IMPROVED WINTER MAINTENANCE IN AUSTRIA

SALT APPLICATION RECOMMENDATIONS FOR WINTER MAINTENANCE PERSONAL AND DRIVING RECOMMENDATIONS FOR ROAD USERS

HOFFMANN, Markus
Institute of Transportation, Vienna University of Technology
Gusshausstraße 28/230/3
A-1040 Wien
mhoffmann@istu.tuwien.ac.at

NUTZ, Peter
Institute of Transportation, Vienna University of Technology
Gusshausstraße 28/230/3
A-1040 Wien
pnutz@istu.tuwien.ac.at

BLAB, Ronald
Institute of Transportation, Vienna University of Technology
Gusshausstraße 28/230/3
A-1040 Wien
rblab@istu.tuwien.ac.at

NEUHOLD, Josef
Road Maintenance Division, Regional Government of Lower Austria
Landhausplatz 1
3109 St. Pölten
josef.neuhold@noel.gv.at

ABSTRACT

Winter maintenance as a part of road maintenance defines the accessibility during the winter period and is therefore of high importance for the people and the economy in Austria. Due to the high costs and necessary resources for 120 to 150 winter maintenance days per year it also plays an important role for road authorities. Winter maintenance is responsible for approximately 20% of operating costs on regional roads; respectively 25% to 30% on highways in Austria. Furthermore, road authorities are pressurized by public opinion to provide high standards at all times. In order to improve the winter maintenance techniques, the federal states, ASFINAG and the federal ministry of Transport (BMVIT) funded a research project at the Institute of Transportation (Vienna University of Technology). The goal was to answer the question of the necessary salt application rate and timing in order to optimize winter maintenance and improve the road safety. The developed mathematical model allows a determination of the necessary application rate and timing of de-icing agents as a function of snow fall, traffic and road surface temperature and texture. Based on extensive field research the resulting skid resistance and speed limits for safe driving can be estimated with the model as well. For the implementation of the findings, a compact summary and a winter maintenance guide were developed. Based on typical winter weather and road conditions, practical winter maintenance recommendations and application rates can be calculated. The winter maintenance guide is being used in winter 2010/11 on the road network of Austria.

KEY WORDS

Winter maintenance, application rate, salting, safe roads

1. STANDARDIZATION: STANDARD PROCEDURE IN WINTER MAINTENANCE

The allocation of winter maintenance personal and the specification of limits in salt application rate are done by the road authorities. However, the ultimate responsibility for the implementation of winter maintenance, particularly for salt application rates, still lies within each individual maintenance vehicle driver. Due to their visible assessment of the current road condition they are able to adjust the salt application rate based on their subjective experience. This experience-based winter maintenance practice leads to completely inconsistent application rates in comparable situations. Every driver is convinced to know the right application rate from e.g. 10 g/m² up to a maximum amount of 40 g/m² per application interval.

The objective of optimized winter maintenance lies therefore in limiting the application rate in similar situations to the necessary extent and to harmonise the different maintenance strategies. To achieve this goal, high quality winter maintenance recommendations and extensive training courses of the winter maintenance personal are required. Furthermore, the instructions must provide drivers with the means to make quick decisions during a treatment routine. If uncertainties cannot be dispelled through training courses and the winter maintenance guidelines, large amounts of salt based on the principle “a lot of salt helps a lot” are applied. This costly overuse of de-icing agents regardless of the physical limits of winter maintenance will then use a lot of resources and damage the environment.

2. LIMITS: LIMITED DE-ICING CAPABILITY OF SODIUM CHLORIDE

The physical impact of salting is to lower the freezing point temperature of the solution of de-icing agents and precipitation on the road below road surface temperature. The main de-icing agent is sodium chloride (NaCl), with a maximum freezing point of -22.6 °C at a brine concentration of 23.4%. A further lowering of the freezing point temperature below this eutectic point of NaCl is not possible. Laboratory tests with different salt concentrations of NaCl and $CaCl_2$ in a climate chamber show that, in contrast to other representations with super saturation of the brine, the freezing point does not increase according to Fig.1.

