Identifying the Parameters for Effective Implementation of Liquid-Only Plow Routes

EVS, Inc.

CLEAR ROADS
research for winter highway maintenance

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16. Abstract This project focused on two key areas. The first was taking a snapshot of current best practices in regard to during-storm liquid applications for snow and ice control. The project learned "why", "where", "when" and "how" the during-storm application approach is used effectively. The second key area was determining and recommending field tests that are needed to help validate and improve the best practices. The project was accomplished primarily via engagement of subject matter expert practitioners from across the United States. The pool of experts also included international expert practitioners, MDSS (weather forecasting) experts, and airport snow and ice control experts.		
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Credits

This project involved many experts in during-storm DLA and related subjects. The following list is an attempt to recognize the persons who contributed so much time and expertise.

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Mr. Jeff Tatkenhorst, CDOT
Mr. Wesley Templeton, CDOT
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Abbreviations

Abbreviation	Definition
gplm	gallons per lane-mile of liquid application
pplm	pounds per lane-mile of granular application
temperature	indicates "pavement temperature" unless otherwise noted
liquid	Indicates anti-icing or de-icing liquid
DLA	Direct liquid application (in this report during-storm is assumed unless otherwise noted). Also called SLA (straight liquid application)
DOS	Dilution of solution (important to always consider dilution potential)
SLA	Straight liquid application (another name used for DLA; see above)
LOS	Level of Service of a roadway

Definitions

Name	Definition
anti-icing	Prevent-icing
de-icing	Remove-icing
pre-wet	Granular material pre-wet with liquid before being applied.
slurry	Similar to pre-wet with higher liquid-to-solids ratio
pre-storm	Before the storm (common anti-icing period)
during-storm	During the storm -- plowing and optionally chemical applications
post-storm	After-the-storm cleanup and conditions
liquid	Indicates anti-icing or de-icing liquid
direct liquid applications	Liquid applied directly to pavement surface.

Executive Summary

The project consisted of the following key phases:

- Perform Research
- Conduct Expert Survey
- Conduct Expert Interviews
- Recommendation of Field Testing
- Development of Documents

The most significant “change” in the planned phases was the first “research” phase. Very little literature was available on the subject matter. Therefore, subject experts in the field were engaged during this phase (earlier than expected) for preliminary discussions/interviews.

Clear Roads provided a nice set of potential experts across Clear Roads states. Additional contacts were obtained from agency websites, references and conference attendance lists.

Because of the lack of available literature, this project became all about “tapping into” the experience of experts in the field. Fortunately, experts were extremely generous with their time and insight.

The second key element of the project was frequent meetings (milestones) with the Technical Advisory Committee (TAC). This allowed continuous feedback and improvement during the project as well as direction. Sometimes focusing (ie during-storm only) and sometimes broadening (ie inclusion of MDSS experts).

Initially, the broad set of experts provided a large variety of approaches in regard to using liquid chemicals for winter maintenance. These included during-storm direct liquid applications, strong traditional pre-storm liquid use, favoring slurry approaches, and success with post-storm de-icing of snowpack/ice. After early TAC meeting, the project direction concentrated on during-storm DLA.

The project (experts) produced good consensus on parameters that govern the effectiveness of during-storm DLA. Experts also provided tips, equipment suggestions and lessons learned.

Based on discussions with experts and our own experience, “buy-in” is key for any new tool. The buy-in is needed at both the management and operation level.

Buy-in is one reason among several the field tests are recommended to validate and tune the findings (parameters).

The following sets of documents were produced for this project

Research Documents

The following are the documents developed for this project:

Research

- Initial Research Summary
- Survey Summary
- Interview Summaries

Key Deliverables

- Summary Report
- Quick Reference Guide
- Field Testing Recommendations
- DLA Slide Presentation

Supplemental Deliverables

- Winter Maintenance Tool Climate Study
- Winter Maintenance Global Network
- Cost Benefit Analysis Implementation Plan

Note that the "Supplemental Deliverables" are a potential project side benefit collected during the normal course of the project.

1. Summary

This report summarizes the results of the research, survey and interviews for "Identifying the Parameters for Effective Implementation of Liquid-Only Plow Routes". The report focuses on during-storm direct liquid applications (DLA). The results clearly show that during-storm (DLA) is a valuable asset for the winter maintenance toolbox. Some of the highlights are shown in the table below.

During-Storm DLA Benefits

Benefit	Result
Reduced application rates	Savings and minimized negative side effects
Reduced loss of material	Savings and minimized negative side effects
Faster post-storm cleanup	• Crew gets to "go home earlier" (employee satisfaction) • Better post-storm LOS (faster regain) • Reduced accidents in safety critical post-storm period as drivers increase speeds • Savings from reduced labor
Quick (instantaneous) effect	Faster improvement of LOS
Prevention of bonding[1]	Improving LOS, reducing post-storm cleanup
Expanded toolbox	Expanded tool selection to best meet event conditions
Accurate low application rates	Liquids can be spread at very low application rates (ie 20 pplm) compared to granular. Thus allows the right amount of material to be used for light storms.
Reduced corrosion effects	Some experts have found that during-storm DLA has reduced corrosive effects on vehicles because of dilution compared to "undiluted" (ie granular) chemical on vehicles.
Leverage proven benefits of liquids	Leverage proven benefits of liquids (pre-storm and pre-wetting granular)
Notes 1) Extends the concept (benefit) of pre-treatment through the storm	

The results show that during-storm DLA can be done as "liquid only", but is also often supplemented with a lighter granular application.

Employee and management "buy-in" along with "equipment considerations" are two primary hurdles identified by experts on the way to success. This report presents suggestions to meet these challenges based on the experience.

The research showed that a variety of strategies and equipment is used to successfully implement during-storm DLA. Having a palette of successful strategies will allow other agencies to consider which approach might best meet their conditions and capabilities.

Success Stories

Note: These success stories are due to strong overall liquid programs (including pre-wet). DLA was identified in these cases as an important tool helping in the overall success.

Location	Description
Denver, CO	Meeting stringent environmental requirements, savings of labor in minimizing required sweeping.
Iowa DOT, District 5	25% less salt used per mile for winter season (overall).
	Reduction in labor and overtime. They get done quicker (and regain roads quicker), meaning they home earlier. This is because of less and quicker post-storm cleanup.
CDOT	Optimized (reduced) salt usage, minimized environment impacts, reduced corrosion impacts, much faster post-storm cleanup and regain of normal LOS.
	By changing policy to only apply chemicals to wet roads (during or post-storm), they eliminated a large number of complaints about corrosion effects (especially from the trucking industry).
McHenry, IL	Optimized salt usage. They did a comparison of liquid routes to granular routes for a snow event that they felt called for direct liquids. The granular routes required 2 or 3 times as much material.
City of Beloit, WI	They think liquids overall has saved them 40-45% on salt budget
	Three severe winters (2006-2009) caused salt shortages in many jurisdictions. Beloit had excess and was selling to others.
MoDOT- KC	Reducing Costs
Ohio DOT - District 4	Faster regain of roads and establishment of normal LOS (they have high ADT and need public with high expectations). Salt use reduced by 33% for their most common application scenarios.
	ODOT custom-built a combination applicator at a cost of about $30,000 more than a standard plow truck. The extra cost was paid for within one year because of the effectiveness of the unit.
Indiana DOT - Winamac	Significantly reduced post-storm cleanup time resulting in: • This was one factor that lead to 50% less material usage per lane mile for the entire winter season (compared to adjacent “granular-only” area). • Accident reduction because of faster road regain time (post storm is safety critical period as drivers increase speeds). • Employee satisfaction because “going home earlier.
UDOT – Parley’s Canyon	Savings in material use; Instantaneous effect to material use.
Mn/DOT - Olivia, Alexandria, others	Limited with only 200 gallons of on-board liquid capacity, they still found a way to use and benefit from during-storm DLA. They innovated a “centerline sprayer” (cost about $20 – PVC and hose) that hooks up to pre-wet system and allows them to switch to DLA and apply liquid on rural

