Vol. 44 No. 2

Spring 2007

SALT & Highway Deicing™

Published by SALT INSTITUTE

for the WINTER MAINTENANCE PROFESSIONAL

RATIONAL SELECTION OF DEICING MATERIALS

Every winter, millions of tons of snow and ice control materials are applied to North American roadways, sodium chloride chief among them. Applauded by highway safety advocates and economic development interests who extol safe and passable winter driving, use of deicers and abrasives has been accompanied by a half-century of concern and distrust by environmental groups and citizens wondering if their tax dollars are being well-spent. Too often, it seems, the decision on which material to apply and in what amounts has been seen as more art than science – and some people just don't like "modern art"!

In May 2007, the Transportation Research Board published a new set of research-based *Guidelines for the Selection of Snow and Ice Control Materials to Mitigate Environmental Impacts*." This article is based on NCHRP Report 577.

Previous studies have exhaustively evaluated the effectiveness of the several deicers being used. Our summer 2004 issue of Salt and Highway Deicing answered the question: *"Are you using the right amount of ice control chemical?"* (http://www.saltinstitute.org/publications/shd/shd-june-2004.pdf). It reported results of another NCHRP study (NCHRP Report 526). Still other studies have examined the environmental impacts of salt and other deicing alternatives. None have tried to integrate the questions of material selection, application rate and environmental impact. That's what Report 577 has done.

Towards Rational, Local Material Selection Decisions

"Rational decision-making guidelines are needed to assist winter maintenance managers in selecting the most appropriate snow and ice control materials for the conditions that exist in their jurisdictions," the Report explains, hinting at what's to come. The report culminates with a user manual *Guidebook to the Decision Tool, Purchase Specification, and Quality Assurance Monitoring Program*. In other words, this isn't a research report destined to be shelved for future reference, it's a hands-on tool for government policy-makers and agency decision-makers to use in how to respond to their local needs. It's been said that the future of manufacturing is "mass customization." That phrase captures the use of this tool quite well.

Each agency can determine how to balance its required level of service with four variables that can be fine-tuned by policy-makers: cost, effectiveness, environmental impact and infrastructure impact. These variables can be weighted in the political process and then the *Guidebook* tool will spit out the most advantageous material after rationally weighing these factors – all of which have been employed with more heat than light, more emotion than reason when decisions have been debated over the years.

Past debates have featured salt proponents' advocacy of salt's economy, handling characteristics and known – if not liked – environmental impacts. Those promoting alternative products have claimed superiority in terms of corrosion reduction and lessened impacts on the environment, arguing that salt's adverse environmental and infrastructure impacts outweigh the higher costs of alternative products. This new tool crunches the numbers dispassionately and should make materials selection a more rational process.

Report 577 examined all deicers being used, 42 in all, including sodium chloride, calcium chloride, magnesium chloride, calcium magnesium acetate, potassium acetate, organic matter from biomass and abrasives (the latter, of course, not a deicer, but sometimes used as an alternative to using a deicer). Recognizing that the effect of a deicer depends on other variables than simply chemical constituency, the Report

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also examined application amounts, exposure pathways, chemical-specific impacts and site-specific characteristics. Areas of greatest environmental concern included water quality and aquatic life, air quality and vegetation impacts. Drinking water source contamination was also considered as were impacts on soil structure that might contribute to impacts on water and vegetation. Infrastructure impacts included corrosion of concreted reinforcing (rebar) and atmospheric corrosion on exposed metals and the research not only examined these impacts, but the mitigating potential of corrosion inhibited products.

Research findings

Analysis of the research produced these significant conclusions:

- High organic concentrations, particularly in liquid products, led to biochemical oxygen demand (BOD) concerns.
- Nitrogen and phosphorus in organic deicers have potential for environmental harm.
- The "total cyanide test" produces significant amounts of toxic cyanide, from otherwise-stable hexacyanoferrate free-flowing agents used with salt.
- Levels of heavy metals were below concentrations of concern in each deicer.
- Variability in product characteristics requires quality assurance monitoring by user agencies.
- Aquatic toxicity is only of concern close to the roadway.
- Chloride deicers affect all tested metals in similar fashion.
- Non-chloride deicers have superior corrosion rates to chlorides for some metals, but worse for others.
- Corrosion inhibitor effectiveness was "varied and poorly quantified" and the benefit is "questionable."
- Tests on normal highway concrete rather than poorer-quality samples designed to fail during shorter (more affordable) test periods has produced no adverse effects in two years of testing; tests are continuing.