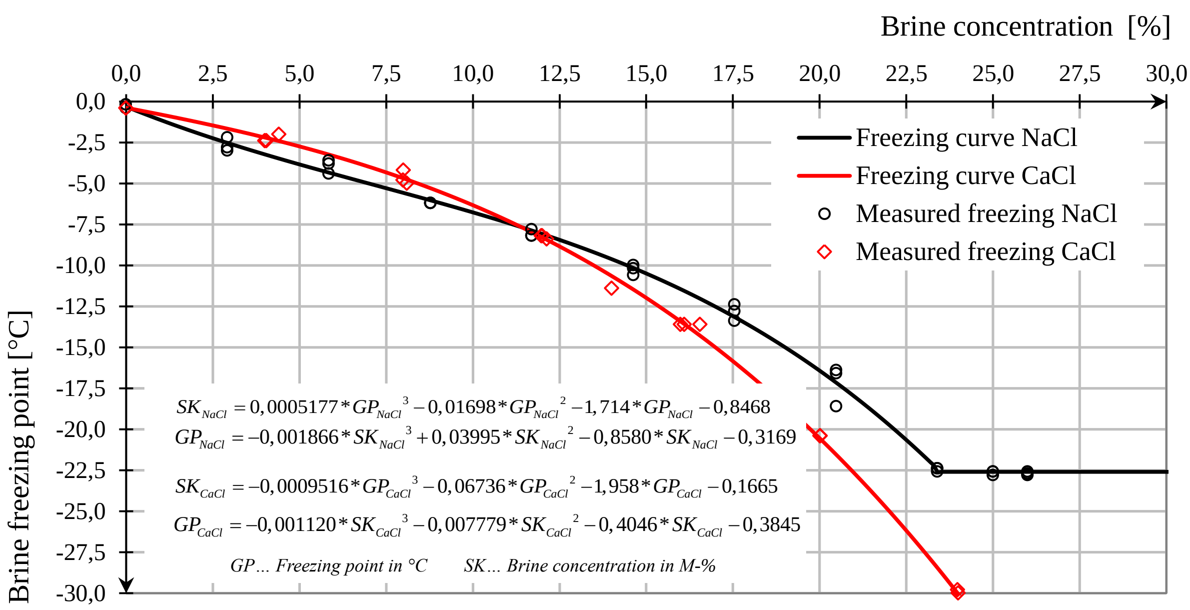


Fig. 1: Eutectic diagram for sodium chloride (NaCl) or calcium chloride ($CaCl_2$) on the basis of freezing experiments in the climate chamber @ TU Vienna with fitted freezing curves

For the winter maintenance practice, the amount of salt applied in dry or pre-wetted application thaws snow and ice until a brine concentration is reached where the freezing point of the brine matches the road temperature. If the amount of snow during a treatment cycle exceeds that limit, the roads cannot be kept free of snow or ice during the entire treatment cycle resulting in a refreezing or gradually covering of the road with snow. With medium to strong snowfall (> 0,5 cm/h) and the maximal application rate (40 g/m^2) in typical intervals of 90 to 180 minutes, the road cannot be kept free from snow or ice due to physical reasons.

In such cases, the attempt to handle the precipitation with high application rates up to 40 g/m² can be even counterproductive, as a snow-covered road has a slightly better skid resistance according to the friction tests than a road covered in refreezing snow slush. In addition, a distinctly and visibly snow-covered road leads to an "adapted" driving behaviour. Therefore, the frequently practised strategy in such cases "a lot of salt helps a lot" is not effective and costs considerably more. The amount of snow in centimetre that can be thawed theoretically with one treatment is shown in Fig. 2, based on salt application rate and road temperature. Each point on the lines corresponds to the freezing point of brine with the concentration resulting from the application rate and the amount of precipitation. Snow quantities above 1 centimetre in the relevant treatment interval even with the maximum application rate of 40 g/m² cannot be thawed by sodium chloride with a road temperature lower than -3°C for physical reasons according to Fig. 2 (left).

If salt losses out of drift and discharge losses due to traffic are taken into account, the available amount of salt for thawing is significantly lower. Based on previous measurement data from HAUSMANN (2009) and TU VIENNA – Institute of Transportation, the remaining amount of salt immediately after the application process can be roughly estimated with 30% to 50% of the initial application rate as pointed out in Fig. 2 (right). For the given scenario above the practical available amount of de-icing agents immediately after salting can therefore at best thaw around 0,3 to 0,5 cm. Depending on the actual traffic between treatment cycles, this remaining amount of salt decreases even further.