	highway "outbound trip" onto centerline area where it begins to "work" the "return trip" lane. They have found that return trip plowing is much easier (peels right off).

Options to Meet Local Conditions and Capabilities

Liquid Only 	Liquid and Granular "Sprinkle" 
Liquid applicator following plows applying granular "sprinkle" 	Consider Special Benefits (ie Centerline Sprayer) 

This report applies experience-based information to describe what, why, where, when and how in regard to during-storm DLA.

2. What is During-Storm DLA Application?

During-storm direct liquid application (DLA) is the technique of directly applying liquids to the roadway surface during the storm event.

During storm DLA can be done as "liquid only" or often it is supplemented with a lighter granular application. Note that if both liquid and granular are applied; this is different than a pre-wet granular or slurry application because each is independently applied directly to the roadway.

3. Why?

Every winter storm is different. Adding during-storm DLA to the toolbox, allows better matching of the appropriate tool to the actual winter event. For some storm event types, during-storm DLA has proven to be the most effective tool.

We know that liquid chemicals have provided great benefits for pre-wetting granular material and pre-storm anti-icing. These two tools remain fundamental tools in the liquids toolbox.

During-storm DLA provides an additional liquid tool that allows us to leverage the benefits of liquid chemicals during a wider range of storm event types.

The tool helps us:

- Optimize material usage producing cost savings
- Minimize necessary post-storm cleanup, allowing us to "get done earlier" producing time savings and often better (and quicker) post-storm level of service which reduces accidents.
- Because it is the most effective tool in some storm conditions, it helps us maintain a more continuous target level of service for a wider variety of conditions
- Helps us minimize environmental, vehicle, and infrastructure effects (less scatter and "lost" material)
- "Instantaneous" effect (no solid to liquid phase change) producing results

Reduced Salt Use

Under favorable conditions, during-storm DLA has been found to require 50% of the material used by granular-only applications. There are two primary reasons for this:

- Application rates are optimized improving efficiency
- Post-storm cleanup time is reduced and eased (see next section)

“Getting Done Earlier” (Minimizing Post-Storm Cleanup)

Areas using DLA often find that they generally are “done earlier” after the storm. This helps in multiple ways.

Post-Storm: Opportunity to Optimize Material Use

A variety of factors may contribute to heavier salt use during post-storm cleanup:

- The crew is tired and rightfully wants to “get it done” which can naturally result in a tendency to use the higher end of application rates ranges.
- Traffic speeds are increasing resulting in more “lost” material from the roadway
- Snow-pack removal generally requires heavier application rates (the rule of thumb is removing ice/snowpack requires 10 times more energy than DLA onto a clean surface).

Therefore, when DLA helps minimize post-storm cleanup, it can have a big positive effect on reducing salt use and labor time.

Post-Storm: Safety-Critical Period

In the post-storm period, drivers start to pick up their driving speeds as they regain confidence in road conditions. With the increased driving speeds, snowpack or ice spots are especially safety-critical.

With DLA helping to improve post-storm conditions (less snowpack and ice spots) and reduce post-storm cleanup time, this can have a big positive effect on roadway safety.

Side Benefit: Buy In

There may be no better way to achieve “buy-in” from the team and also “interest” from adjacent areas when your team is simply “going home earlier” with roads in good condition.

Environmental Impacts

Environmental regulations are becoming more stringent. During-storm DLA has been utilized by some agencies as a pro-active approach when working with environmental organizations. Some regulations require street and shoulder sweeping to remove all salt after storm events. DLA can satisfy this requirement, but does not require any sweeping. Not only is the environmental requirement met, but “savings” are gained because the elimination of the sweeping job.

Reduced Overtime

Experience has shown that agencies who utilize more liquid approaches typically “get done earlier”. More work is done during “regular hours” minimizing overtime and weekend work.

Agencies add organics (liquid corn syrup LCS, beet juice, molasses, etc) to salt brine to increase the “adhering” (residual) property of the chemical which can help for subsequent events.

4. Where? (Climate Considerations)

The general climate of a maintenance area will help you plan your approach to gain the most benefits from during-storm DLA.

In addition to the following discussion (in regard to temperature) it should be noted that areas who deal with more ice conditions relative to snow events are also generally well-suited for liquid chemicals.

Note that during-storm DLA is a potentially beneficial tool for the toolbox in most climate types. However, the best implementation approaches may vary for different climates/areas.

Here we will describe climates relative to temperature (very mild, moderate and colder areas).

<u>Benefits in Very Mild Winter Climates</u>

Example - Typical events close to 30F, almost all events above 25F. Post-storm “warm-ups” more common. Some illustrative examples include Kansas City, MO and the southeast corner of Iowa along the Mississippi River (warming effects).

Mild areas are very well suited for DLA applications. Dilution and refreeze potential is lower.

Key equipment considerations might include a snowplow with liquid only applicator.

<u>Benefits in Moderate Winter Climates</u>

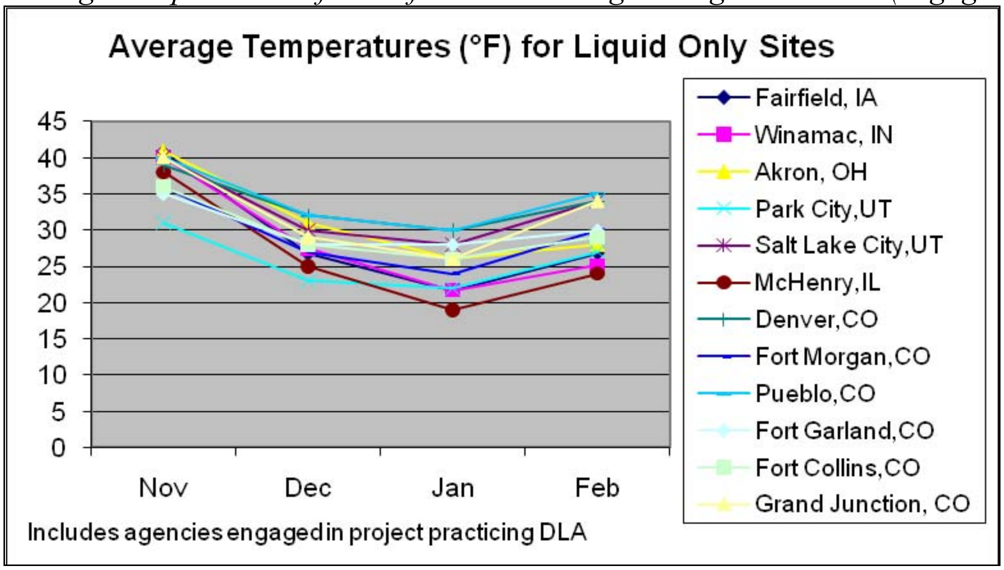
Example - Typical events mostly close to 25F, almost all above 20F. Some illustrative examples include the northern halves of Illinois, Indiana and Ohio.

