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New findings in winter maintenance and their implementation in Austria

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ABSTRACT

Winter maintenance is essential to provide a high accessibility of regions with extensive snow fall or long winter periods. Typical decisions on a strategic level include choosing between de-icing agents, defining minimum treatment intervals, route quality targets, generalized winter maintenance strategies and specific application rates. On a practical level the winter maintenance personal has usually not enough time or information for an optimal consideration of all relevant factors in a changing environment. The winter maintenance personal is first in line if accidents happen and thus they tend towards a "safe approach" that differs from optimal application rates or timing of treatment. The comparison of typical winter maintenance situations with practical application rates showed a high potential of savings by preventing unnecessary salting. This leads to the main research question of optimized application rates and winter maintenance strategies for all typical situations that can still be applied in winter maintenance practise. To answer these questions the federal states of Austria, the Austrian highway operating company (ASFINAG) and the federal ministry of Transport (BMVIT) funded a research project at the Vienna University of Technology. Based on extensive field and lab testing at the Institute of Transportation the complex mechanical and physical impact of all main factors and their influence on winter maintenance could be determined. Practical testing and persistent discussion with selected personnel completed the verification and implementation of the findings in a comprehensive winter maintenance model. Further results include a compact practical winter maintenance guide and training courses for winter maintenance personnel. The presented paper gives a short overview of the findings with special emphasis on the contents of the winter maintenance guide.

Keywords: Winter maintenance, application rate, salting, safe roads, user guide

1 INTRODUCTION

General rules and standards in winter maintenance such as personal allocation or salt application rate boundaries are done on a strategic level by road authorities. The ultimate responsibility for implementation, particularly salt application rates, still lies within each maintenance vehicle driver. Due to their visual assessment of the current road condition they are able to adjust the salt application rate based on their subjective perception of the situation. This experience-based winter maintenance practice leads to completely inconsistent application rates in comparable situations. Due to public and legal pressure, some drivers tend to apply significantly higher total amounts of salt compared to the actual needs [4].

The objective of optimized winter maintenance lies therefore in limiting the application rate in similar situations to the necessary extent and to harmonise the variation of maintenance strategies. To achieve this goal, high quality and easy to understand winter maintenance recommendations are required. Only then different individual opinions on how to find the optimal approach in fighting snow and ice on the road can be replaced by a more optimized uniform strategy.

The essential question "When is salting necessary and how can the optimal application rate be determined?" must be answered in order to implement such an optimized uniform strategy. Furthermore, winter maintenance guides and training courses must provide drivers with the means to make quick decisions during a treatment routine. Only if uncertainties can be dispelled, the large amounts of applied salt based on the principle "a lot of salt helps a lot" can be reduced. Thus the costly overuse of de-icing agents regardless of the physical limits of winter maintenance will be minimised resulting in more economic use of resources and less damage to the environment. From the legal framework and standards in Austria, the surveys of the winter maintenance authorities and the previous studies following treatment principles can be derived:

- Regulations about maximum treatment intervals have to bear in mind the capacity of different road authorities and priority of roads
- Further categories and priorities may be set according to AADT
- Pre-wetted salt has less discharge and a better spread pattern as dry salting, and is preferably applied [1]
- The impact of de-icing agents is limited due to physical reasons; thus snow or ice-free roads cannot be provided in cases of heavy snowfall at low temperatures, even if short treatment intervals (<60 min.) and maximum spreading rates (40 g/m^2) are used.
- Shorter treatment intervals lead to cost increases without significantly improving road conditions.
- The actual application rates of de-icing agents should not exceed the necessary amount in order to prevent high costs without improvement of road conditions.
- Preventive salting has to be timed close (1h) prior to precipitation events (about 5 - 10 g/m²) in order to optimize impact and minimize premature salt losses due to traffic.
- Hard-packed snow or ice on the roads cannot be removed quickly enough with salting alone. A mechanical removal is therefore mandatory previous to any further salting.

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 cost efficient and mainly used de-icing agent is sodium chloride (NaCl) with a freezing point of -22.6 °C at a brine concentration of 23.4%. Further lowering of the freezing point temperature below this eutectic point is not possible with sodium chloride at atmospheric conditions. Laboratory tests with different salt concentrations of NaCl and $CaCl_2$ in a climate chamber show no increase in freezing points in super saturated brines (Figure 1) in contrast to other publications.