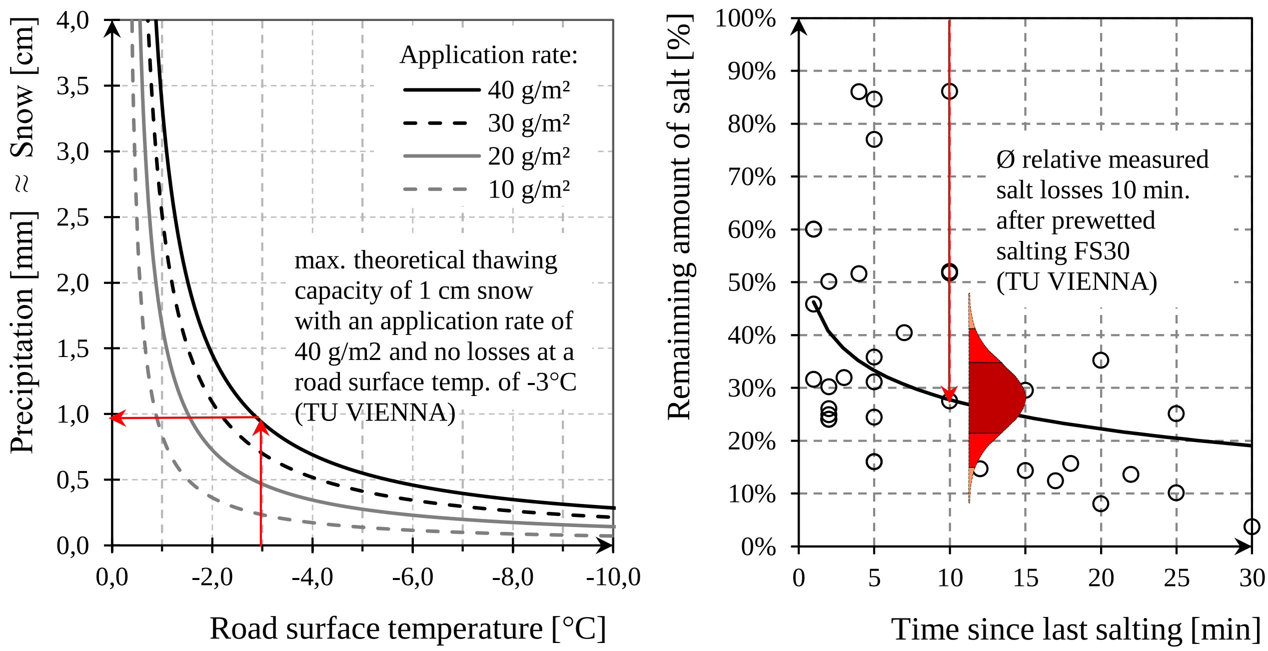


Fig.2: Theoretical thawing capacity of sodium chloride with typical application rates of 10 to 40 g/m² (left) and relative salt losses after treatment for prewetted salting (right) @ TU Vienna

3. DEVELOPED MODEL: BASE FOR OPTIMIZED WINTER MAINTENANCE

The goal of the study was to answer the question of the necessary salt application rate and timing in order to optimize winter maintenance and to improve the road safety. Based on extensive field and laboratory research, a mathematical model was developed that allows the determination of the application rate and timing of de-icing agents as a function of snow fall, traffic and road surface texture. Furthermore, the resulting skid resistance and speed limits for safe driving can be estimated based on the filling rate of the texture reserve and the resulting skid resistance. The model in Fig.3 describes the residual salt loss and the water quantity on the road based on several factors and the resulting time-dependent brine concentration. If the road surface temperature drops below the freezing point of the brine on the road, there is danger of frost. Sleekness is only at risk if the water on the road freezes and the texture reserve is insufficient. The reserve in texture depends on the macro texture of the pavement and describes the amount of frozen precipitation needed to fill the texture preventing direct tire – asphalt contact resulting in reduced skid resistance.