During-storm DLA applications in these areas has also proven to benefit programs, but generally require different equipment considerations. Benefits may vary seasonably (ie the most benefits may be found early and later in the winter season where climates may be more like the milder areas).

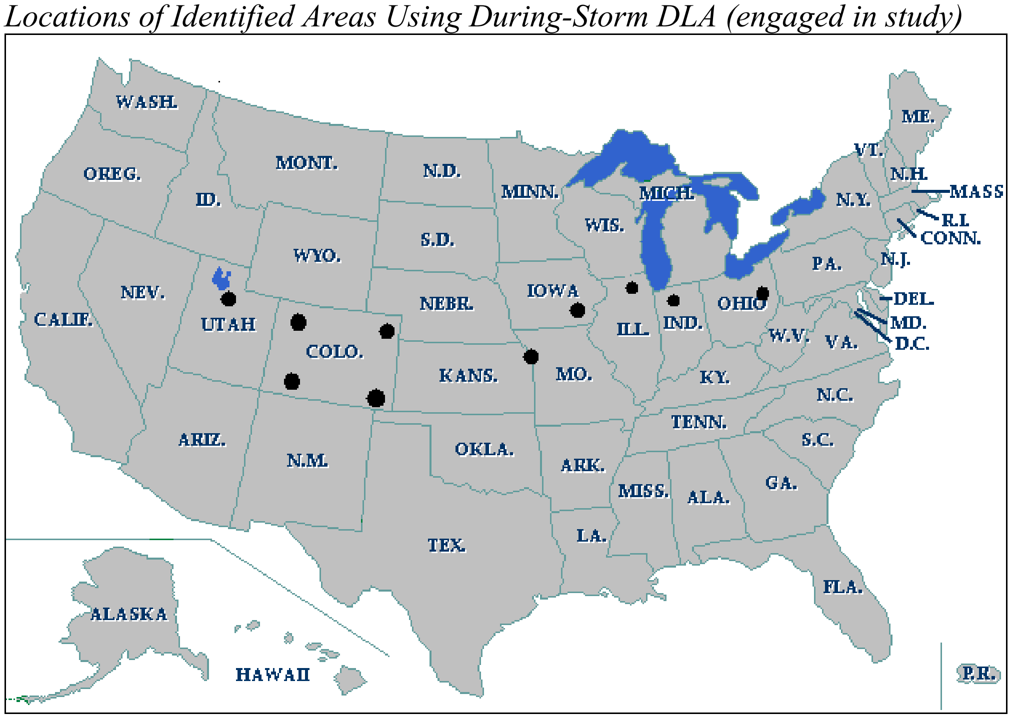
Equipment considerations should allow for “dynamic” equipment that allows liquid and/or granular applications. Examples include applicator “slide-in” liquid tanks allowing “swapping” an applicator from/to liquid and granular applications. Other examples are “combination” units that allow simultaneous application of DLA and/or granular.

Another approach that some use for “combination” applications is to have a liquid applicator following truck(s) applying granular material. The liquid applicator can be a small unit up to a tanker with three-lane spread width.

Average Temperatures of Identified Areas Using During-Storm DLA (engaged in study)



Locations of Identified Areas Using During-Storm DLA (engaged in study)



Benefits in Colder Winter Climates

Example: Events have a wider range of temperatures from mild to colder. Post-storm decreasing (nose-diving) temperatures are more common. Some illustrative examples include North Dakota, South Dakota, Minnesota, Wisconsin and northern Vermont.

DLA can benefit these areas in a variety of ways:

- Although these areas have colder average temperatures many snow events occur during warmer temperatures
- As maintenance areas gain continue to gain more confidence in weather forecasts and related tools, they will be able to realize more opportunities to match the best tool for the winter event (which results in savings). This will increase opportunities to select the during-storm DLA tool when applicable.
- Many areas limit pre-storm anti-icing using the rule “do not apply chemical to a dry road” (especially in areas susceptible to blowing snow). During-storm DLA can help overcome this limitation.

5. When?

During-storm DLA (like any tools in the snowfighting toolbox) is condition-dependent. The table below shows rules-of-thumb for during-storm DLA, based on field experience.

Note that considering dilution and re-freeze potential is fundamental for DLA.

Rules-of-Thumb for During-Storm DLA
(For Illustration Only)

Factor	Limits of Direct Liquid Applications[1]
Storm Intensity	Some use a rule-of-thumb that snowfall rates should be 0.5 inches/hour or below. Others use a slightly higher rule-of-thumb maximum value of 1 inch/hour and below
Pavement Temperature[2]	All experts find 25°F and above favorable for during-storm DLA. Some consider during storm DLA when 20°F or above.
Moisture Content	Ordinary moisture content is most conducive to during-storm DLA. Wetter events produce higher dilution potential. Dryer (ie powder) events may not need any chemical (plow only).
Cycle Times	Generally about 1.5 hours is a reasonable cycle time. Shorter cycle times help reduce refreeze potential. **Caution** should be used with this parameter because of variation in cycle times due to slow moving traffic, liquid loading, etc.

Notes:

1) Note that these are ***rules-of-thumb***. In practice, all parameters will have to be considered together along with other factors such as traffic, equipment availability, timing, etc.
2) Consider temperature trends (increasing/decreasing temperatures)

Application Rates

Application Rates - for during-Storm DLA (For Illustration Only)

- Some successful practices utilize one application rate and others vary rate per conditions. Also some use a combination of liquid and granular.
- The range of application rates generally used is about 30 gplm to 90 gplm.

The following chart is similar to charts used by the Iowa DOT. The values in the chart agree reasonably well with the range of 30 to 90 gplm used by DLA experts engaged in this study.