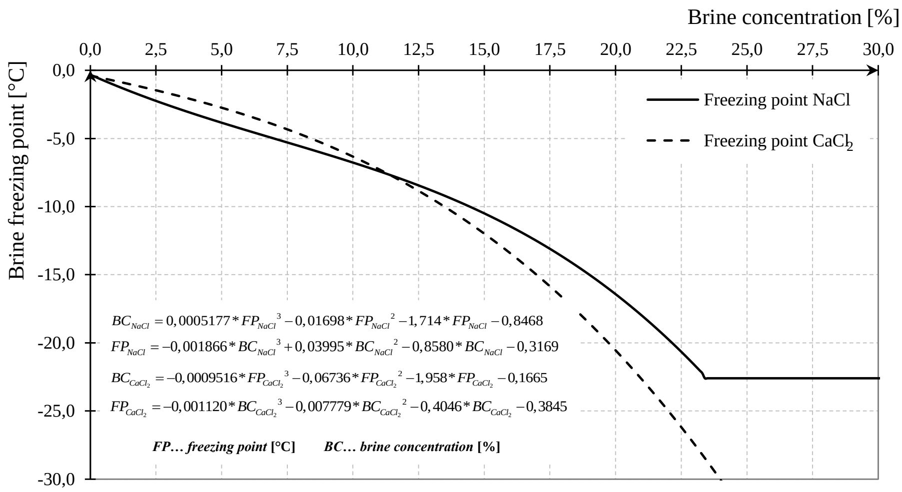


Figure 1. Freezing point for sodium chloride and calcium chloride based on freezing experiments [4]

The amount of applied dry or pre-wetted salt thaws snow and ice until a brine concentration with a freezing point matching road surface temperature is reached. If the amount of snow during a treatment cycle exceeds that limit, the road cannot be kept free of snow or ice during the entire treatment cycle resulting in refreezing or gradually snow covered roads. One of the key points in training courses of the winter maintenance personnel is therefore to show the physical limits of de-icing agents. According to the regulations in Austria (RVS 12.04.12), the statutory treatment cycle on highways has to be lower than 3 hours respectively 5 hours on regional roads. With medium to strong snowfall rates and the maximal application rate in significantly shorter intervals of 90 to 180 minutes, the road cannot be kept free from snow or ice purely 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 than a road covered in refreezing snow slush. In addition, a distinctly and visibly snow-covered road is more likely to evoke an "adapted" driving behaviour. An example of the theoretical amount of snow that can be thawed based on salt application rate and road temperature with a single treatment is shown in Figure 2. Snow of more than 1.0 cm in a treatment interval with sodium chloride and a maximum application rate of 40 g/m² cannot be thawed at road temperatures lower than - 3°C.

If salt losses due to drift and discharge caused by road traffic are taken into account, the amount of residual salt for thawing is even lower. Based on previous measurement data from [2, 3], the residual salt immediately after the application process (< 10 min) can be roughly estimated with 40 - 50% of the initial application rate. For the given scenario above the practical available amount of de-icing agents immediately after salting can at best thaw around 0.5 cm. Dependening on the actual traffic between treatment cycles, this amount of residual salt is scattered even further over time. Thus the road cannot be held free of snow or ice over the entire treatment cycle for the given scenario.