User products

The decision tool. The Report recognizes that "factors affecting the decision processes can be numerous and complex," but boil down to four basic considerations which "balance economic value related to cost and performance with potential consequences of use related to environmental and corrosion impacts." This balance must be the product of a local process for both unique environmental and infrastructure exposures and, perhaps even more importantly, because users are voters who, themselves, balance costs against the quality of the product (safe and passable roads) they expect from snowfighters. The end product: "a practical tool that generates a numerical evaluation that can be used to compare snow and ice control materials." The Report wisely concedes a "one size fits all" approach is unworkable. "Each agency will have unique objectives and priorities that will affect their selections for the decision categories" The decision tool requires agencies to weight the variables explicitly and includes several subcategories under "environment" and "infrastructure" that fit such customization to local needs. The subcategory impacts, in turn, are "based on a material's potential to elicit an effect on a receptor, as developed from a comprehensive information review and analytical test results." The weighting is subjective – and, frankly, political; the result is an evidence-based, rational product of the political judgments.

Purchase specification. After the agency uses the decision tool to select its preferred product, the purchase specification is applied, primarily to ensure the material meets its environmental performance objectives, particularly in the protection of aquatic ecosystems. The Report divides snow and ice control materials into three categories: those with a base in the hardness ions (calcium and magnesium, e.g. CaCl, MgCl, CMA), other deicers (NaCl, KA, organics) of greater risk due to heavy metals, and abrasives which, although themselves not soluble, "may contain contaminants that are soluble…(and) can contain high toxicant levels."

Quality assurance monitoring program. The Report recommends that agencies specify quality assurance tests in the contract documentation and then perform "a suite of qualifying tests and submittals" before accepting delivery. It references standard test methods to quantify material characteristics.

Development of relative purchase price rankings.

	NaCl	$CaCl_2$	$MgCl_2$	KA	CMA	Abrasive
Purchase Price per Ton ($)[1]	$ 50	$ 130	$ 120	$ 1000	$ 1150	$ 80
Active Ingredient Concentration (%)	23 %	32 %	30 %	50 %	25 %	NA
Purchase Price per Dry Pound ($/lb)	$ 0.11	$ 0.20	$ 0.20	$ 1.00	**$ 2.30**[2]	$ 0.04
Maximum Price ÷ Material Price	21	11	12	2	1	58
Price Ranking (Maximum 100)	37	20	20	4	2	100

[1] Pricing was gathered from contracts published on the Internet and provides semi-realistic demonstration of relative purchase price calculations and rankings.
[2] Bold text indicates maximum purchase price per dry pound ($/LB)

ASSESSING THE FOUR FACTORS

Cost. The cost comparison worksheet used to develop and rank material purchase costs considers the concentration of the active ingredient (e.g. 23% for salt, 30% for MgCl) and produces a "price ranking" based on 100 points. Among deicers, salt fared best with 37 points; CaCl and MgCl tied for second with 20, while KA scored 4 and CMA, 2.

Performance. As would be expected, evaluating performance entails a complex of variables including, assessment of the melting performance of the concentration of active chemical ingredients, physiochemical properties of the deicer such as solubility and whether it takes on or gives off heat as it works, operating conditions like the rates of precipitation and temperature, the timing and amounts of material to be applied and associated variables like spreader controls, roadway factors such as topography and pavement roughness, and, finally, operational considerations like operator training, handling, storage, supply reliability, etc.

Environmental impacts. The decision tool has six subcategories to describe environmental impacts on aquatic life, drinking water, air quality, vegetation, soil and animals. And most of these have multiple sub-subcategories; aquatic life has 14, the most. Each subcategory is scored 1-5 reflecting the scientific evidence for the extent of impact. Agencies weight each sub (and sub-sub) category for its relative importance to them. Some will be easy – there may be none of a particular type of ecosystem (e.g. large, nutrient poor lake) in the service area – but often tough decisions are required in assigning weighting.

Infrastructure impacts. There are four subcategories of infrastructure impacts: vehicles, metal infrastructure, concrete pavements and structures, and rebar. As with the environmental impacts, each is scored separately (there is only one subcategory, under metal infrastructure), and then weighted.