Example During-Storm Direct Application Rates for Salt Brine (NaCl)[2,5] Illustration Only (adjust based on local factors and experience) Gallons Per Lane Mile (gplm) *Pounds Per Lane Mile (pplm) shown in parentheses*				
	Pavement Temperature			
Event Type	32-30°F	29-27°F	26-24°F	23-21°F
For 2-Hour (or less) Cycle Times				
Light Snow (less than 0.5"/hour)	20 (45)	35 (80)	40 (91)	55 (125)
Medium Snow[1] (0.5"/hour to 1.0"/hour)	35 (80)	45 (102)	55 (125)	NR
For 3-Hour Cycle Time[3]				
Light Snow (less than 0.5"/hour)	35 (80)	50 (114)	65 (148)	80 (182)
Medium Snow[1] (0.5"/hour to 1.0"/hour)	50 (114)	65 (148)	80 (182)	NR

Notes:
1. Only consider using DLA for medium snow events based on your experience, and when other factors are highly favorable such as pavement temperature and moisture content.
2. It is suggested to generally **supplement the DLA application with a light direct pre-wet granular application** (70 pplm) when possible (especially as dilution-refreeze potential increases).
3. **For cycle times greater than 2 hours**, supplementing DLA with direct granular is strongly suggested (see Note 2).
4. NR = Not recommended
5. For enhanced chemicals and blends, work with vendors. Verify that these rates are reasonable or where they should be adjusted.

Combination Applications

Most experts agree that the most effective application is usually some form of a "combination" application (DLA supplemented with direct granular). In conditions that favor DLA, the granular application can be applied at a very low rate such as 50 pplm to 75 pplm. The liquid provides an instantaneous/quick effect and complete roadway coating. The granular reduces dilution potential. The granular may also provide a small amount of "grit". Additionally, pre-wetting the granular application will minimize "bounce".

6. How?

Gaining Buy-In

Like any new tool, gaining buy-in can be challenging. There will be skeptics. This is especially true for during-storm DLA, because granular-only applications have been the only tool exercised for a generation of supervisors and operators.

Employee and Management Buy-In

Key Facet	Description
Employee Empowerment	Encourages employee buy-in and innovation
Management "Support"	Listen and employees, support with equipment considerations, acknowledge success

Tips for Gaining Buy-In

Set DLA up to succeed	One approach (when starting during-storm DLA) is to supplement existing granular applications with liquids. As success is observed and confidence gained, dial back granular rates.
Visit sites	Many have found quicker team buy-in when they visit shops first-hand who have had some success with liquids.
Partner as much as possible	If you do not have brine-making and blending facilities, consider purchasing from a nearby agency.
Contact experts	This report includes a list of experts in DLA. Contact experts and visit nearby sites. This will help you get the latest on lessons learned.
Utilize existing equipment	Utilize and convert/retrofit existing equipment as much as possible to save costs. Consider different strategies that best match your equipment.
Communication	For example, one supervisor's area had problems with an initial direct liquid application. The supervisor quickly communicated to all concerned that the supervisor was responsible for the problem, and noted the lessons learned. This helped avoid the potential for the team to quickly turn against the new tool.
Know Limitations	Some agencies have expected "too much" initially from this one tool. This produced initial frustrations and slowed down buy-in. The "big toolbox" generally applies.
Acknowledge and Support Success	It is important to listen to and support success stories (for both directly and indirectly related success). This will help with overall buy-in of liquid chemicals.

Equipment Considerations

Also see “Climate” section above.

Generally, equipment for DLA should be as dynamic as possible (supporting both liquid applications and granular applications). In milder climates you may find that equipment might require more DLA capabilities; while in colder climates you might find that equipment may require more granular (pre-wet) capabilities.

The following table demonstrates how much coverage (lane miles) are possible for different on-board tank sizes. **Example:** for an application rate of 40 gplm and on-board capacity of 2,000 gallons, we find the road coverage is 50 miles.

DLA Coverage versus On-Board Tank Capacity (for various application rates) (lane miles)						
		Application Rate (gallons per lane mile)				
		20	40	60	80	100
On-Board Tank Capacity (gallons)	**250**	13	6	4	3	3
	500	25	13	8	6	5
	750	38	19	13	9	8
	1000	50	25	17	13	10
	1250	63	31	21	16	13
	1500	75	38	25	19	15
	1750	88	44	29	22	18
	2000	100	50	33	25	20
	5000	250	125	83	63	50

<u>Tips for equipment considerations</u>

- Consider climate
- Contact other agencies to leverage their experience and lessons learned with equipment
- Ensure “user-friendly”:
    - Swap-in units should allow minimal “swap time” (some experts report that 15 minute swap times are possible).
    - Liquid loading should be made as user-friendly and quick as possible. Consider how long team members will be outside in wet conditions during loading. Consider high capacity pumps to minimize load times.
- Consider off-season equipment (truck) use
- Consider engaging outside owner-operators (ie tankers, etc) who can help minimize capital costs

- Provide good equipment training for operators. Otherwise, there will be a natural tendency to switch to "manual mode" which can avert potential savings
- Allow time for operators to "get comfortable" with new equipment. Some of this equipment (ie trailers, etc) is challenging to operate. Once comfortable with the new equipment, experience has shown it becomes preferred equipment.

<u>Equipment Examples</u>

Combination Units – These are often identified as the "most valuable" applicators in a fleet. Allows simultaneous applications of direct granular and/or direct liquid. The granular is typically pre-wet to minimize "bounce". Also see "Combination Applications" section above.

Slide-In Units - A plow truck that that allows a slide-in liquid tank to swap to/from liquid and granular applications. The unit is converted back and fourth as needed. One example is a seasonal DLA approach where the tank would be installed for the milder early and late winter and removed (allowing granular) during the colder part of winter.

Liquid-Only Snowplows – Valuable in milder climates where it has been determined that no/little granular will be required. Also valuable if there are designated "liquid routes" for other reasons such as environmental constraints.

Liquid-Only applicators (no plow) – Traditional pre-storm units. Often already on-hand in maintenance areas (for pre-storm anti-icing). Consider starting your during-storm applications with these units to get a feel for the practice. Can be useful for very light storms to help gain clean pavement without plowing. Can also be used to apply liquids behind plow trucks.

Tankers – Traditionally very helpful to achieve quick pre-storm anti-icing coverage. Also are effective for applying liquid "on top" of granular being applied by plow truck(s). A successful example might be a liquid applicator that spans three lanes following "gang plowing" on a multi-lane roadway.

Missouri DOT "Salty Dog" Tanker	McHenry, Illinois Applicator
	

Missouri DOT Side Plow Applicator

INDOT - Winamac Centerline Sprayer

INDOT - Winamac Slide-In Applicator

Utah DOT
Parley's Canyon
Combination Unit

Iowa DOT Combination Unit
1,200 gallon liquid + 5 tons granular

Iowa DOT Combination Unit
900 gallon liquid +6 tons granular

Iowa DOT Trailer
2,700 gallons liquid

Equipment Components

Most agencies find that applicator bars with nozzles approximately 12 inches above the ground are effective.

If windy conditions are common, some find nozzle extension hoses helpful to apply the liquid closer to the pavement. However note that the extensions may reduce application pressure, so some prefer not to use extensions.

Chemical quality control is important to ensure proper chemical concentrations. Fortunately, testing this concentration is relatively simple with inexpensive instruments such as a hydrometer or salometer. Also "knowing actual application" of your applicators is fundamental. Equipment should be checked (measured) annually (or more often) and re-calibrated as required.

Good blades are helpful for DLA applications. The cleaner the pavement the less initial dilution potential. If DLA is applied on top of snow accumulation or snowpack, dilution begins immediately.