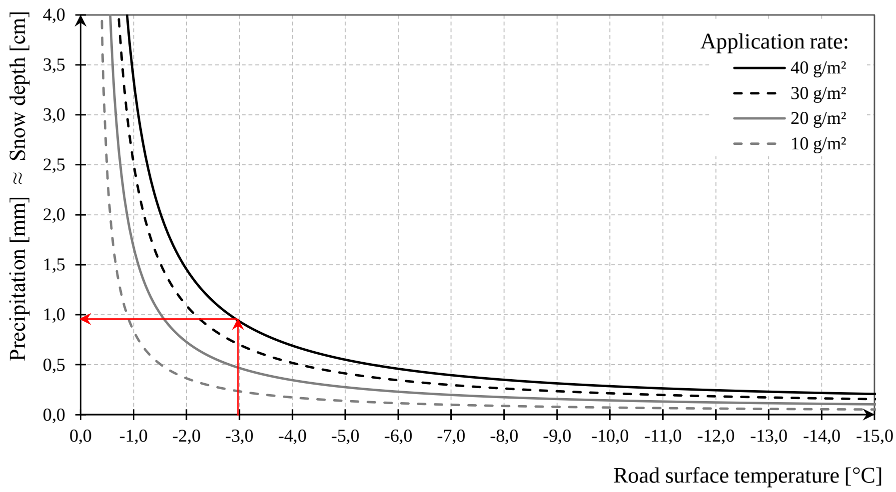


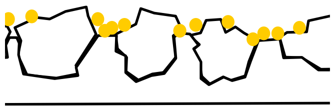
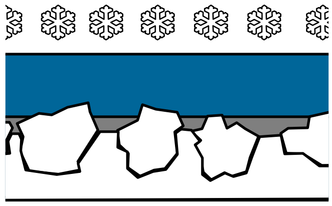
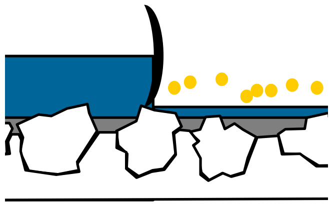
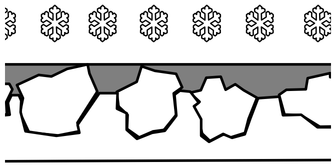
Figure 2. Theoretical maximum amount of snow sodium chloride can thaw at different road surface temperatures without drift and discharge by traffic for typical application rates of 10 to 40 g/m²

3 PREVENTIVE TREATMENT: MECHANISM AND APPLICATION STRATEGY

From the limited thawing capability of de-icing agents as well as the identified correlations, the mechanism of preventive treatment can be derived in order to avoid potentially slippery roads (e.g. hoarfrost) and ease snowploughing in the next treatment. Therefore, a preventive treatment has to be performed prior to each precipitation event unless sufficient residual salt from previous treatments is available on the road. Hoarfrost as the formation of ice out of water vapour often 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 prior to hoarfrost, a slippery road surface can be avoided. However, a treatment in the evening before with change of shifts is not effective due to the occurring discharge and scattering losses.

If the physical limited thaw capability of salt is exceeded due to the amount of snow between two treatment 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 resulting in 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 a freezing and poorly visible snow slush. In such cases a preventive application of 10 g/m² is usually sufficient to form a release coating out of salt and first precipitation. This release coating is to be renewed after each ploughing and prevents the adherence of snow or ice on the road surface, without creating large amounts of snow slush (Figure 3). With the end of the snowfall the remaining snow can be cleared by ploughing and salting. At very low temperatures the melting capacity of salt is very low leading to no further improvements of road condition with appropriate ploughing being a sufficient treatment.

Compared to a preventive treatment a delayed treatment addresses a situation where snow is already compressed by traffic and frozen onto the road surface with no release coating present. In such cases the quality of snowploughing is very low leaving significantly higher amounts of residual snow on the road. Any thawing attempt will create a slippery brine film on top of the snow layer. Depending on the situation the snow will either thaw over time if salting rate/road temperature are high enough or a snow-brine-snow formation will be formed leading to roads with even lower skid resistance compared to doing nothing.

Physical mechanism „Preventive treatment“	
	**1. Preventive treatment just before snowfall event** e.g. 10 g/m² immediately prior to snowfall of about 1 cm/h Road surface temperature = - 5°C Treatment interval = 3 h 3 cm snow height during interval
	**2. Dilution and forming of 2 phases** 1. Phase snow/ice (about 0% salt) 2. Phase brine below (8% salt) The applied salt is dissolved gradually, until an equilibrium concentration is reached at 8% and -5°C
	**3. Snowploughing and salting** The brine 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)

