Research institute for roads and road traffic
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«Winter service»

Information on the planning, construction and operation of chemical thawing agent spraying installations (TMS)

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English translation (original in French)

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1 Scope

Chemical thawing agent spraying systems (TMS) are fixed equipment of the winter service. Road surface and weather condition detectors detect the ice formation of a road and trigger a thawing agent spraying system into operation. Conventional short-notice interventions necessary at critical spots of the road network or preventive measures thus become unnecessary.

A TMS allows the timely prevention of icing on hazardous places and assists a conventional (usually mechanical) winter service, by preventing the packing down of the snow layer.

Several factors have to be considered during the planning and the construction of a TMS. The knowledge of these factors helps to avoid wrong decisions.

2 Application criteria

2.1 General

The winter service has to ensure the below objectives even in unfavourable weather conditions:

- Maintain the drivability of the roads and hence the operation of the road network,
- Ensure a **sufficient road security**.

These objectives can be attained:

- By preventing the formation of ice (ice, hoarfrost, black ice) and
- maintaining of the fresh snow until the arrival of the snow ploughs in such a condition as to allow its removal (no packing).

The TMS supports these tasks. TMS installations of greater length often provide a combined effect. If such is the case, both aspects should be taken into consideration at the planning stage.

The necessary measures of the winter service depend on the weather conditions. The below table shows to what extent the TMS, together with the Ice Early Warning System (GFS) can help to confirm or cancel the decision of a measure, or it can complete a measure.

weather conditions	**Advantage**	
	TMS	**GFS**
ice formation on big surfaces, freezing humidity	quick availability in case of slipperiness, spares preventive spraying operations	helps to determine intervention decisions
rain / icing rain on undercooled road surface	instantaneous help in case of early detection by warning system	information on weather conditions for the winter service, concerning the beginning and end of precipitations
light snow fall near freezing point temperatures (without removal intervention)	prevents snow slipperiness and spares preventive interventions	helps to determine intervention decisions
heavy snow fall	prevents snow slipperiness and packing until the arrival of snow removal vehicles	helps to determine intervention decisions (in the case of snow layer measurement)
ice formation on limited surfaces (hidden slipperiness)	spares special interventions	reduces the number of necessary checking rounds

2.2 Measures to prevent icing

Icy roads are a heavy hindrance for the winter traffic and a serious road security hazard. «Slippery traps» present a particular danger. By these we understand short road stretches where:

- ice formation sets in earlier than on the rest of the road network
- the driver will have problems to detect the ice, and consequently an adapted driving behaviour is less probable
- accidents due to icy road surface are more frequent.

«Slippery traps» form on sections with a humidity above that of neighbouring areas and where the temperature sinks earlier below freezing point. The causes for the building up of humidity on the road surface are:

- precipitation or snow (ice) thaw water
- important humidity during temperature drop (slipperiness due to ice)
- fog emanating from humid spots or waters (slipperiness due to ice)

The untimeliness of the freezing point is the consequence of:

- temperature fall due to
  - shadow (forest, north slope, etc)
  - diminished heat supply from below (bridge, etc)
  - heat reflexion/absorption (road surface material, or other..)

- quicker cooling due to
  - evaporation-induced cooling of a wet road surface
  - particular exposure (wind, accumulation of cold air, etc)

2.3 Maintaining the snow condition until removal

Icy roads are a heavy hindrance for the winter traffic and a serious road security hazard also at such spots where heavy snow fall already hampers the traffic. In such conditions the snow is packed particularly in sections with heavy traffic. The removal of snow on sections of this kind is difficult. Up- and downhill slopes, where traffic jams or transverse stationary lorries hamper the operation of the winter service vehicles, present typical sore spots. A TMS can help to maintain the snow in such a condition as to be easily evacuated by the removal vehicles. In this case the TMS should not be limited to a too short section but rather cover an entire up- or downhill slope that is menaced by rough weather.