The residual amount of salt is determined by resistance measurements (SOBO 20) at predetermined measurement points and is a function of application rate, traffic, road surface texture and speed. The thickness of the water film resulting from the precipitation, traffic and air temperature was measured by Vaisala - Cameras (DSC 111, DST 111). In simultaneously running measurements, the effective skid resistance and its development in various winter maintenance situations with known weather conditions and precipitation over the entire test section were examined (Grip Tester MK II). The combination of sand patch method, texture measurement by laser and RoadSTAR - data to determine the texture reserve, guarantee a widespread applicability of the model on any possible road surface.

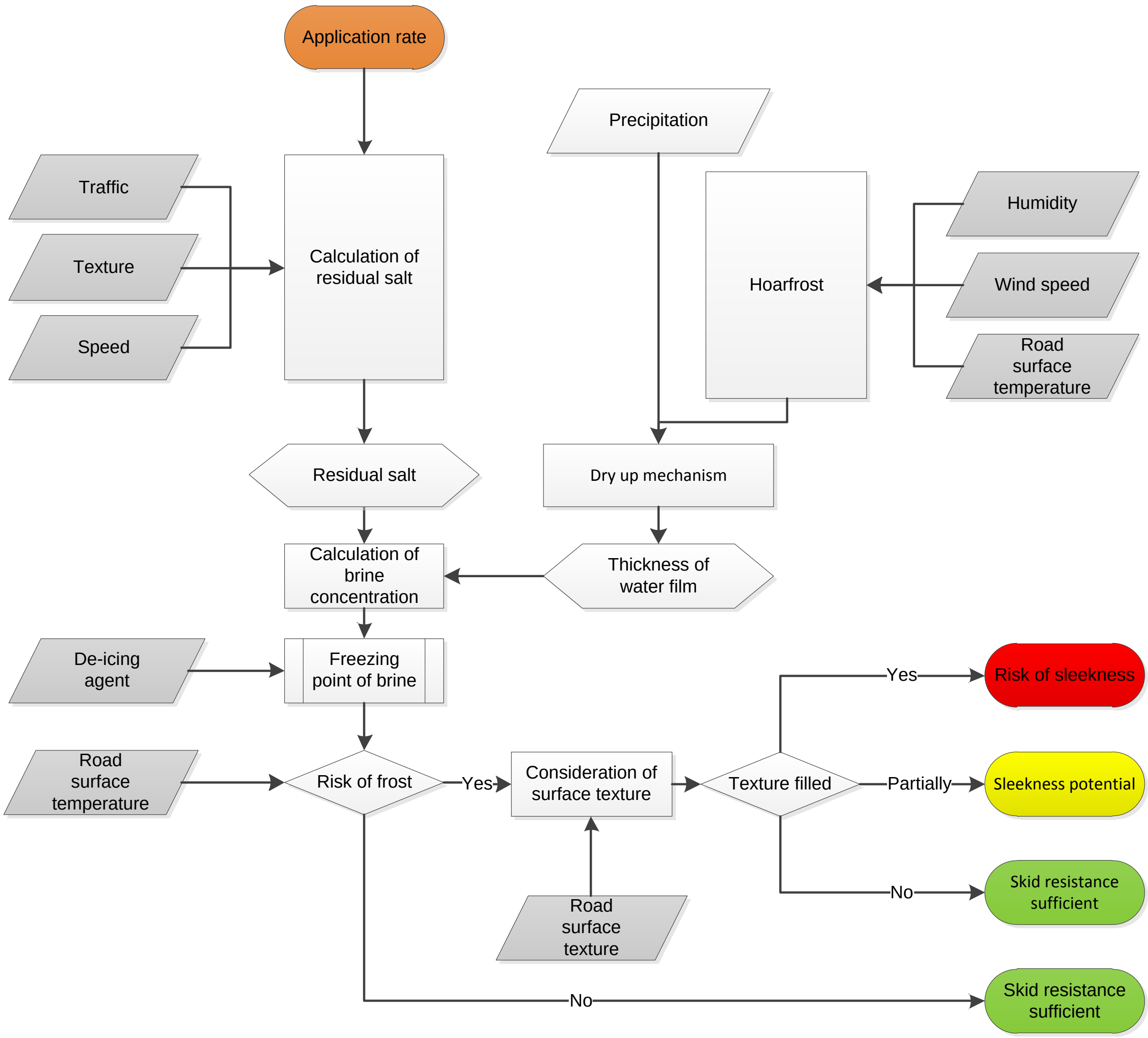
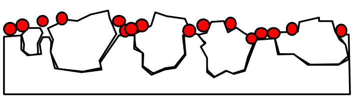
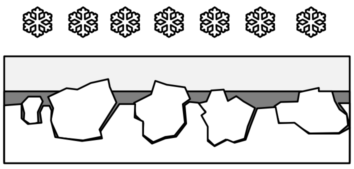
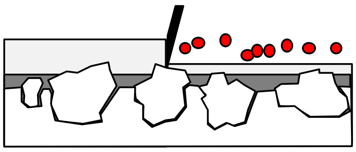
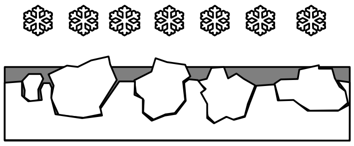