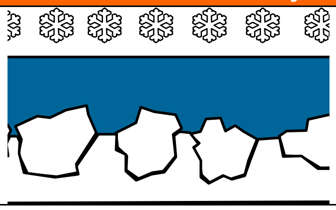
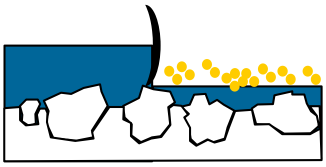
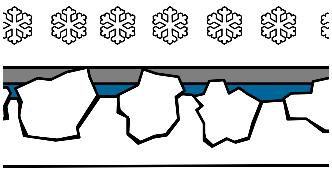
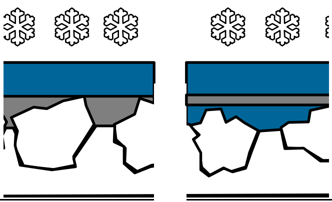
Physical mechanism „Delayed treatment“	
	**1. Snowfall and ice formation** Snowfall of 1cm/h adds up to 3cm during the interval which are discharged or compressed by traffic. Possibility of ice formation due to high pressure or freezing of snow to the road surface
	**2. Snowploughing and salting** Increased Ploughing energy needed due to absence of release coating, higher remaining snow volume= higher salt rates needed Residual snow + salt = brine > 8% (Salt consumption depends on quality of ploughing and road condition)
	**3. Icy conditions during melting process (2 phases)** 1. Phase brine on top (>8% salt) 2. Phase snow/ice (about 0% salt) During the melting process >15 - 30 minutes vehicles drive on a layer of ice
	**4. (Partial) Thawing of remaining snow** With adequate ploughing and salting remaining snow thaw under formation of brine > 8% concentration Otherwise further development as in point 2 of the preventive treatment. With insufficient salting threatens icy conditions.

Figure 3. 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 and delayed treatment

4 APPLICATION RATES: PRINCIPLES AND QUANTITY DETERMINATION

The theoretical required application rate according to Figure 4 is a function of precipitation or snow depth, temperature and traffic volume during a treatment interval. The coloured regions mark situations where application rates up to the maximum of 40 g/m² are sufficient to keep the road free of snow and ice during the entire treatment interval. In the grey-coloured areas more than 40 g/m² of Sodium Chloride would be needed making preventive treatment with 10 g/m² and maintenance of a release coating the more efficient strategy. The given application rates are calculated on the conservative side, considering the upper limit of precipitation and no heat induction on the road surface from passing vehicles. The heating of the road surface due to traffic volume amounts to 0,001 °C per car and hour based on thermography is neglected to account for uncertainties. However, this warming has a considerable effect on thawing, especially in temperature ranges between 0° and -2° Celsius on roads with high traffic volume. Considering this effect and/or cascaded treatment, the controllable area with snow and ice-free roads may be expanded substantially. However, this approach has to be weighed against substantially higher salting costs and resulting environmental impacts and is therefore only an option under special circumstances (e.g. highways).

Precipitation 0,0 mm to 0,25 mm - Snow hight 0,0 cm to 0,25 cm – Hoarfrost or slightly visible snowfall

	Application rate [g/m²]	Road surface temperature [°C] -1	-2	-3	-4	-5	-6	-7	-8	-9	-10
Traffic during interval	250	5	16	26	36	10	10	10	10	10	10
	500	6	16	27	37	10	10	10	10	10	10
	1.000	6	17	28	39	10	10	10	10	10	10
	1.500	6	18	30	10	10	10	10	10	10	10
	2.000	6	19	31	10	10	10	10	10	10	10
	2.500	7	20	33	10	10	10	10	10	10	10
	3.000	7	21	35	10	10	10	10	10	10	10
	3.500	8	23	37	10	10	10	10	10	10	10
	4.000	8	24	40	10	10	10	10	10	10	10

Precipitation 0,25 mm to 0,5 mm - Snow hight 0,25 cm to 0,5 cm – Very light snowfall

	Application rate [g/m²]	Road surface temperature [°C] -1	-2	-3	-4	-5	-6	-7	-8	-9	-10
Traffic during interval	250	11	32	10	10	10	10	10	10	10	10
	500	11	33	10	10	10	10	10	10	10	10
	1.000	12	34	10	10	10	10	10	10	10	10
	1.500	12	36	10	10	10	10	10	10	10	10
	2.000	13	38	10	10	10	10	10	10	10	10
	2.500	14	10	10	10	10	10	10	10	10	10
	3.000	14	10	10	10	10	10	10	10	10	10
	3.500	15	10	10	10	10	10	10	10	10	10
	4.000	16	10	10	10	10	10	10	10	10	10

Precipitation 0,5 mm to 0,75 mm - Snow hight 0,5 cm to 0,75 cm – Light snowfall

	Application rate [g/m²]	Road surface temperature [°C] -1	-2	-3	-4	-5	-6	-7	-8	-9	-10
Traffic during interval	250	16	10	10	10	10	10	10	10	10	10
	500	17	10	10	10	10	10	10	10	10	10
	1.000	17	10	10	10	10	10	10	10	10	10
	1.500	18	10	10	10	10	10	10	10	10	10
	2.000	19	10	10	10	10	10	10	10	10	10
	2.500	20	10	10	10	10	10	10	10	10	10
	3.000	22	10	10	10	10	10	10	10	10	10
	3.500	23	10	10	10	10	10	10	10	10	10
	4.000	24	10	10	10	10	10	10	10	10	10

