THE WINTER MODEL − A FIRST TEST CALCULATION

S. Möller
Swedish National Road and Transport Research Institute (VTI), Linköping, Sweden
staffan.moller@vti.se

ABSTRACT

The first test of the Winter Model has just started. The test involves the calculation of socio-economic costs associated with the lowering of the winter service standard applied to the lowest class of roads which are subject to combined snow ploughing and salting.

The objective with the Winter Model is to assess the most important socio-economic effects of different winter road maintenance strategies, giving the road administrators a means for optimising strategies and activities.

The key model is the Road Condition Model, where the state of the road surface (dry, wet, icy or snowy etc.) is assessed on an hourly level. Using specified weather courses throughout a whole winter season, consideration is given to weather impact, maintenance actions and traffic.

The effects of the different road conditions are assessed in the following sub-models:

- The Accident Model
- The Accessibility Model
- The Fuel Consumption Model
- The Corrosion Model
- The Environmental Model – effects of salting on vegetation and ground water
- The Road Administrator Model – the cost for measures taken

KEYWORDS

WINTER ROAD MAINTENANCE / MODEL / EFFECTS / SOCIO-ECONOMIC COSTS

1. INTRODUCTION

The objective of the Winter Model is to assess the most important socio-economic effects of different winter road maintenance strategies, giving the road administrators a means for optimising strategies and activities.

2. METHOD

The Winter Model uses input data for a road network: traffic, weather, maintenance rules and actions. The estimations of the effects are calculated using six different sub-models [1].

The key model is the Road Condition Model, where the state of the road surface (dry, wet, icy or snowy etc.) is assessed on an hourly level. Using specified weather courses throughout a whole winter season, consideration is given to weather impact, maintenance actions and traffic [1].

The effects of the different road conditions are assessed in the following sub-models:

- The Accident Model
- The Accessibility Model
- The Fuel Consumption Model
- The Corrosion Model
- The Environmental Model – effects of salting on vegetation and ground water
- The Road Administrator Model – the costs for measures taken

3. A FIRST TEST CALCULATION

3.1. Background

Recently the first test of the Winter Model started. The test involves the calculation of the socio-economic costs associated with the lowering of the winter service standard applied to the lowest class of roads which are subject to combined snow ploughing and salting. The changes to the winter service standard involved increasing the snow depth start criteria and action times. The test started with a road condition calculation for a period of 14 days or 336 hours. The days had a mixture of light and heavy snow falls and fair weather. The depth of snow during ten snow fall periods varied between 0.5cm and 12cm. The prerequisites for the calculations were that the same weather description and the same traffic characteristics were used. Only the service standard was changed.

3.2. Start criteria and action time

A start criterion states at which snow depth on the road the action will start. The action time dictates the length of time the combined action pass should take (i.e. when the snow plough must have completed the action and be back at the starting point of the combined action pass).

For the lowest class of roads subject to combined snow ploughing and salting, Class 3, the current start criterion is a snow depth of 1.0cm and the action time is 4 hours. For the first reduction to the standard, Class 3 minus, the start criterion is 2.0cm and the action time is 4 hours. For the second reduction to the standard, Class 3 minus minus, the start criterion is 2.0cm and the action time 5 hours.

Regular weather reports detail snow depth on the road every 60 minutes. These depths are then divided by two to give half hourly depths.

3.3. Example

Figure 1 shows how different start criteria and action times affect the start and finish of the first and second combined action pass.

For standard Class 3, the first pass starts in the middle of hour 43 (at 43:30). The accumulated depth of snow at that time is 0.3 + 1.4 + 6.6 + (8.9/2) = 12.8mm. This means that the start criterion of 1.0cm snow depth is reached.

Four hours later, in accordance with the action time, the first pass finishes and the snow plough is ready to start a second pass. Again, we test if the start criterion is reached. Since the snow plough started the first pass, the accumulated depth of snow is (8.9/2) + 13.0 + 3.0 + 0.8 + (0.5/2) = 21.5mm. Thus, the start criterion is reached and the second pass starts at hour 47:30 and finishes at hour 51:30.