Fig.3: Preliminary model of residual salt decrease and dry up mechanism as well as the freezing point of the brine in order to determine the application rate of de-icing agents @ TU Vienna

4. PREVENTIVE TREATMENT: MECHANISM AND APPLICATION STRATEGY

From the limited thawing capability of de-icing agents as well as the identified correlations in the model, the mechanism of preventive treatment can be derived. A preventive treatment is an application of de-icing agents prior to the occurrence of a precipitation event. This serves the purpose of avoiding potentially slippery roads (e.g. hoarfrost) and eases snowploughing in the next treatment. Therefore, a preventive treatment has to be performed prior to each precipitation event. In case of hoarfrost, water vapour in the air settles on the cold road surface in form of ice. Usually hoarfrost appears in the early morning, usually not exceeding 100 g/m². With a preventive treatment and a salt application rate of 10 g/m² timed close to the beginning of the hoarfrost, a slippery road surface can be largely avoided. However, a preventive treatment in the eve the day before is not effective due to the occurring discharge and scattering losses.

If the thaw capability of the spread salt is exceeded due to the amount of snow between two treatments cycles and the remaining snow after the first snowploughing, the development of snow slush cannot be avoided. This snow slush freezes after further dilatation of the brine on the road due to on-going precipitation. The result is a lower skid resistance compared to a snow-covered road. In addition, it is easier for the road users to adapt their driving to an observable snow covered road than on freezing and poorly visible snow slush. In such cases a preventive application according to Fig. 4 of 10 g/m² is usually sufficient to form a release coating. This release coating is to be renewed after each treatment and prevents the adherence of snow or ice on the road surface, without creating large amounts of snow slush. For anticipated amounts of snowfall, temperatures and road traffic loads where the road can be kept free of snow and ice, the necessary application rate is established based on the developed preliminary model according to Fig.5.

	**1. Preventive treatment before snowfall event** e.g. 10 g/m^2 on the eve of a snowfall event of 1 cm/h road surface temperature = - 5°C mit treatment intervall = 3 h resulting in 3 cm snow depth per treatment interval
	**2. Dilution and formation of 2 phases** 1. Phase snow/ice above (about 0% salt) density 0,1-0,9 g/cm^3 2. Phase brine below (8% salt) density 1,1 g/cm^3. The applied salt is dissolved gradually, until an equilibrium concentration is reached at 8% and -5 °C
	**3. Snowploughing and salt application** The brine film prevents adhesion of the snow on the road surface and relieves further snowploughing. For salt application applies: remaining snow + applied salt = brine 8%> (salt consumption depends on quality of ploughing and road condition)
	**4. Thaw residual snow (continue with 2)** Thaw of the remaining snow and brine formation > 8%; ongoing development according to 2 until end of snowfalls (discharge loss due to traffic and mixing not considered)

Salt Snowfall Snow/Ice Brine

Fig.4: Mechanism of preventive treatment in winter maintenance in order to form a release coating with snowfall amounts that cannot be thawed in typical treatment intervals

5. APPLICATION RATES: PRINCIPLES AND QUANTITY DETERMINATION

From the existing legal framework and standards, the surveys of the winter maintenance authorities and the previous studies and results of the preliminary model following treatment principles can be derived:

- On highways, express roads and their junctions the maximum treatment interval (cycle time) is 3 hours in the period between 0h to 24h (category A).
- At high-level country roads with AADT > 5000 vehicles per day the maximum treatment interval is 5 hours in the period between 4h to 22h (category B).
- At high-level country roads with AADT > 1000 to 500 vehicles per 24 hours at the maximum treatment interval is 5 hours in the period 5h to 20h (category C).
- Pre-wetted salt has less discharge and a better spread pattern as dry salting, and is preferably applied up to a brine amount of 30% (BADELT 2007).
- The amount of snow that can be thawed is limited for physical reasons. Therefore snow or ice-free roads cannot be maintained with heavy snow falls (> 1cm/h) & deep temperatures (<-5°C).