Precipitation 0,75 mm to 1,0 mm - Snow hight 0,75 cm to 1,0 cm – Light/moderate snowfall

	Application rate [g/m²]	Road surface temperature [°C] -1	-2	-3	-4	-5	-6	-7	-8	-9	-10
Traffic during interval	250	22	10	10	10	10	10	10	10	10	10
	500	22	10	10	10	10	10	10	10	10	10
	1.000	23	10	10	10	10	10	10	10	10	10
	1.500	24	10	10	10	10	10	10	10	10	10
	2.000	26	10	10	10	10	10	10	10	10	10
	2.500	27	10	10	10	10	10	10	10	10	10
	3.000	29	10	10	10	10	10	10	10	10	10
	3.500	31	10	10	10	10	10	10	10	10	10
	4.000	33	10	10	10	10	10	10	10	10	10

Figure 4. Melting capacity of salt depending on precipitation, road surface temperature and traffic including drift and discharge losses during a treatment cycle.

5 ROAD SAFETY: DRIVING AND TREATMENT RECOMMENDATION

In addition to treatment principles, winter maintenance strategies, application rates, and driving recommendations for typical winter scenarios have been developed. These scenarios consist of clearly distinguishable road conditions and weather development scenarios according to their importance for winter maintenance and road users. These scenarios are given in Figure 5 with pictures of typical road conditions and an overview of winter maintenance strategies and associated driving recommendations (Figure 6). The winter maintenance recommendations do not replace local expertise and responsibility of the winter maintenance staff and adaptation of application rates for special requirements (e.g. on bridges, drain asphalt, etc.). However, they encourage a harmonized appraisal of the situation in order to achieve better winter maintenance results.

With a 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 necessary braking distances cannot be met without a severe reduction in speed. With clearly distinguishable road conditions from Figure 6, a good assessment of the driving situation becomes feasible. Based on a comprehensive model of skid resistance under winter conditions [5], an adapted driving behaviour for safe driving according to the regulations (§ 20 STVO) can be defined. Thus any driver can assess the actual road conditions according to the reference images and is able to reduce the driving speed accordingly.

Picture documentary	Road condition	Treatment recommendation
	**Dry road:**	**Minimal salting only at hoarfrost:**
	No sleekness expected Surfact temperature: -30°C to +60°C High skid resistance, µ = 0,6 – 1,0	No treatment required
	Hoarfrost possible or expected (usually at 2 - 4 am)	Preventive treatment 5 – 10* g/m² with beginning hoarfrost
	**Moist or wet road:**	**Salting at temperatures below 0°C:**
	Road surface temperature > 0° C Moderate skid resistance, µ = 0,4 – 0,7	No treatment required (Watch temperature!)
	Road surface temperature ≤ 0°C Moist road Moderate skid resistance, µ = 0,2 – 0,6	Preventive treatment with 5 – 10* g/m² Before beginning freezing
	Road surface temperature ≤ 0°C Wet road Very low skid resistance, µ = 0,1 – 0,6	Treatment with 20 to 40* g/m² before freezing critical Warning messages if black ice forms!
	**Snow next to wheel tracks:**	**Ploughing and salting:**
	No snowfall Wheel tracks free of snow Moderate skid resistance, µ = 0,3 – 0,5	Ploughing and salting with 10 – 20* g/m², to remove remaining snow
	Snowfall less than 0,5 cm/interval Low skid resistance, µ = 0,2 – 0,4	Ploughing and salting with 10 – 20* g/m²
	Snowfall more than 0,5 cm/interval Snow in wheel tracks Low skid resistance, µ = 0,2 – 0,4	Ploughing and salting 10 g/m² (release coating!) until end of snowfalls, then ploughing and salting with 10 – 20* g/m²
	**Snow in wheel tracks:**	**Ploughing and salting:**
	No snowfall Road covered with snow Low skid resistance, µ = 0,2 – 0,3	Ploughing and salting with 20 – 30* g/m², to remove remaining snow
	Snowfall less than 0,5 cm/interval Low skid resistance, µ = 0,2 – 0,3	Ploughing and salting with 10 – 20* g/m²
	Snowfall more than 0,5 cm/interval Very low skid resistance, µ = 0,1 – 0,3	Ploughing and salting 10 g/m² (release coating!) until end of snowfalls, then ploughing and salting with 20 – 30* g/m²
	**Very low skid resistance**	**Salting as required:**
	No precipitation Road surface temperature ≤ 0°C. Very low skid resistance, µ = 0,05 – 0,2	Preventive treatment if possible, Maximum treatment at critical/icy Spots, Further treatments as necessary
	Black ice and further precipitation (Snow or rain) Very low skid resistance, µ = 0,05 – 0,2	Maximum treatment until ice is cleared Closure of road sections as necessary. Opening after closure only if skid resistance is sufficient