Once again we test if the start criterion is reached. Since the snow plough started the second pass, the accumulated depth of snow is (0.5/2) + 0 + 0 + 0 + (0/2) = 0.3mm. This small amount will not result in another action. The combined action is finished.

We also have to decide when the change of road condition is relevant due to the passing of the snow plough. The first meter of the pass is ploughed immediately after the start and the last meter four hours later. As an average, it is reasonable to assume that the change of road condition happens half way through the action time. The events where there is a Change of Road Condition are marked CRC.

Now we continue with standard Class 3 minus. Since the start criterion is a snow depth of 2.0cm, the first pass will start at hour 44:30. The depth of snow at that time is 0.3 + 1.4 + 6.6 + 8.9 + (13.0/2) = 23.7mm.

The first pass is finished 4 hours later, at hour 48:30, in accordance with the action time. Since the snow plough started the first pass, the accumulated depth of snow is (13.0/2) + 3.0 + 0.8 + 0.5 + (0.0/2) = 10.8mm. Thus, the start criterion of 2.0cm is not reached. However, as the snow fall has stopped, according to the weather description, the last pass starts at hour 48:30 and is finished at hour 52:30. The changes of road condition happen at hours 46:30 and 50:30.

The last example is standard Class 3 minus minus. Since the start criterion is a snow depth of 2.0cm the first pass will start at hour 44:30 (the same time as for standard Class 3 minus).

The finish of pass one will be at hour 49:30 because the action time is 5 hours. The accumulated depth of snow is 10.8mm. Again the snow fall has stopped, as in the case for the standard Class 3 minus, and the last pass starts at hour 49:30 and finishes at hour 54:30. The changes of road condition happen at hours 47:00 and 52:00.

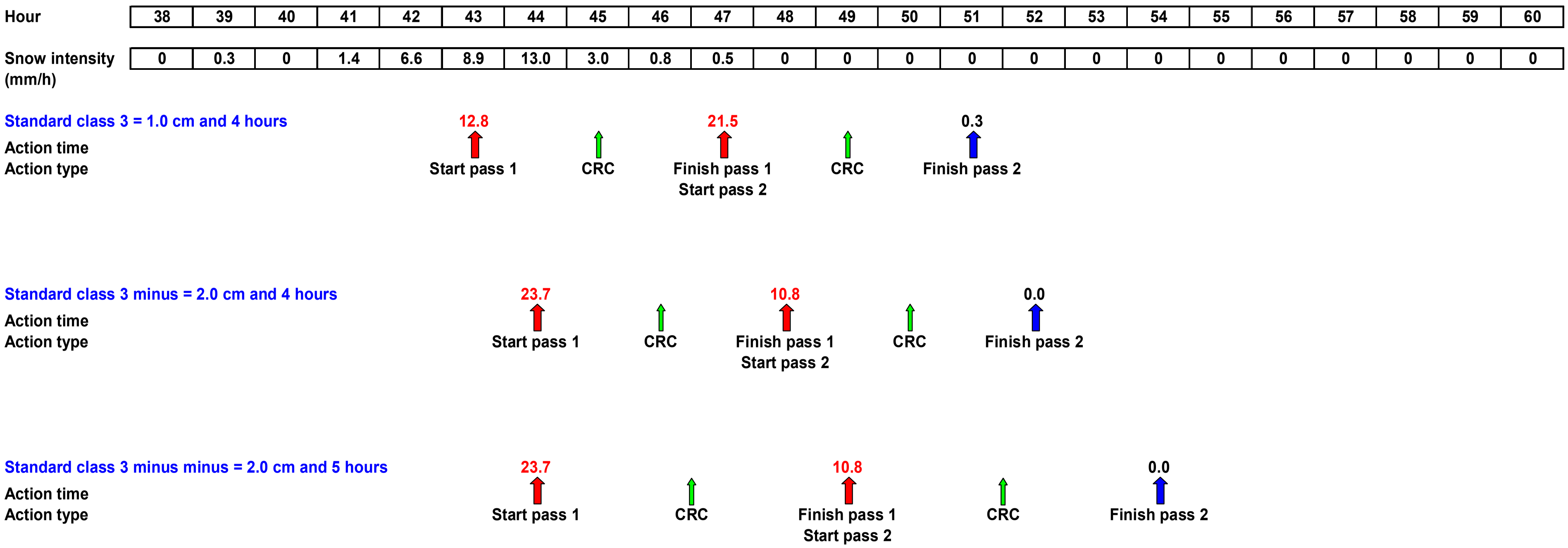

Figure 1 - Start and Finish of the First and Second Combined Action Pass Depending on Start Criteria and Action Times