Partnering

Cost

One primary reason to partner is that brine-making and chemical blending equipment and facilities require significant cost and time. Sharing this cost between agencies by buying/selling helps both partners. In some cases, agencies have engaged owner-operators of applicators (ie tankers) thus avoiding a large capitol cost.

Expertise

Brine-making and blending takes time to develop expertise. By buying from an experience brine-making agency, partners tap into the gained experience.

Sample Equipment Costs

This is just an illustrative example of some ballpark equipment costs to give an idea of the cost of some key during-storm DLA equipment.

Examples of Applicator Equipment
Ballpark Costs and Design Considerations[1] (Table 1 of 2)

Equipment	Notes (with Ballpark costs)
Combination applicator	"Ohio DOT - District 4" custom-built a combination applicator with a cost of about $30,000 more than a standard plow truck. They feel that the extra cost was paid for within one year because of the effectiveness of the unit
Applicator Spray Bar Boom	$1,000 - $2,000
Applicator Discharge Pump and Plumbing	$5,000 - $10,000 small flows (lower speed roads/parking) $10,000 - $15,000 large flows (higher speed roads) McHenry County shares lesson learned – for higher DLA required flows (ie 80 gplm) 370 gpm preferred over 210 gpm
Applicator Slide-In Tank (1,800 gallon)(tank only)	$3,500
2,600 gallon liquid trailer (field ready)	$26,000
Trailer Only (for up to 2,700 gallon tank)	$12,000
In-House Conversion Trailers[2] (for up to 2,700 gallon tank)	• 3 tanks @ $1,000 each - $3,000 • 2 air brake axels with 30/30 chambers $1,600 each - $3,200 • 1 air brake kit complete with fittings, tank, glad hands, air line and all the vales - $350 • Steel cost for legs and rear support - $800 **Total** - $7,350 (labor not included)
Notes (1) Unit ballpark costs shown; labor not included when applicable (2) Assumes trailer is already owned by maintenance area	

Examples of During-Storm DLA Support Equipment
Ballpark Costs and Design Considerations[1] (Table 2 of 2)

<table>
<tr><th>Equipment</th><th colspan="2">Notes (with ballpark costs)</th></tr>
<tr><td rowspan="2">Applicator Loading Pump[2]</td><td colspan="2">Chemical pump
Ensure it is designed for a specific gravity of approximately 1.5 (not a water pump)
Minimum 2” port (larger preferred)
As short of discharge hose length as possible
Consider applicator tank inflow line size
Consider storage tank outflow lines and valve sizes to match pump capacity
Design loading setup to be user-friendly</td></tr>
<tr><td><u>Minimum</u>
2” port
140 gpm max
110 gpm @ 20 psi
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Load 5,000 gallons in 8 hours (approximate)
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For City or smaller maintenance area</td></tr>
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(1) Unit ballpark costs shown; <u>labor not included</u> when applicable
(2) Tips for applicator loading pump (and plumbing from storage tank):
Leaks in seals can occur, resulting in liquid (ie brine) leaking into the motor. This can burn out the pump motor. To prevent this, consider using units that have pump and motor separated by shaft.
May consider filling applicator tank into top of tank (bypassing applicator tank inflow line if smaller). <u>However</u>, this may not be as user-friendly, and may discourage “buy-in” for using liquids.
The number of pumps required for loading will vary depending on the number of DLA liquid application trucks supported. It is important to get applicator tanks loaded fast and back on the road.</td></tr>
</table>

7. Special Considerations

Focus on Hazard Areas

There is some argument (Mn/DOT Olivia, Oregon DOT) that chemical use during-the-storm should focus on hazard areas. The Oregon DOT has posted public announcements that drivers should use caution on straighter, flatter segments which may not be treated.

Granular only on Hazard Areas

This is a variation (materials reversed) of the pre-storm approach of liquid anti-icing on hazard areas. This technique (for favorable conditions) says that (during the storm) primarily apply DLA to the roadway, except for hazard areas which may also receive some granular material application (Mn/DOT Olivia).

Lower Speed Roadways

Lower speed roadways appear to be an easier place to start using during-storm DLA. Road condition (friction) requirements are less than high speed roadways (ie highways) to yield a safe condition.

Plow Only

Another side effect (benefit) of experimenting with ways to produce savings and meet budget constraints, organizations are finding more conditions that warrant plow-only (no chemicals).

This typically requires good pre-storm anti-icing (unless snowfall is dryer; with low moisture content).

One favorable condition for this strategy is events with "dryer snows" (lower moisture content). Others suggest that chemicals are not effective during heavy "wetter snows", so will plow only.

Possibly, this strategy combined with a post-storm "finisher" liquid application could be a good liquid only approach. Iceland utilizes this strategy for heavy storms to try to reduce salt use during these larger events that can consume a relatively large amount of chemical.

Consider Target LOS

It can be helpful to establish your target LOS.

In the past, it in some cases it may have been common practice to achieve high level of service on all roadways, without regard for optimal chemical usage.

With budgets now more constrained and environmental and infrastructure effects more often established, it can be helpful to establish target LOS requirements and aim to meet those requirements more precisely with optimal chemical use thus minimizing possible negative side impacts.

This can be an especially useful consideration for lower speed roadways and secondary routes.

Communication with City Councils and other governing bodies is key to this consideration.

<u>Future Considerations</u>

As discussed in this report, during-storm DLA is most effective when having accurate weather forecasts. In colder climates, the relative difficulty of predicting "falling temperatures" values makes it more difficult to plan liquid chemical use. As forecasting improves, maintenance areas in colder climates will have more opportunities to match strategies with forecasts.

The forecast of moisture content would be helpful for during-storm DLA applications. It is perceived that the existing roadway weather forecasting network needs to improve in capability to accurately forecast this parameter. Forecasters and system developers of weather forecasting tools such as RWIS should continue to be pushed to forecast this and other key parameters.

<u>Chemical Considerations</u>

This report addresses chemicals in a general sense; it does not break down different chemical types. Salt brine is the most common chemical used by the experts in this research. However, MgCl2, CaCl2, blends or other chemicals are also used.

If starting a new program, it is suggested to <u>start with salt brine</u> (NaCl), and then evaluate and consider enhanced chemicals as needed.

Local climate and other factors may influence the chemical(s) that will work best in your area.

<u>Pavement Type Considerations</u>

Italy is having success with during-storm DLA on their standard pavements. They also have a relatively good amount of "porous" pavement, which they do <u>not</u> find DLA effective on.

Super drainage sections (ie increased cross slope such as 2.5%) may be more difficult to apply any chemical (and get it to "adhere"), especially liquids.