2.4 Position of the section in the road network

The installation of a TMS is particularly advisable for sections with a high difficulty of snow clearing by the competent operating centre by means of conventional equipment. The increased difficulty can be due to particular topographical conditions, e.g. the great distance of the section from the operating centre.

3 Cost/benefit estimate

A cost/benefit estimate is imperative before the installation of a TMS. A thorough analysis ought to be followed by the calculation of the benefit potential with respect to the expected investment and operation cost. For every installation the problems of the winter service and road traffic will be considered. The installation, operation and maintenance costs of a station can be compared against the possible benefits drawn from the operation of the road network as well as the expected financial economies gained through prevented accidents and traffic jams.

The total cost of an installation is composed of investment cost and current cost. Current costs comprise the purchase of thawing agents, energy consumption, personnel, repair and other costs, such as adjuncts or technical enhancements of the installation.

The investment comprises all expenses of the setting up of the installation, including secondary works, building, energy supply, excavation works, thermographic topometry, equipping the road section with crash barriers. The service lifetime of a TMS is calculated at 15 years.

The TMS installations can not replace winter service, but complete it with respect to road security. It is not possible to save on chemical thawing agents and on the number of interventions of the winter service.

A benefit can be expected owing to the fact that it is possible to considerably reduce the preventive interventions of the winter service, the on-call services and checking expenses. Decreasing the number of these interventions presents a benefit potential especially when the operating centre is far away from the hazardous section. In such a case the installation of a TMS can render the maintenance of a base unnecessary. Further economy can be expected owing to the lower cost of performed interventions - no blocked roads by traffic jams.

Benefits concern also the road security, traffic flow, environmental protection and the protection of road users. Quantified benefits are situated in the fields of:

- road security (accidents due to winter weather conditions on the roads avoided) and
- traffic flow (less traffic jams).

For the calculation of the accident costs, refer to the actual «Rates for the calculation of accidents» of the Federal Roads Institute (Institut fédéral des routes). The costs of traffic jams is composed of changes in operation expenses and of the time gain for the road user.

For calculation details see «RAS-W» (instructions for road construction, part: Study of profitability).

The installation of a TMS is advisable if the expected overall benefit exceeds the cost.

4 Technical principles of the installation

4.1 Principles

To be taken into consideration are the objective, the local conditions and the traffic conditions (density, hourly distribution, part of heavy traffic, etc).

The TMS consists of three system modules:

- Ice Early Warning System GFS
- electronic control
- hydraulic system

The perfectly harmonized operation of the three elements allow the achievement of the objective of the installation, ensuring an overall optimum operation from the standpoints of environment and profitability.

4.2 The Ice Early Warning System

GFS is a monitoring element and as such detects icing of the road surface and triggers the intervention of the TMS. The points of installation must be chosen most carefully. Longitudinally, they must be in concordance with

- the competent winter service (experience)
- the manufacturer (experience) as well as
- the weather service (meteorological knowledge).

If necessary, the installation points should be checked by means of a topo-thermography (thermic land survey; for bigger installations generally a thermal chartography followed by an analysis of the weather service).

Normally one measurement point per installation is necessary. In a bigger installation with several sections it is possible to provide a reduced equipment of several measurement points.

Measurement data detectors of the TMS (measurement data of the road surface and of precipitations) are essential for controlling the TMS.

Great importance should be attached to the logical function between the different measurement data, in order to ensure the perfect activation of the TMS as well as the perfect timing and orientation of the sprays. The interval between the triggering of the spraying cycle and the time of icing should not be too long, so that useless spraying and loss of thawing agent due to traffic be avoided.

4.3 The electronic control unit

Within the operating field of the TMS, the environmental conditions are unfavourable for electronic elements. The diffusion of liquid chemical thawing agents creates a spray fog and the projection of salt water.

Failures due to influences listed below or such due to mechanical impact, like e.g. road accidents or road maintanance work (e.g. mowing) can be avoided by :

- a protected disposal of the elements (the control unit must be placed, if possible, in the pumping station),
- laying the control cables underground or in protection tubing, behind the crash barriers with respect to the traffic,
- and by
- the use of rugged elements (free of energy supply and control elements).