3.4. Road conditions

The road conditions are calculated individually for the following five strips of the lane:

1. Edge of lane
2. Right wheel track
3. Between wheel tracks
4. Left wheel track
5. Middle of the carriageway

Figure 2, on the next page, gives a description of the road conditions on different strips. The allocated road condition is the actual road condition at the end of each hour period.

The road conditions shown in figure 2 are:

- Dry bare ground (DB)
- Moist bare ground (MB)
- Wet bare ground (WB)
- Slush (SL)
- Hard-packed snow (PS)
- Loose snow on hard-packed snow (LS/PS)

The numbers following SL or LS are snow depths in mm.

According to the model, the road conditions in the wheel tracks are bare ground; except during two hours after a heavy snow fall, when hard-packed snow and slush occurs. These road conditions are determined by the weather and the traffic flow and are independent of start criteria and action times.

In the middle of the road, and also between the wheel tracks, the road conditions are slush followed by bare ground. The exception being four hours after heavy snow fall, when loose snow on hard-packed snow will be found. The road condition types during these four hours are determined by the weather and the traffic flow and independent of start criteria and action times.

At the edge of the lane, the road conditions are slush followed by bare ground.

For all tested standard classes, the same pattern of road conditions occurs. The difference is the time point when a certain road condition will occur. For example, when the road is almost free from slush, i.e. 4 strips have bare ground, (light green marking), or when 3 strips with dry bare ground occur (yellow marking). These conditions will happen 1 hour or 2-3 hours later when the standard class is lowered one or two steps.

Another difference, depending on the standard class, is the time point when the snow depth on the road diminishes, i.e. when the snow plough passes.

Hour	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Snow intensity (mm/h)	0	0.3	0	1.4	6.6	8.9	13.0	3.0	0.8	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0

Standard class 3 = 1.0 cm and 4 hours

	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Action time						12.8				21.5				0.3									
Action type						Start pass 1		CRC		Finish pass 1 Start pass 2		CRC		Finish pass 2									
Road condition																							
middle of the road	DB	SL 0.2	SL 0.2	SL 0.9	SL 4	SL 9	LS 5/PS	LS 4/PS	LS 4/PS	LS 4/PS	SL 9	SL 3	SL 3	SL 3	SL 3	WB	WB	WB	WB	MB	MB	DB	DB
left wheel track	DB	WB	MB	WB	WB	WB	PS	SL 5	WB	WB	WB	WB	MB	MB	MB	DB	DB	DB	DB	DB	DB	DB	DB
between wheel tracks	DB	SL 0.2	SL 0.2	SL 0.9	SL 4	SL 9	LS 5/PS	LS 3/PS	LS 3/PS	LS 3/PS	SL 8	SL 2	SL 2	SL 2	SL 2	WB	WB	WB	MB	MB	DB	DB	DB
right wheel track	DB	WB	MB	WB	WB	WB	PS	SL 5	WB	WB	WB	WB	MB	MB	MB	DB	DB	DB	DB	DB	DB	DB	DB
edge of lane	DB	SL 0.2	SL 0.3	SL 2	SL 8	SL 17	SL 30	SL 6	SL 6	SL 7	SL 7	SL 4	SL 4	SL 4	SL 4	SL 4	SL 4	WB	WB	WB	WB	WB	WB