8. Expert Contact List

Expert Contact List

(ask for "winter maintenance expert")

Area	Special Notes
City of Beloit, WI www.ci.beloit.wi.us	buy-in strategies, partnering
City and County of Denver, CO www.denversnowplan.com www.denvergov.org/Street_Maintenance 720-913-1311	special environmental considerations
Colorado DOT www.coloradodot.info/topcontent/contact-cdot David.Wieder@dot.state.co.us Phillip.Anderle@DOT.STATE.CO.US 970-350-2100	enhanced (cold- temperature) chemicals, corrosion considerations
Colorado DOT - Region 2 www.coloradodot.info/topcontent/contact-cdot Phillip.Anderle@DOT.STATE.CO.US 970-350-2100	combination units, utilizing MDSS, optimizing application rates
Colorado DOT - Glenwood Canyon www.coloradodot.info/topcontent/contact-cdot Phillip.Anderle@DOT.STATE.CO.US 970-350-2100	combination units, determining "no plow" conditions, optimizing application rates
Iowa DOT District 5 – Fairfield http://www.iowadot.gov/district5/maint_garages.htm	liquid trailers, combination units, customized equipment, optimizing liquid/granular application rates
McHenry County, IL (815) 334-4000	retrofitting equipment, slide-in units, cold climate DLA, seasonal DLA
Missouri DOT - Kansas City District (816) 622-6500 **kristy.hill@modot.mo.gov**	use of tankers in during-storm DLA strategy
Ohio DOT - District 4 (330) 786-3100	high ADT routes, building up large liquid storage capacity
Indiana DOT – Winamac **574-946-3732**	loading pumps, Overall benefits of liquids
Vermont Agency of Transportation, District 8 http://www.aot.state.vt.us/ops/dist8.htm	buy-in Strategies
Utah DOT - Parley's Canyon Parley's Station 234 (801) 582-2115	combination units, shortened cycle times for reduced temperature DLA
Ask for winter maintenance expert when contacting above references	

9. Research Summary

The conclusions presented in this report are based primarily on expert practitioner experience. Little research and field testing has been done on during-storm DLA.

The experience-based information was obtained from phone discussions, an email survey, and follow-up interviews with experts.

The appendices in Volume II of this report include the detailed research document summaries, phone discussions, survey results, and interview summaries.

Note that in discussion with MDSS experts, the MDSS systems would benefit from field test results yielding DLA application rates. This might allow a good **partnership between Clear Roads** and MDSS Organizations in future projects (see Section #10 below).

Some of the ***highlights*** are presented here. Please also see detailed content for research, survey and interviews (project task 1, 2 and 3).

<u>Primary Benefits</u>

There was a common theme in the research that when DLA was done in favorable conditions, crews "got done quicker" with minimized post-storm cleanup required, which resulted in many benefits as described in this report.

Application rates were also generally lower to varying degrees.

Both of these resulted in "savings" in use of less material.

The minimized post-storm cleanup appears that it may result in a quicker return to normal road conditions, resulting in improved road safety as traffic resumes speeds.

Another benefit was in environmentally sensitive areas. Some of these areas have regulations requiring sweeping material after storms. Utilizing DLA has proven to both satisfy the regulations and produce time "savings" because sweeping is not required.

<u>Pavement Temperature</u>

It was not surprising that pavement temperature was a primary parameter. However, it may have been somewhat surprising just how much it is a governing parameter.

Actually, the milder areas utilizing more DLA helped indicate the importance of the parameter. These milder areas with much DLA experience had pockets of even milder climates (ie warming water body effect) where they felt DLA really shined. Also, areas with successful DLA in moderate to milder areas talked about show DLA would be more effective to the south of their areas.

Combination Applications

A common theme among experts was that combination applications were perceived as very effective, if not generally the most effective approach. Generally, DLA was applied as the primary chemical (under favorable conditions) with granular applied as support (“sprinkled”) at lower rates like 50-75 pplm, which helped reduce dilution potential.

Buy-In

Buy-In came up often during the research. Experts identified it as a challenge, and suggested ideas to help achieve it.

Equipment

As discussed in the report, equipment is a key component. Most of the experts suggested dynamic equipment that can be utilized for both DLA and granular applications. Examples included slide-in units that can be flipped from granular to liquid and “combination” units that can apply both liquid (DLA) and granular simultaneously. Another option is designated units such as tankers often used to cover large areas for pre-storm anti-icing, but also proven effective to produce “combined” applications by ie following a group of plows.

Performance Measurement

The general theme during the interviews is that detailed performance measurement is “tough”. Event severity and the number of parameters are challenges. Extraction of a subset of results (ie during-storm without pre-storm are some of the challenges. Most do seasonal usage totals by area and compare to other areas. Some agencies are looking to do more automated testing in the future. One agency recently tried automated measurement and comparisons using MDSS but felt it did not adequately measure performance. Note that for this project only sub-areas within larger agencies were engaged so this is not an overall assessment of available information on performance measurement for any agency (ie it may be managed at a higher level within agencies, etc).

10. Partnership with MDSS

It was learned during discussions with MDSS experts/teams that MDSS systems would benefit greatly from field tests that yielded DLA application rates and procedures. A **partnership** between Clear Roads and MDSS Organizations would allow collaboration to help in the accomplishment of field tests.

11. Field Testing Recommendations

These field testing recommendations are for the Clear Roads project "Identifying the parameters for effective implementation of liquid-only plow routes".

For this section it will be assumed that the baseline (control) method is pre-wet granular applications. Other control methods could be used such as slurry mixes.

DLA in this section assumes Sodium Chloride Salt Brine (NaCl) unless otherwise noted.

It is recommended that "Parameters Field Tests" be considered for plan and execution by Clear Roads.

The "Quick Reference Guide" provides current best practices that will help Public Works teams try DLA. This "Quick Guide" can be utilized before field tests are conducted.

The field tests, when completed, would provide additional evidence to help validate and tune results, and also help supervisors and decision makers in planning their snow and ice control operations.

The field tests will provide the direct and indirect benefits described in the next section.

Field Testing Objectives

The primary objectives (values) of the tests will be:

- Validate and fine-tune key parameters (when to use DLA)
- Learn more about secondary parameters
- Provide additional evidence for decision makers (more evidence provides better chance of buy-in)

There will be additional valuable benefits that the tests will produce:

- Allow partnership and collaboration between Clear Roads and MDSS organizations
- Calibrate and strengthen field testing procedures using results from real world results
- Setup testing framework that is repeatable to help States perform tests at their own facilities
- Leverage the availability and capabilities of testing facilities available around the country (Virginia, Montana, many others)
- Calibrate and strengthen field testing procedures using results from real world results

Field Testing - MDSS Partners

During this project, there were many discussions with persons working on MDSS systems. They shared that DLA field testing results would greatly benefit their systems. They also shared how field tests (as related to application rates and other parameters) are needed to establish or fine-tune parameters relationships.

Therefore, it seems like there is a good opportunity for Clear Roads and MDSS partners to team together on field testing for DLA. This collaboration will help ensure that all perspectives and needs are included in the planning and execution of the tests. It will help ensure that the test results satisfy both the Clear Roads target audience and the MDSS system needs.

Field Testing Framework

Test Location

These field tests should be done in an **off-road** testing site. This can be a designated testing site, or a selected temporarily off-road testing area. See "Field Guide for Testing Deicing Chemicals" (Clear Roads, 2009). Note that ice conditions may be produced during these tests, so testing must be **off-road**. It may be possible to control weather parameters (ie snow-making) at some designated test sites.