The following details are of particular importance:

- The user must have the possibility of modifying or selecting the trigger criteria of the TMS via the operation software.

- It must be possible to activate the control manually from the competent service station.

- It must be possible to activate the different parts of the TMS in the field, to allow checking, maintenance and repair prcedures as well as operation tests (manual or using other technical devices).

- Installations covering unusually long sections should be divided, as far as the control is concerned, into sections of 500 to 600 m. These sections must operate independently and according to topographical data have a maximum lemgth of 1200 m.

- The system must contain a self-check device and display in an appropriate way its operating condition (display, monitor, other unit).

- Triggering criteria, status, spraying and failures have to be visualized and listed.

- A remote diagnosis of failure and trouble analysis should be included.

- Provide for the ulterior possibility to complete or modify the data respectively control lines.

- The electrical installation within the installation area must be designed in low-voltage equipment.

- VDE instructions should be respected.

4.4 The hydraulic system

The hydraulic system of a TMS comprises the following components:

- Pumping station and thawing agent tank (in big installations: sub-stations with pump and partial thawing agent tank)
- Thawing agent duct network with hydraulic elements
- Spray units

4.4.1 Pumping station, thawing agent tank, sub-stations

The pump and the thawing agent tank assure the central thawing agent supply of the TMS. For bigger installations, the different sub-stations must be equipped with a pump and a partial thawing agent tank.

The tank's volume varies as a function of the overall size of the installation as well as of the local winter conditions. For a bridge of a length up to 100 m a tank volume of about 8000 l proved to be sufficient. Such a reserve covers in general the needs for one winter period. For bigger installations, the reserve has to be limited on account of storage cost. Consequently one or several refillings per winter should be scheduled. For a TMS of 1 km length (bi-directional traffic, 4 to 6 traffic lanes) a minimum of 10'000 l of chemical thawing agent should be on stock to cover a period of 10 to 15 days of very cold weather and allow for timely refilling. The judicious choice of the volume of the sub-station tanks allows a variation of the main storage capacity and to plan it in consequence.

Recommended tank volumes are:

Motorway bridges :	up to 100 m	8'000 l
	up to 500 m	20'000 l

Bi-directional motorways :

up to 1 km	appr. 20'000 l (minimum 10'000 l)
up to 2 km	appr. 30'000 l (minimum 20'000 l)
up to 3 km	appr. 40'000 l (minimum 30'000 l)
up to 4 km	appr. 50'000 l (minimum 40'000 l)

The pump and tank (also the sub-stations) should be installed in protected areas to prevent acts of vandalism. Collector basins should be designed to prevent environmental damage in case of leakage. Various technical solutions are available.

Prefab garages or, as a less expensive alternative, closed steel containers or prefabricated building units (concrete/wood) can be used as shelter for the pump, control and tanks. The chosen material will be placed on foundations built on the spot.

The pump with the tanks as well as the sub-stations should be as far as possible below the level, i.e. at the foot of a bridge embankment or slope, at the lowest point of an uphill section. When situated on a summit, two (2) tanks should be provided at the lowest point of the TMS.

The following remarks should be further respected:

- The pump and ducts must be installed in conformity with «e 19 WHG» (qualification certificate of the manufacturer established by an independent supervising organ, such as TÜV for example).
- The material for the pump, ducts, valves, manometer etc (e.g. stainless steel V4A, synthetic materials) must be compatible with each other (dilatation coefficients) as well as with the thawing agent used.
- The necessary valves should be if possible realized as diaphragm valves (deposit-resistant). Less expensive ball valves can be used in other areas, where less security is required.
- The tanks must be designed for the thawing agent used. The volume weight of the thawing agent should be taken into consideration.
- A visualization device of the tanks' fill-up level should be provided.
- Provide a thawing agent flow control valve. For this, as well as for duct rincing purposes, the pump should be equipped with a manual control.
- Technical devices for the emptying of the tanks should be provided.
- The parameters of the electrical connection for the pump power supply must be respected.