Standard class 3 minus = 2.0 cm and 4 hours

	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Action time							23.7				10.8				0.0								
Action type							Start pass 1		CRC		Finish pass 1 Start pass 2		CRC		Finish pass 2								
Road condition																							
middle of the road	DB	SL 0.2	SL 0.2	SL 0.9	SL 4	SL 9	LS 5/PS	LS 7/PS	LS 3/PS	LS 3/PS	SL 8	SL 8	SL 3	SL 3	SL 3	SL 3	WB	WB	WB	WB	MB	MB	DB
left wheel track	DB	WB	MB	WB	WB	WB	PS	SL 5	WB	WB	WB	WB	MB	MB	MB	DB	DB	DB	DB	DB	DB	DB	DB
between wheel tracks	DB	SL 0.2	SL 0.2	SL 0.9	SL 4	SL 9	LS 5/PS	LS 7/PS	LS 3/PS	LS 3/PS	SL 8	SL 8	SL 2	SL 2	SL 2	SL 2	WB	WB	WB	MB	MB	DB	DB
right wheel track	DB	WB	MB	WB	WB	WB	PS	SL 5	WB	WB	WB	WB	MB	MB	MB	DB	DB	DB	DB	DB	DB	DB	DB
edge of lane	DB	SL 0.2	SL 0.3	SL 2	SL 8	SL 17	SL 30	SL 33	SL 4	SL 5	SL 5	SL 5	SL 4	SL 4	SL 4	SL 4	SL 4	SL 4	WB	WB	WB	WB	WB

Standard class 3 minus minus = 2.0 cm and 5 hours

	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Action time							23.7					10.8					0.0						
Action type							Start pass 1		CRC			Finish pass 1 Start pass 2		CRC			Finish pass 2						
Road condition																							
middle of the road	DB	SL 0.2	SL 0.2	SL 0.9	SL 4	SL 9	LS 5/PS	LS 7/PS	LS 7/PS	LS 3/PS	SL 8	SL 8	SL 8	SL 8	SL 3	SL 3	SL 3	SL 3	WB	WB	WB	WB	MB
left wheel track	DB	WB	MB	WB	WB	WB	PS	SL 5	WB	WB	WB	WB	MB	MB	MB	DB	DB	DB	DB	DB	DB	DB	DB
between wheel tracks	DB	SL 0.2	SL 0.2	SL 0.9	SL 4	SL 9	LS 5/PS	LS 7/PS	LS 7/PS	LS 3/PS	SL 8	SL 8	SL 8	SL 8	SL 2	SL 2	SL 2	WB	WB	WB	MB	MB	DB
right wheel track	DB	WB	MB	WB	WB	WB	PS	SL 5	WB	WB	WB	WB	MB	MB	MB	DB	DB	DB	DB	DB	DB	DB	DB
edge of lane	DB	SL 0.2	SL 0.3	SL 2	SL 8	SL 17	SL 30	SL 33	SL 34	SL 5	SL 5	SL 5	SL 5	SL 5	SL 4	SL 4	SL 4	SL 4	SL 4	SL 4	WB	WB	WB

Figure 2 - Road Condition Development for Different Standard Classes

Table 1 shows the road condition distribution, for the three standard classes, during the total test period of 336 hours.

Table 1 - Road Condition Distribution for Three Standard Classes During the Test Period of 336 Hours

Road condition	Standard class 3 (number of hours)	Standard class 3- (number of hours)	Standard class 3-- (number of hours)
Dry bare ground	189	191	188
Moist + wet bare ground	56	55	55
Black ice + hoar frost	5	5	5
Hard-packed snow + thick ice	6	6	6
Loose snow + slush	80	79	82
Total	336	336	336

As shown in the table, the differences in road condition between the standard classes are very small. One explanation is that during one of the ten periods of snow fall, the snow plough just had to go one pass instead of two. This occurred when the start criterion was changed from 1.0 to 2.0cm. This means that the action is finished about 2 hours earlier. For the period after this particular snow fall, when the standard class is changed from 3 to 3 minus or 3minus minus, the hours with slush will diminish and the hours with bare ground will increase. Considering the rather small test period, the impact of this single snow fall is substantial.

Because of this impact and the small differences in road condition between the standard classes, the socio-economic calculation, detailed below, is made only for standard class 3. No comparison between standard classes will be done.