Finally, the four variables are weighted one against the other (total = 100%). Thus, the model is constructed. Changes are required only when costs change, application operations are altered or policy-makers re-evaluate the political importance of the environmental and/or infrastructure impacts. Done right the first time, such fine-tuning would not be expected to alter the outcomes in most circumstances.

USING THE DECISION TOOL

Obviously, each agency is going to come out differently. Its variables are different. Even neighboring communities which share similar weather patterns and common materials sourcing will have different topography, crews with different skills and preferences, different local ecosystems (e.g. a wetland here or a river there) and, most of all, they will reach unique weightings reflecting their perceived desires of their customers – the roadway users and local voters who provide their funding.

The Report, usefully, illustrates the Guidebook process with three examples of agency policy weightings. The investigators surveyed snowfighting agencies and determined that those surveyed weighted the variables emphasizing cost and performance (45% cost, 35% performance, 11% environment and 9% infrastructure). They worked the model using two other sets of assumptions: one where the four variables were equally weighted (25% each) and the other emphasizing environment and infrastructure impacts (though they caution "Given that the primary objective of winter maintenance is controlling snow and ice, it is recommended that performance weighting not be assigned a value below 25%"). The "environment and infrastructure priority" example disregards cost entirely, assigns the self-imposed minimum 25% for performance and divides the remaining 75% equally, 37.5% for environment and 37.5% for infrastructure. All the examples assume an anti-icing strategy, prices were obtained from Internet-published contracts and the results calculated at temperatures ranging from 30° F to -20° F. The decision tool calculates a numerical product score that incorporates user priorities and conditions with a technical assessment of potentials for impairment. It produces scores, the highest being the preferred product. The agency, of course, is free to accept the model results or make its decision on other criteria, ignoring the "rational" calculation.

Three example agency policy weightings.

Decision Category	Example 1 (Section 2.7.1.1) **Survey Objective Weighting**	Example 2 (Section 2.7.1.2) **Equal Objective Weighting**	Example 3 (Section 2.7.1.3) **Environment Infrastructure Priority**
Purchase Price	45 %	25 %	0 %
Performance[1]	35 %	25 %	25 %
Environment	11 %	25 %	37.5%
Infrastructure	9 %	25 %	37.5 %

[1] Given that the primary objective of winter maintenance is controlling snow and ice, it is recommended that performance weighting not be assigned a value below 25%.

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THE ENVELOPE, PLEASE...

It didn't surprise us much at the Salt Institute that the decision tool, applied to the survey object weighting, gave the edge to salt. That's not only reassuring to salt users, but a useful means of validating the model, since most product used today is sodium chloride. In the temperature range for most snowfall, 25° to 30°, salt (NaCl) scored 90.4 compared to second-place MgCl (71.1 to 76.4), followed by CaCl (64.8 to 76.1), KA (23.9 to 31.6) and CMA (18.2 to 19.2). Sodium chloride retains its strong preference score of 90.4 down to 15° F (at that temperature, MgCl is 83.6; CaCl, 77; KA, 35.3 and CMA, 18.6). Salt surpasses the acetates down to zero Fahrenheit (we don't recommend NaCl at this temperature ourselves, even though we sell it!) and salt is still preferred to CaCl down to 10° F, though narrowly, 80.8 for NaCl to 78.2 for CaCl (and 91.3 for MgCl). This model, of course, reflects the current preference for cost-savings and roadway clearing performance.

The second example weights all four variables equally. Surprise, while salt's advantage is muted by lowering the weight of its strongest suits, its lower cost and effective performance, the results are unchanged. Unchanged. Salt earns the highest scores down to 15° F and the other deicers follow in rank, though more tightly bunched (e.g. at 15°, NaCl is 75; MgCl, 72.2; CaCl, 68.1; KA, 52.8; and CMA, 43.1).

Now for some real news. Using the "environment/infrastructure priority" weightings, all four deicers are tightly clustered between 15° and 30° F. Potassium Acetate earns top honors at 63.8 to 67.4; narrowly edging out CMA at 63.5 to 63.6; NaCl is third, 62.5 at each temperature; MgCl is 59.2 to 63.1 (edging out salt below 20° F; while CaCl registers 57.2 to 61.0.