4.4.2 Thawing agent duct with accessories (valves, pressure control, etc)

The thawing agent ducts have the function to supply the spray heads and valves with the agent. The duct is equipped with different hydraulic and electro-hydraulic elements for the pressure and flow control, the flow direction control (inversion valves) and the security (e.g. no-return valves). Any trouble or failure has immediate impact on the operation of the entire or partial installation. They can cause limited harm to the environment if e.g. a thawing agent quantity seeps into the soil, waters or spreads on the road surface.

The thawing agent duct should have a loop design to allow rincing. It should further be possible to maintain the greater part of the installation in good operating condition by inverting the thawing agent's flow direction.

In slopes and installations of a certain length the different parts of the installation should be designed to avoid extreme differences of pressure.

When installing the duct the following points should also be respected:

Place the duct underground if possible. In case of above-ground laying:
- lay the duct in such a way that damage through an accident or maintenance work be avoided
- provide protection tubes at accessible points to prevent vandalism
- take appropriate measures to compensate modifications of length due to temperature changes (e.g. expansion bends or joints)

Provide a flowmeter so that any leakages be immediately detected.

When in stand-by mode, keep the duct in hazardous areas (road traffic) free of pressure.

4.4.3 Spraying units

One of the following two systems can be used for the distribution of the thawing agent:

- either active systems with electromagnetic valves and spray heads directly connected

- or passive systems where the electromagnetic valves are separated from the spray heads in a protected area (beside the road surface, under a bridge, behind the crash barriers). In this case the thawing agent supply is effected via ducts between the valve and the spray head.

The spraying units or the spray heads can be mounted:

- beside the carriageway
- in the central dividing path or/and
- on the shoulder

on a post of the crash barrier, in the gaps of the crash barriers etc., or

- as integral distributor spray discs embedded into the carriageway, according to local conditions at appropriate locations of the carriageway cross-section.

On a bridge the duct to the embedded spray discs is either incorporated into the road surface and cast or directly connected from below through the bridge roadway. In order to keep the intervals between the sprays as little as possible it is preferable to install the spray heads near the traffic lanes, provided that they are not cast into the road surface cross-section.

The installation intervals between the spray units constitute an important issue of the study. The TMS's cost is strongly influenced by the number of spray units. The purpose of the installation should however not be forgotten, that is the prevention of slipperiness and the maintaining of the snow in a condition allowing its easy removal. Hence the intervals will depend on the location and the traffic conditions. The distribution effect of the thawing agent is enhanced by the passing car tyres.

It is important to note that icing intervenes often at times of low traffic, which means that the additional distribution of the thawing agent through the tyre mouvement drops out. In addition the distributed quantity should be limited so that the forming of water pools be avoided, because of the thus induced projection effect by the car tyres. This problem can be met by a repeated distribution of small quantities of thawing agent per spray head/disc (ca. 1 litre).

The below installation intervals are to be taken as indicative (empirical) values. They should be adapted to local conditions.

TMS for	spray head interval (m)	
	traffic lane per direction	
	2	3
bridges and short sections	15	10
long sections	25	17

In order to limit the pump power only one spray head (per section or per pump) is activated. The spraying should be oriented against the traffic dirction so that a vehicle can not be sprinkled more than once per section. The spray squirt's vertical angle should be as small (low) as possible.

5 Operation

5.1 Thawing agents

One TMS allows several different thawing agents to be used -nowadays mostly $CaCl_2$ solutions and NaCl brine. Other liquid chemical thawing agents are possible, but often rejected because of higher cost.