3.5. Socio-economic calculation

3.5.1. Accident costs

The start of calculating the number of accidents is to determine the accident rate for dry, moist and wet bare ground. These rates vary in different climate zones.

The next step is to calculate the accident rates for the three road conditions; hard-packed snow/thick ice, black ice/hoar frost, and loose snow/slush. They are calculated using the functions shown in Figure 3. Input data has been derived from the duration likelihood of each road condition (hard-packed snow/thick ice, black ice/hoar frost, and loose snow/ slush) during the winter period. Relative duration = share of total vehicle mileage.

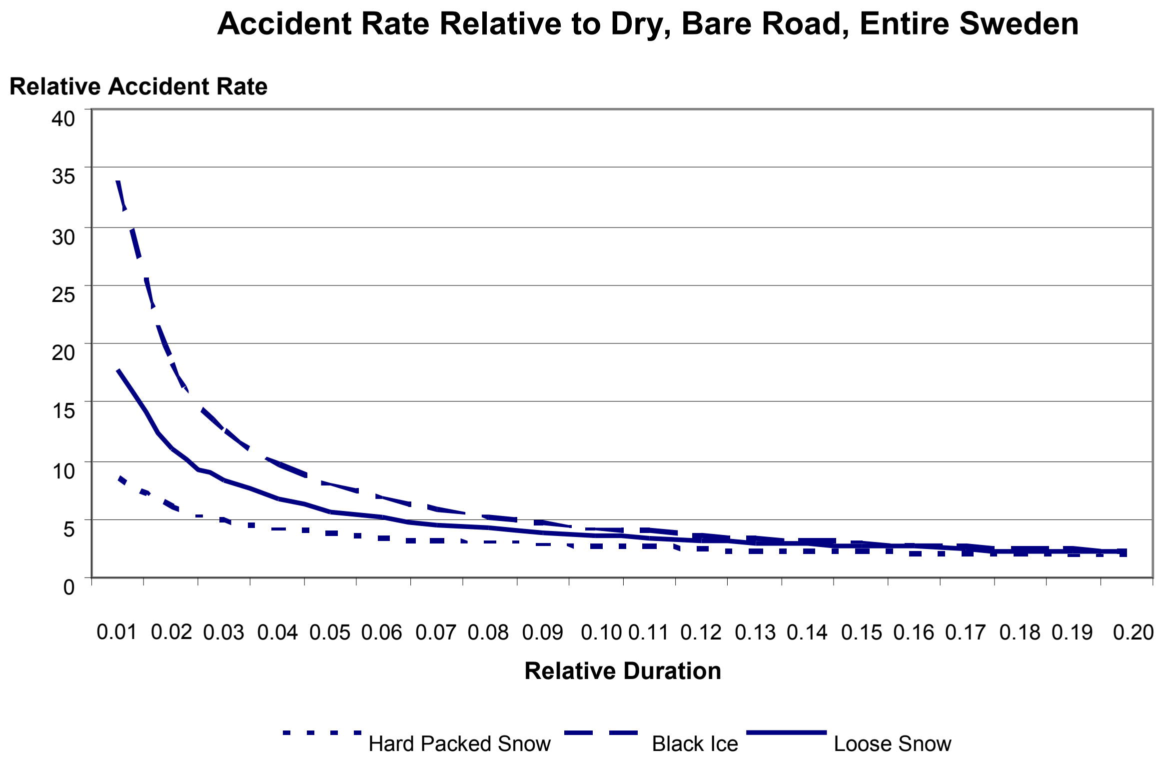

Figure 3 - The Relative Accident Rate (Relative to the Rate at Dry, Bare Road) as a Function of Relative Duration for Three Ice and Snow Road Conditions

After multiplication by the vehicle mileage on the road network in question, the number of accidents on different road conditions can be calculated and summed up for both bare ground and snowy/icy road conditions.

The last step is to take the accident consequences into consideration. The consequences – the number of fatalities, seriously injured, light injured and vehicle damage only – vary with type of accident, type of road condition and climate zone. By taking into account the different monetary value for different accident consequences, the total accident costs can be calculated [1].