Test Result Format

The following table illustrates the expected key results of the field tests.

Example "Summary Results" Table[1,2]
Parameters Field Test
(to be elaborated and refined during test design and setup)

Date	Time	Chemical	Application Rate (gplm)	Pavement Temperature	Storm Intensity	Storm Moisture	Pavement Condition[3]
Time to Refreeze:			minutes				

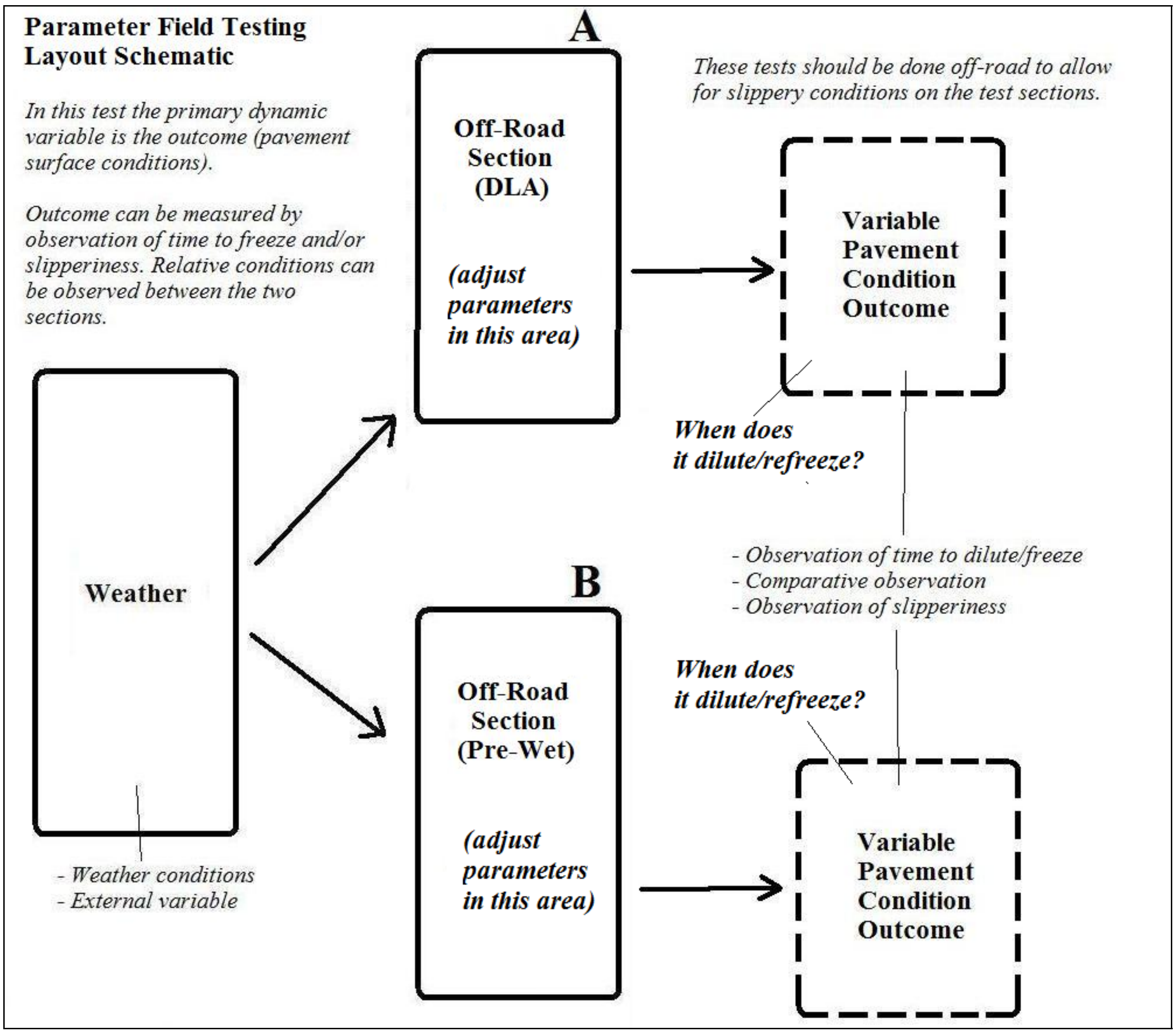
Notes
1. One key "summary result" is the "time to refreeze" which will yield the effectiveness of a chemical for different environmental and operational conditions
2. This table just shows some key "summary" parameters. See appendix "Detailed Parameters List" for a full list of parameters. Collect as many parameters as possible during each test
3. Pavement condition could be measured either quantitatively by a friction measurement device or by observations (presence of ice/slipperiness)

Field Test Layout

Setup an area (See "A" in diagram) for a "test section" (DLA) and another area (See "B" in diagram) for a "control section" (pre-wet).

For area "A" (DLA) setup a test cell at least 12' wide by 200' long. Cells should be large enough so that "standard" application equipment can be used to apply materials uniformly. Optionally, setup additional cells in Area "A". Repeat this setup for area "B".

"When does the area dilute/refreeze" is the fundamental question to be answered for the tests (for different environmental conditions).



Field Test Procedure

(see “Detailed Parameters List” in appendices)

1. Identify a test location(s) with expected weather conditions that will cover the desired environmental parameters
2. Setup a “test grid” on off-road pavement to conduct one or tests. Cells should be large enough so that “standard” application equipment can be used to apply materials uniformly (ie 12’ wide by 200’ long).
3. Identify grid cells which will receive DLA applications
4. Optionally, setup one or more grid cells that will receive a control base-line method (i.e. pre-wet granular application). This will enable the test results to be compared to the base-line method.
5. Keep track of the test and control methods on separate log sheets
6. Using *“Detailed Parameters List”* in appendix, first capture “static” information such as equipment type and configuration
7. Select test measurement interval such as 30 minutes or is reasonable for site
8. Identify parameters that are relevant for given site. These will be the parameters measured at each interval during the test.
9. Especially consider the listed “Performance Parameters” for this test method.
10. For each winter event:
    a. Pavement should be clean and free of snow-pack and ice before the event
    b. The first application should be done at the point during the storm which is reasonably typical of the maintenance area for the given event. If testing multiple cells, applications should be done at the same time (or one right after the other)
    c. The application rate(s) used should be those that have been found effective for the given maintenance area conducting the test (or refer to DLA “Quick Reference Guide”).
    d. The application parameters (see detailed parameters list) should be recorded
    e. At each time interval, measure and record parameters
    f. Continue the test until “refreeze” has occurred to an extent that the pavement would be considered unsafe (to “failure point”)
    g. Summarize the results (see following “Example Test Summary Results Table”)
11. Repeat for a number of different storm events and at different locations using different equipment.

Notes:

1. Field tests could be conducted to include as many of the different “Site Parameters” values as possible (ie pavement type, etc). See “Detailed Site Parameters”

Appendices

Appendix - Calibrate Real World Field Testing

We have a general goal of producing field testing that simulates real world conditions. This is challenging and snow and ice control is one of the most difficult areas to test given the large parameter set (weather+).