- Reducing the treatment intervals still further increases the costs without significantly improving the road condition.
- The application rate of de-icing agents should not exceed the necessary amount. Larger application rates lead to disproportionate high costs without improvement of road conditions.
- The salting has to be timed as close as possible previous to any precipitation event (about 5 - 10 g/m² preventive application < 1h previous to precipitation).
- Hard-packed snow or ice on the roads cannot be removed quickly enough by the application of salt. A mechanical removal must therefore always take place previous to salting.

Based on the preliminary model, the required application rate as a function of precipitation or snow depth, temperature and traffic volume in the treatment interval can be found in Fig. 6 in grams per square meter. In the coloured region up to a maximum application rate of 40 g/m², the road can be kept free of snow and ice during the whole treatment interval. In the grey-coloured areas only a preventive treatment with 10 g/m² and maintenance of a release coating according to the previous presented strategy has been proved to be effective. The given application rates in Fig. 5 from the model are calculated on the conservative side, considering the upper limit of precipitation. In addition, the heating of the wheel tracks due to traffic volume of about 0,001 °C per car and hour is neglected. This has a considerably positive effect on thawing, especially in temperature ranges between 0° and -2° Celsius on heavily loaded roads. Taking into account the reserves and/or a cascaded treatment, the controllable area with snow and ice-free roads may be expanded substantially. However, this has to be compared against the substantially higher salt costs and environmental impacts and is therefore usually only an option under special circumstances on highways.

Precipitation 0,0 mm to 0,25 mm - Snow depth 0,0 mm to 2,5 mm or hoarfrost

Cars in treatment interval / application rate [g/m²]	Road surface temperature [°C] -1	-2	-3	-4	-5	-6	-7	-8	-9	-10
250	7	14	21	27	33	39	10	10	10	10
500	8	16	23	30	36	10	10	10	10	10
1.000	10	19	28	36	10	10	10	10	10	10
1.500	12	23	34	10	10	10	10	10	10	10
2.000	15	29	10	10	10	10	10	10	10	10
2.500	18	35	10	10	10	10	10	10	0	0
3.000	22	10	10	10	10	10	0	0	0	0
3.500	27	10	10	10	10	0	0	0	0	0
4.000	33	10	10	10	10	0	0	0	0	0

Precipitation 0,25 mm to 0,5 mm - Snow depth 0,5 mm to 5 mm

Cars in treatment interval / application rate [g/m²]	Road surface temperature [°C] -1	-2	-3	-4	-5	-6	-7	-8	-9	-10
250	15	28	10	10	10	10	10	10	10	10
500	16	31	10	10	10	10	10	10	10	10
1.000	20	38	10	10	10	10	10	10	10	10
1.500	24	10	10	10	10	10	10	10	10	10
2.000	29	10	10	10	10	10	10	10	10	10
2.500	36	10	10	10	10	10	10	10	0	0
3.000	10	10	10	10	10	10	0	0	0	0
3.500	10	10	10	10	10	0	0	0	0	0
4.000	10	10	10	10	10	0	0	0	0	0

Precipitation 0,5 mm to 0,75 mm - Snow depth 5 mm to 7,5 mm

Cars in treatment interval / application rate [g/m²]	Road surface temperature [°C] -1	-2	-3	-4	-5	-6	-7	-8	-9	-10
250	22	10	10	10	10	10	10	10	10	10
500	24	10	10	10	10	10	10	10	10	10
1.000	29	10	10	10	10	10	10	10	10	10
1.500	36	10	10	10	10	10	10	10	10	10
2.000	10	10	10	10	10	10	10	10	10	10
2.500	10	10	10	10	10	10	10	10	0	0
3.000	10	10	10	10	10	10	0	0	0	0
3.500	10	10	10	10	10	0	0	0	0	0
4.000	10	10	10	10	10	0	0	0	0	0

