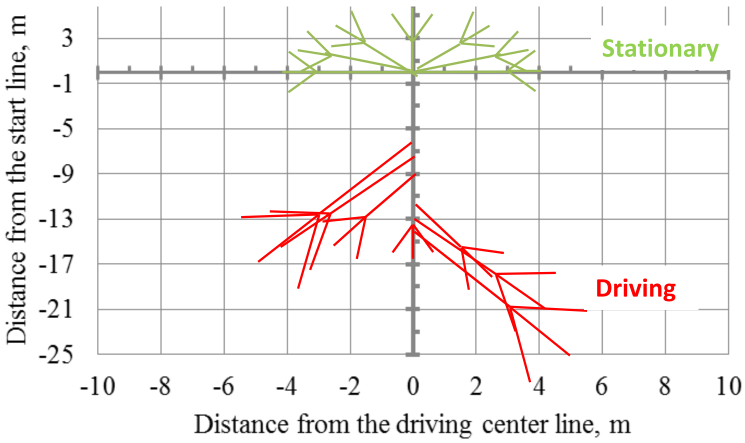

Figure 10. Simulation of symmetric spreading including bouncing of 4 mm rock salt.

SIMULATED SALT DISTRIBUTION

The simulated salt distribution is shown in figure 11. The lower curve shows the % of salt mass on the road at different distances from the driving center line.

In this case the distribution is fairly constant within ±4m with maximum spreading width of 7m to the sides. The distance from the start line to final position on the road is shown by the upper curves indicating that the larger particles travel further than the smaller ones before coming to rest.

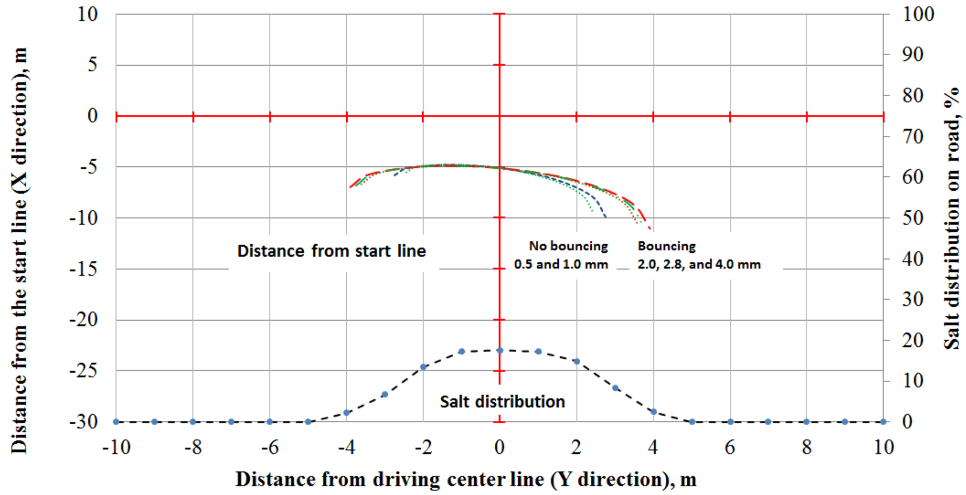

Figure 11. Distance from the start line to the end of first bounce (top) and simulated salt distribution (bottom).

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

Parameters like irregular bouncing, particle spinning, swarm transport, road surface condition and turbulent airstream are not included. 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 is important to develop an intelligent control of the salt spreading process

CONCLUSION

3S is a prototype software covering the whole spreading process from the salt tank on the spreader 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, driving speed of the truck, initial particle velocity, spreading angle, wind speed and direction.

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