So a beneficial side effect of this parameter testing will be the calibration and fine-tuning of real-world field testing.

There is relatively good agreement from practitioners on key parameters in regard to DLA. This is based on ten years of experience. Some of the key variables are perceived to be quite “solid”. Therefore, these parameters can help to “calibrate” the field tests themselves. For example, practitioner experience has shown that DLA is most effective at 25°F and above. If the field tests produce results showing this temperature point at 12°F, the first that should be looked at is the field test to determine if there is something different between the practitioner “real world” conditions and the test conditions. Calibrating the field test will help hone in on other parameters that are less defined in the field (ie traffic effects, etc). By perfecting the general field testing procedures, the “real world” field testing program will be strengthened in general, which will help for future testing needs for existing and emerging technologies (slurry, etc).

Appendix - Detailed Parameters List (Field Testing)

The following list describes measurable parameters to be collected during the various field tests.

Parameter	Notes
General	
Date of Test	
Tester	
Location of Test	
Timing Parameters	
Date of Test	
Interval	Frequency/Interval for measurement/observation/pictures (suggested 30 minute maximum)
Period	Measurement period (suggested from before storm to achievement of bare lane)
Key Environmental Parameters	
Temperature	refreeze potential per any dilution that occurs
Storm Intensity (inches/hour)	dilution potential
Snowfall Moisture Content	ie. wet, ordinary, dry, power; (dilution potential)
More Environmental Parameters	
Event Type	snow, freezing rain, …
Wind Direction and Speed	maximum, gusts
Air Temperature	
Humidity	
Sunny/Cloudy	ie pre and post-storm
Temperature trends	Before and after field test period
Blowing snow	
Application Cost Parameters	
Application Method	DLA, pre-wet granular, slurry, dry granular - % liquid for pre-wet and slurry
Application Times	Note time of each application; intervals (cycle times) may vary through test period
Application Rate	
Applicator Unit Speed	
Plow Blades	
Chemical Type	

Site Parameters	
Climate	arid, wet
Roadway Grade	flat, % grade
Shaded	yes/no
Blowing Snow Potential	crusted or loose snow cover
Wind Potential	protected or open area
Pavement Surface Type	Concrete/Bituminous
Porous Pavement	yes/no
Roadway Type	2-lane rural, 4-lane interstate, curve, ...
Traffic (typical for roadway and time period)	
Volume	Traffic is commonly observed to “help” chemical treatments (especially granular) by “working” in the chemical and sometimes having some “warming” effect on the pavement
Vehicle Mix	truck percentage
Posted Speed	
Equipment - Applicator Type	
DLA - Plow truck with DLA	
DLA - Designated DLA Unit	Applying DLA behind plow truck
DLA - Tanker	Applying DLA behind plow truck
Combination - Single Unit	Applying both DLA and direct granular (usually pre-wet)
Combination - With Trailer	Applying both DLA and direct granular (usually pre-wet)
Pre Wet	
Slurry	
Equipment - Applicator and Loading Configuration	
Applicator Pump type and size	See Appendix 1 in this document for more information to capture
On-Board Liquid Capacity	
Spray Bar Type (nozzle, fan, etc)	nozzle, fan, etc
Spray Bar Height	height above ground
Lane Coverage (one/two/three lanes)	one/two/three lanes spread width
Special (centerline sprayer)	ie centerline sprayer
Loading Pump type and size (storage tank discharge pump)	See Appendix 1 in this document for more information to capture

Performance Parameters (Benefits - Roadway Conditions)	
Regain time - wheel track	
Regain time - bare lane	
Regain time - bare pavement	
Dilution	available on some RWIS stations
Concentration of Chemical	available on some RWIS stations
Freezing Point of Chemical	available on some RWIS stations
Friction Measurement	where equipment is available
Average Traffic Speed	available on some RWIS stations
Snowpack/ice spots	
Photographs and Video	

Appendix - General Field Testing Guidance

Observations

Also reference the testing guide "Field Guide for Testing Deicing Chemicals" (Clear Roads, 2009).

Test results should include pictures and video. Where available, friction measurement equipment can be used. A primary test result will be dilution (chemical concentration) and the resulting time to re-freeze, which should be captured whenever possible.

Note that both field test approaches (cost benefit evaluation and parameter tests) should include capturing as many parameters is reasonable. Note that although the outcome in the cost benefit evaluation is considered effectively "fixed", measurements should be taken to validate and capture any changes.

Key Parameters

Experts engaged in this project identified the following as key environmental parameters in regard to during-storm DLA:

- Pavement Temperature
- Storm Intensity (inches/hour)
- Snowfall Moisture Content (ie. wet, ordinary, dry, power)

Key operational parameters include cycle time, application rates and equipment. As mentioned previously time to dilution-refreeze is a fundamental outcome/performance parameter.

Minimize Dynamic Parameters

As mentioned in the 2009 Clear Roads testing field guide, it is suggested to minimize the number of dynamic (changing) parameters.

This increases the chance of the test to clearly show the results as related to the smaller set of parameters(s).

Run Multiple Tests Simultaneously

Note that it is possible to setup multiple test sections to run multiple tests simultaneously (a test cell grid -- test cells adjacent to another). This can be valuable for parameters such as application rate(s).

Suggested Testing Locations

It is suggested to initially leverage off-road testing sites that Clear Roads is familiar with. The initial tests will help perfect the testing framework setup in this document. The updated testing framework will then be useful to States wishing to conduct their town tests for geographic reasons or simply wanting see results for themselves.

Additional Benefits of Pictures and Video

In addition to helping evaluate test results and provide reference, pictures and video will have the additional benefit of being good material for future demonstration/discussion of the tools and methods. It is suggested to take as many pictures (and video) as possible.

Emerging Technologies

It should be considered if it is cost effective to integrate the field tests to include field similar tests for emerging technologies such as “combination applications”.

Appendix - Equipment Information (for Field Testing)

(for reference – to help identify some of the equipment that could be "captured" during field tests)

Examples of Applicator Equipment
Ballpark Costs and Design Considerations[1] (Table 1 of 2)

Equipment	Notes (with Ballpark costs)
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Minimum 2” port (larger preferred)
As short of discharge hose length as possible
Consider applicator tank inflow line size
Consider storage tank outflow lines and valve sizes to match pump capacity
Design loading setup to be user-friendly</td></tr>
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Leaks in seals can occur, resulting in liquid (ie brine) leaking into the motor. This can burn out the pump motor. To prevent this, consider using units that have pump and motor separated by shaft.
May consider filling applicator tank into top of tank (bypassing applicator tank inflow line if smaller). <u>However</u>, this may not be as user-friendly, and may discourage “buy-in” for using liquids.
The number of pumps required for loading will vary depending on the number of DLA liquid application trucks supported. It is important to get applicator tanks loaded fast and back on the road.</td></tr>
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CLEAR ROADS

research for winter highway maintenance

Lead state:
Wisconsin Department of Transportation
4802 Sheboygan Ave.
P.O. Box 7965
Madison, WI 53707-7965