Precipitation 0,75 mm to 1 mm - Snow depth 7,5 mm to 10 mm

Cars in treatment interval / application rate [g/m²]	Road surface temperature [°C] -1	-2	-3	-4	-5	-6	-7	-8	-9	-10
250	29	10	10	10	10	10	10	10	10	10
500	32	10	10	10	10	10	10	10	10	10
1.000	39	10	10	10	10	10	10	10	10	10
1.500	10	10	10	10	10	10	10	10	10	10
2.000	10	10	10	10	10	10	10	10	10	10
2.500	10	10	10	10	10	10	10	10	0	0
3.000	10	10	10	10	10	10	0	0	0	0
3.500	10	10	10	10	10	0	0	0	0	0
4.000	10	10	10	10	10	0	0	0	0	0

Fig.5: Model - based application rate as a function of precipitation, temperature and road traffic without use of reserves (e.g. heat losses of cars, frictional heat of tyres etc.)

6. ROAD SAFETY: DRIVING AND TREATMENT RECOMMENDATION

In addition to the treatment principles, application rates for typical scenarios based on the developed model are presented. These scenarios in Fig. 6 consist of the road condition and weather development descriptions according to their importance for winter maintenance vehicle drivers and road users. These scenarios are illustrated with pictures of typical road conditions along with an overview of winter maintenance strategies and driving recommendations. The treatment recommendations for typical road situations should not replace the expertise and responsibility of the winter maintenance staff including the adaptation of the application rate on local requirements (e.g. on bridges, drain asphalt, etc.). However, they can help to harmonize the appraisal of the situation in order to achieve a better winter maintenance.

Picture documentation	Road conditions	Treatment recommendations	Driving recommendations
Dry Road:	**Very good (usually no problems)**	**Minimal salt application:**	**No limitation:**
	High skid resistance µ = 0,7 – 1,0 Road surface temperature -30°C to + 60 °C	No treatment required	No restrictions within speed limits based on road conditions are required.
	No sleekness due to hoarfrost expected	No treatment required	The road is generally safe to use within speed limits
	Sleekness due to hoarfrost possible	Preventive Treatment 5 - 10 g/m² with beginning hoarfrost (usually between 02:00 - 04:00)	The road is usually safe after treatment (consider visibility in case of fog!)
Wet Road:	**Good (black ice possible!)**	**Treatment only at tempetrures below 0°C**	**Speed reduction nessecary:**
	Road surface temperature ≥ 0°C no spray Medium skid resistance µ = 0,4 - 0,7	No treatment required	Adapted driving style
	Spray medium to low skid resistance µ = 0,3 - 0,6	check lane grooves (risk of aquaplaning)	Speed restriction when lane grooves below 70 km/h (highways and regional roads)
	Road surface temperature < 0°C risk of black ice; very low skid resistance µ = 0,1–0,6	Preventive treatment is crucial! Ploughing & salt application from 20 to 40 g/m² & warning messages	Risk of black ice, massive speed reduction below 30 km/h or walking pace is highly recommended
Snow next to wheel tracks:	**Fair (problems when changing lanes)**	**Ploughing and salt application as required**	**Careful driving and speed reduction necessary:**
	No snowfall	Ploughing and salt application 20 - 30 g/m²	Adapted driving style. Speed reduction of 20 - 30%
	Wheel tracks dry or weg skid resistance µ = 0,3 – 0,5	Ploughing and salt application 10 - 20 g/m² when less than 0,5 cm snowfall in treatment interval	Adapted driving style. Speed reduction of 20 - 30%
	Snowfall, Snow remains in wheel tracks (grey - white surface) low skid resistance µ = 0,2 – 0,4	With snowfall > 0,5 cm ploughing & salt application of 10 g/m² until end, then 20 g/m² to 30 g/m²	Adapted driving to road conditions, reducing the speed limit by up to 50%
Snow in wheel tracks:	**Bad (very low skid resistance)**	**Ploughing and salt application as required**	**Adaptive driving and speed reduction necessary:**
	No snowfall, cleared low skid resistance µ = 0,2 - 0,3 road surface temperature ≤ 0°C	Treatment with ploughing and salt application to clear the road of snow	Reducing the speed limit below 80 km/h (highways) and below 50 km/h (regional roads)
	Snowfall, cleared, not cleared, precipitation < 0,5 mm in treatment interval (≈ 3 - 5 mm snow)	Preventive treatment prior to preciptitation event if possible, then ploughing and salt application	Reducing the speed limit below 70 km/h (highways) and below 50 km/h (regional roads) - Visibility!!
	Snow > 0,5mm in treatment interval low skid resistance µ = 0,2 - 0,3 road surface temp. -20°C to 0°C	With snowfall > 0,5 cm ploughing & salt application of 10 g/m² until end, then 20 g/m² to 30 g/m²	Reducing the speed limit below 50 km/h (highway) and below 30 km/h (regional roads) - Visibility!!
Black ice:	**Critical (almost no skid resistance)**	**Mechanical removal & maximum salt application, closing of roads:**	**Driving restrictions (walking pace may be allowed)**
	No precipitation Roadway surface satin silk to reflective Almost no skid resistance µ=0,1–0,2 Precipitation (Snow) Road surface temperature ≤ 0°C	Preventive treatment if possible, maximum salt application at icy parts. Staggered treatment. Closing of roads only in consultation with the police, then mechanical removal combined with maximum salting to remove the ice. Best strategy to avoid accidents is to close the roads until a sufficient skid resistance is reached again.	Possible driving restrictions have to be considered. Postpone unnecessary trips. During a trip continue in exceptional cases and reduce velocity on potentially dangerous parts to walking pace.