3.5.2. Travel time costs

The travel time costs can be calculated with the use of speed reduction percentages. The reductions, for different road conditions and vehicle types, are shown in Table 2. The speed reductions are expressed as a percentage of the speed on a dry, bare road surface.

PC denotes passenger car, TNT truck with no trailer, and TWT truck with a trailer.

The road conditions shown in Table 2 are: hoarfrost (HF) or black ice (BI), hard-packed snow (PS) or thick ice (THI), loose snow (LS) or slush (SL), rutted conditions with bare ground in the ruts (RB), and rutted conditions with black ice in the ruts (RBI).

Rutted conditions develop when ice or snow layers in the wheel tracks are worn down to the pavement. Conditions in the ruts are then either bare ground or black ice.

Table 2 - Decrease in Speed (%) for Different Road Conditions on Roads with Different Widths, Relative to Dry, Bare Roadway

Road condition	Width 6.0 – 7.9m (20 – 26ft)			Width 8.0 – 9.5m (26 – 31ft)		
	PC	TNT	TWT	PC	TNT	TWT
Moist	2	2	2	1	1	1
Wet	3	3	3	2	2	2
HF/BI	8	7	7	7	6	6
PS/THI	19	18	15	15	14	10
LS/SL	16	15	11	13	12	7
RB	7	6	6	6	5	5
RBI	10	8	8	9	7	7

After multiplication by the vehicle mileage on the road network, the number of travelled hours for different vehicle types can be calculated. The monetary value of different vehicle types will give the total travel time costs [1].

3.5.3. Fuel consumption costs

The fuel consumption costs are assessed by means of a linear function which mainly takes into consideration speed, road condition and type of vehicle. Multiplication by the price of petrol and diesel oil, excluding tax, will give the total fuel consumption costs [1].

3.5.4. Corrosion costs

The costs for corrosion of bodywork and electronic equipment are, for the present, only calculated by help of the vehicle mileage. No consideration is given to how often a vehicle is driven on salted roads [1].

3.5.5. Environmental costs

Environmental costs are calculated by the amount of damage on vegetation caused by salt (according to simulated roadside exposure), a vulnerability function, and the chosen "price tag" for the damage. For groundwater, a one-time-cost can be incurred if a chosen limit value is exceeded or if the long term trend is rising [1], [2].

3.5.6. Action costs

The costs for the actions taken by the road administrator are calculated as a cost per hour for the driver plus the truck equipped with a snow plough and a salting unit. The costs for salt are calculated per used ton [1].

3.5.7. Total costs

The calculated socio-economic costs for standard class 3 are shown in Table 3.

Table 3 - Calculated Total Socio-economic Costs for Standard Class 3 for the Test Road Network of 100 km During a Period of 14 Days. AADT = 5,000.

Costs (million SEK)	Standard Class 3
Accident costs	4.5
Travel time costs	12.0
Fuel costs	3.1
Corrosion costs	1.5
Environmental costs	1.5
Action costs	0.2
Total costs	22.8

According to the table, the dominating costs are the travel time costs. These represent more than half the total costs. The action costs are a very small part of the total costs.

4. EXPERIENCES FROM THE TEST CALCULATION

- The differences between the tested standards were unexpectedly small.
- One single snow fall can have a substantial impact on the road condition distribution for a shorter period of for example 14 days.
- A more realistic difference between tested standard classes can probably be obtained if the road condition calculation is done at a level of ½ hour.
- The Road Condition Model calculates the snow depth but none of the effect models take snow depth into consideration.

REFERENCES

[1] Wallman, C-G; Möller, S; Blomqvist, G; Gustafsson, M; Niska, A; Öberg, G; Berglund, C. M. & Karlsson, B. (2006). The Winter Model. Stage 2. Final report. (In Swedish). VTI rapport 531. Linköping, Sweden.
[2] Blomqvist, G. (2010). The environmental sub-model of the Swedish winter model – updated algorithms for the description of salt damage to roadside environment. PIARC XIIIrd International Winter Road Congress.