If a considerable quantity of $CaCl_2$ is spread on the road surface, as a consequence of a TMS malfunction for example, and the weather conditions are unfavourable (low relative humidity, road surface temperature higher than air temperature), the road's anti-skidding proprieties could considerably diminish and the risk of accident increase (Study report of the Federal Roads Institute; Institut fédéral des routes, section technique de la circulation routière: «The anti-skidding proprieties of road surfaces and the use of calcium chloride in thawing agent spraying installations»,.Bergisch Gladbach, February 1989).

For the use of NaCl the TMS's control should be equipped with an operation limiter. This limitation is situated at temperatures below -15°C. Experience has shown that the activation of a TMS at temperatures below -15°C is useless.

The table on page 12 provides a summary of the material characteristics, the cost and effect of $CaCl_2$ solution and NaCl brine.

5.2 Checking and maintenance

The first checking degree is the TMS's self-check. Checking results (see 4.3) are transferred to the competent operation service and appropriately displayed. In addition, visual supervision of the TMS should be effected in regular checking rounds of the sections.

The installation itself must be overhauled before the setting in of the winter. This maintenance work must be done in agreement with the manufacturer, either by the latter himself or by specially instructed and trained personnel. The maintenance work should focus on an operational check and a visual check of all electronic and hydraulic elements, and comprise repair work if necessary. The TMS control should be adapted to possible modifications concerning the road or its environment.

At the end of the winter the installation should be set out of operation according to the manufacturer's instructions.

	$CaCl_2$ solution	NaCl
concentration (% of mass)	34	22/23
freezing point (cryostatic point)	-55°C	-21°C
hygroscopicity of cristallized salt	>	
road condition	wet for a long time	rapidly drying (NaCl cristallizes)
quantity needed	roughly equal	
scope of action, temperature	ca. from -25°C	limited (ca. from -25°C)

5.3 Efficiency monitoring

The efficiency of the TMS should be checked by comparing it to previous years and considering especially the following:

- listed ratings of the installation
- registered data of the GFS
- the evolution of accidents, number of traffic jams and the length attained by traffic jams.

On the basis of this data analysis the installation's control must be optimized. If necessary, the whole installation should be basically modified.

6 Comments on the cost/benefit estimate

The cost/benefit estimate of a planned installation could be based on the simplified method of liquid assets. In this method the annual mean values for the different elements of the cost/benefit report are considered. We suppose that the average annual cost/benefit value can apply to the same extent during the whole operation period. These cost/benefit values are increased by the interest given by the factor of liquid assets b_f over the period. At an interest rate of 3 % and a presumed service lifetime of 15 years, the factor of liquid assets b_f is approximately $b_f \sim 12$.

The different cost/benefit elements are listed in the below table.

Mean annual cost		Mean annual benefit	
write-off cost cost of thawing agents energy cost personnel cost repair cost		accident costs operation cost time cost	
total		total	

To determine the write-off cost the total cost of the installation has to be considered, including secondary works, building, energy supply, excavation works, thermographic topometry, equipping the road section with crash barriers. Maintenance cost must be estimated by means of empirical values obtained from other operating installations.

Accident costs can be evaluated by the stating and juxtaposition of the total of accidents due to winter conditions before and after the setting into operation of the installation. The positive difference of the values yields the number of avoided accidents.

Benefits imputable to changes in the road's operating cost (road users) result from the difference between operating costs at a normal average speed for all vehicles (v_1 = 90 km/h) and a reduced speed in a traffic jam (v_2 = 5 km/h). In order to calculate the time cost it has first to be determined what the annual loss of time due to traffic jams was before operating the installation.

The factor of profitability (return on investment) Fw is calculated according to the simplified method of liquid assets, of the quotient of liquid assets of the mean values of costs and benefits:

$$F_w = \frac{\text{mean value of costs including interest}}{\text{mean value of benefits including interest}}$$

A practical calculation example can be found in the journal «Berichte der Bundesanstalt für Strassenwesen, Verkehrstechnik», issue V3, under the titel «Wirksamkeit und Wirtschaftlichkeit von Taumittelsprühanlagen». (Effectiveness and economic viability of thawing agent spray installations)