Decision tool example 1— survey priorities.

Temperature (F)	Final Product Scores Based on Temperatures				
	NaCl	$CaCl_2$	$MgCl_2$	KA	CMA
30	90.4	64.8	71.7	23.9	18.2
25	90.4	76.1	76.4	31.6	19.2
20	90.4	68.8	72.7	32.4	18.8
15	90.4	77.0	83.6	35.3	18.6
10	80.8	78.2	91.3	38.1	18.2
5	57.4	76.3	91.3	38.0	17.3
0	39.3	76.0	91.3	38.7	Too Cold
-5	12.6	73.5	91.3	37.4	Too Cold
-10	Too Cold	72.3	91.3	39.5	Too Cold
-15	Too Cold	70.0	91.3	39.9	Too Cold
-20	Too Cold	66.0	91.3	40.2	Too Cold

See graph on facing page

Decision tool example 2— equal priorities.

Temperature (F)	Final Product Scores Based on Temperatures				
	NaCl	$CaCl_2$	$MgCl_2$	KA	CMA
30	75.0	60.4	64.4	45.7	42.9
25	75.0	67.5	67.7	50.5	43.6
20	75.0	62.9	65.4	51.0	43.2
15	75.0	68.1	72.2	52.8	43.1
10	69.0	68.8	77.0	54.6	42.9
5	54.4	67.6	77.0	54.5	42.4
0	43.1	67.4	77.0	54.9	Too Cold
-5	26.4	65.8	77.0	54.1	Too Cold
-10	Too Cold	65.1	77.0	55.4	Too Cold
-15	Too Cold	63.6	77.0	55.7	Too Cold
-20	Too Cold	61.2	77.0	55.9	Too Cold

See graph on facing page

Decision tool example 3— environmental and infrastructure priority objectives.

Temperature (F)	Final Product Scores Based on Temperatures				
	NaCl	$CaCl_2$	$MgCl_2$	KA	CMA
30	62.5	57.2	59.2	63.8	63.5
25	62.5	60.7	60.8	66.3	63.8
20	62.5	58.5	59.7	66.5	63.6
15	62.5	61.0	63.1	67.4	63.6
10	59.5	61.4	65.5	68.3	63.4
5	52.2	60.8	65.5	68.3	63.2
0	46.6	60.7	65.5	68.5	Too Cold
-5	38.2	59.9	65.5	68.1	Too Cold
-10	Too Cold	59.6	65.5	68.7	Too Cold
-15	Too Cold	58.8	65.5	68.8	Too Cold
-20	Too Cold	57.6	65.5	68.9	Too Cold