Figure 5. Typical weather and road conditions and winter maintenance recommendations for regional roads in Austria

Picture documentary	Road condition	Driving recommendation
	**Dry road:**	**Usually no restrictions expected:**
	No sleekness expected Surface temperature: -30°C to +60°C High skid resistance	No restrictions due to weather based road conditions needed.
	Hoarfrost possible or expected (usually at 2 - 4 am)	Reduction of the speed by at exposed road sections (e.g. bridges)
	**Moist or wet road:**	**Local ice at sub-zero temperatures:**
	Road surface temperature > 0° C Moderate skid resistance– 0,7	Reduction of speed in case of lane grooves
	Road surface temperature ≤ 0°C Moist road Moderate skid resistance	Caution, black ice possible, Reduction of the speed by 50% at exposed road sections
	Road surface temperature ≤ 0°C Wet road Very low skid resistance	Caution, black ice possible, Reduction of the speed by 70% at exposed road sections
	**Snow next to wheel tracks:**	**Adapted driving:**
	No snowfall Wheel tracks free of snow Moderate skid resistance	Adapted driving. Reduction of the speed by 20 to 30%
	Snowfall more than 0.5 cm/interval Snow in wheel tracks Low skid resistance Visibility restricted!	Adapted driving to road conditions. Reduction of the speed by 30 to 40% Consider restricted visibility!
	**Snow in wheel tracks:**	**Adapted driving::**
	No snowfall Road covered with snow Low skid resistance	Adapted driving. Reduction of the speed by 40 to 50%
	Snowfall Snow in wheel tracks Very low skid resistance Visibility restricted!	Adapted driving to road conditions. Reduction of the speed by 60 to 70% Consider restricted visibility!
	**Black ice on road:**	**Particular caution, walking pace:**
	No precipitation, Road surface temperature ≤ 0°C. Very low skid resistance	Follow driving restriction until clearance of road. Pass dangerous areas with walking pace
	Black ice and further precipitation (Snow or rain) Very low skid resistance	Caution, ice beneath snow layer is not visible and therefore dangerous. Adapted driving to road conditions. Reduction of the speed to walking pace

Figure 6. Typical weather and road conditions with driving recommendations for regional roads in Austria.

6 CONCLUSIONS

The goal of winter maintenance is to improve accessibility of regions and safety of roads during winter periods. Basic decisions in winter maintenance including timing of treatment and salt application rate are done by winter maintenance personal usually on the road while driving a truck fitted with often more than 3 m wide snowploughs. Thus a practical winter maintenance guide must be easy to read and clear in its statements based on a profound knowledge of fundamental physical evidence. An introduction and explanation of the winter maintenance guide in form of training courses is required in order to achieve high acceptance and impact of the new findings. Complex physical relations must be delivered in small understandable steps to avoid misinterpretation or neglection.

The presented paper is based on extensive field and lab testing at the Institute of Transportation allowing a determination of the complex mechanical and physical impact of all main factors and their influence on winter maintenance. Practical testing and persistent discussion with selected winter maintenance personnel completed the verification of the developed winter maintenance model and maintenance guide. The implementation of the findings in practical winter maintenance during the winters from 2010 to 2012 based on extensive training courses proved to be successful with positive feedback and considerable savings in salting and expenses.

Furthermore the research results proved that even extensive winter maintenance cannot ensure dry or wet roads due to the limited thawing capacity of sodium chloride at all times. With snow or ice on the road, careful driving and a reduction of speed compared to actual speed limits is mandatory. 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. Thus, above all winter maintenance efforts stands a responsible and adapted driving style in order to achieve safer roads for all road users.

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