Fig.6: Typical weather and road conditions with winter maintenance and driving recommendations for highways and regional roads in Austria [HOFFMANN et. al. 2010; NUTZ 2010]

With the minimum curve radius and necessary range of sight from the planning guidelines in Austria (eg. RVS 03:03:23) as well as the required minimum skid resistance, safe driving in both dry and wet conditions is possible. With snow or ice on the road, careful driving and a reduction of the speed compared to the actual speed limits is required. Since a snow-covered road is usually accompanied by snowfall and poor visibility conditions, the resulting braking distances are particularly problematic. Due to these conditions the necessary braking distances cannot be met without severe reduction in speed. Based on the noticeable road conditions shown in Fig.6, a good assessment of the situation becomes feasible. With the preliminary model, an adapted driving behaviour for safe driving in accordance with § 20 of the road traffic regulations (STVO) from 1964 can be defined. The driver can assess the road conditions according to the reference images and is therefore able to reduce the speed accordingly.

7. CONCLUSIONS AND OUTLOOK

The planning guidelines in Austria for highways and regional roads prevent accidents during dry or wet conditions due to a lack in skid resistance given the compliance of speed limits. With snow or ice on the road, careful driving and a reduction of the speed compared to the actual speed limits is required. Since these conditions usually come with snowfall and poor visibility, the necessary braking distances to avoid collisions are usually insufficient without severe reductions in speed [HOFFMANN M. 2010].

The goal of winter maintenance is to improve the accessibility of regions and the safety of the roads during the long winter periods in Austria. The physical impact of salting is to lower the freezing point temperature of the solution of de-icing agents and precipitation on the road below road surface temperature. To make this possible, the accumulating snow has to be cleared constantly and the salt losses due to spreading losses and scattering have to be replaced. With the developed model these processes considering all important influence factors can be simulated over several treatment cycles. Based on this simulation the optimal timing and necessary application rate of de-icing agents of each treatment cycle can be predicted together with the resulting costs. The calculations in the model consider the uncertainties by not using reserves (e.g. heat losses of cars, frictional heat of tyres) leading to stable results for the given conditions.

Further experiments to verify and improve the model will be continued during the winter 2010/2011 on highways and regional roads in Austria as well as in the laboratory of the Institute of Transportation. With the joint efforts of all project partners, we will be able to implement further improvements, both to the model and the winter maintenance practise. In the medium term our goal is the implementation of the model as a fully automated prognosis - system in order to create winter maintenance forecasts for all main roads in Austria. The developed winter maintenance guide is based on the findings of the model and is already used in the winter of 2010/11 on highways and regional roads in Austria. This guide will define the winter maintenance standards and is still evolving. However, it cannot replace a careful, responsible adaptation of the strategies and application rates by the winter maintenance personnel. Above all stands a responsible and adapted driving style in order to achieve safer roads for all road users.

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