See graph on facing page

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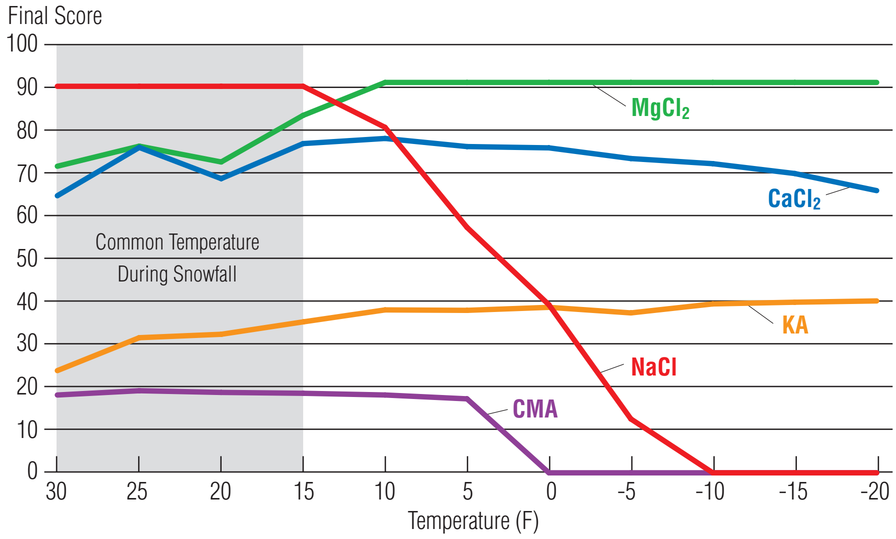
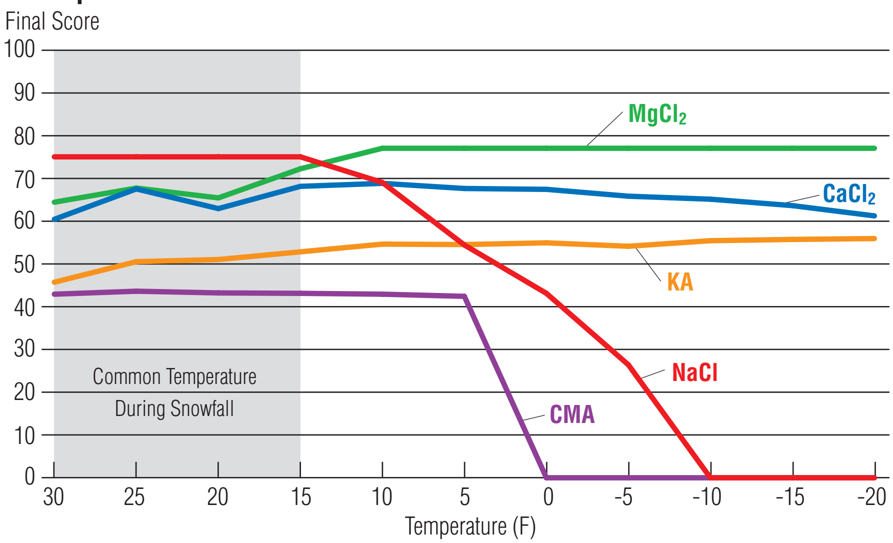
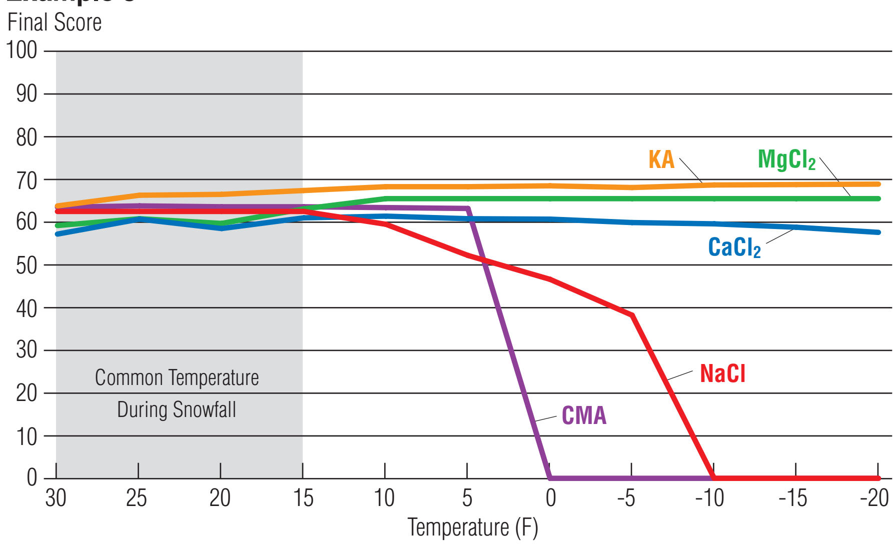
Example 1



Example 2



Example 3



The Report sums up: (For the survey priorities example): "NaCl is the preferred product between 22 and 12°F, after which $MgCl_2$ and $CaCl_2$ are preferred." (For the equal priorities example): "NaCl is the preferred product between 22 and 12°F, after which $MgCl_2$ and $CaCl_2$ are preferred." (For the environment/infrastructure priority example): "All materials have similar scores until temperatures reach below 10°F and NaCl and CMA lose performance benefits. Although KA is the preferred product, CMA also scores well at warmer temperatures."

SUMMARY

If your community has been restive with the choice of sodium chloride as its primary deicer – pre-wet with another chloride below 15° F, this Report, five years in preparation, provides a scientifically-sound basis both for examining options and community priorities – and for affirming your choice of salt. That has never been to say that there are not locations, as well as operating temperatures, where an alternative should be preferred. Sensible Salting remains, after more than 36 years as the centerpiece of environmentally-sensitive snowfighting, the preferred solution to keeping our winter roads safe and passable. ■

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