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GUIDEBOOK FOR MECHANICAL METHODS FOR SNOW AND ICE CONTROL OPERATIONS

FINAL REPORT

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DISCLAIMER

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Abstract

This report presents the research conducted in the creation of a guidebook for mechanical methods for snow and ice control operations. The research began with a review of the literature, and with collection of additional knowledge through contacts with public and private organizations involved in snow and ice removal.

Once the information was collected, it was organized into the guidebook. The guidebook addresses the different types of vehicles upon which the various mechanical tools may be mounted. Each broad category of mechanical tool is addressed in its own chapter (thus front plows, wing plows, underbody plows, and towplows each have their own chapter together with chapters on cutting edges, ice breakers, and snowblowers). Since the context within which agencies must operate may limit their equipment choices, additional chapters on climate effects, road geometry effects, and traffic effects on the operational use of the various tools are included. There is a stand-alone chapter on safety as well as a section in each of the tools chapters on specific safety concerns for each tool type.

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SUMMARY

This report outlines the development of a guidebook for mechanical snow and ice control methods. It began with gathering information on these methods through literature reviews and consultations with relevant public and private entities. The guidebook, organized by vehicle types and tool categories, details different mechanical tools like front plows, wing plows, underbody plows, towplows, cutting edges, ice breakers, and snowblowers. Each tool category has its own chapter, with cross-cutting chapters considering climate, road geometry, and traffic impact on tool usage. Additionally, the guidebook features a dedicated chapter on safety and addresses specific safety concerns for each tool type.

To achieve the objective of this research, relevant domestic and foreign literature, research findings, and information that was pertinent to mechanical methods for snow and ice control operations had to be collected and reviewed. This information was obtained from both published and unpublished documents, and through contacts with public and private organizations involved in snow and ice removal.

Using this information, the guidebook was developed on a chapter-by-chapter basis. Once all chapters were completed, they were assembled into a coherent document. That document will be considered by AASHTO (American Association of State Highway and Transportation Officials) for adoption.

CHAPTER 1: Background

Prior to the conduct of this research project, there were no widely accepted guidelines to address the strategies and practices of using mechanical methods for snow and ice control operations. The purpose of this project was to identify, review, and evaluate the strategies and practices in use in the United States. Having obtained that information, the project developed a guidebook to address the various aspects of these operations and to indicate how agencies might select appropriate strategies for specific climatic, traffic, and road geometry situations. The guidebook will assist state departments of transportation personnel (and other personnel in other transportation agencies) in making decisions regarding snow and ice control operations. Further, the guidebook will facilitate these agencies in implementing safe, cost-effective, and environmentally friendly winter maintenance strategies.

The objective of the project has been to develop a guidebook on the use of mechanical methods for snow and ice control operations. The guidebook provides information on the equipment platforms (e.g., trucks) to which typical mechanical snow and ice control tools are attached, the tools most typically used for mechanical snow and ice control operations, the impacts of climate, road geometry, and traffic on the selection of various tools, and the safety concerns that should be considered when using such tools. The guidebook is structured so that chapters stand on their own and can thus be used independently, depending on an agency's specific needs for the information contained in the guidebook.

CHAPTER 2: Research Approach

To achieve the objective of this research, described in Chapter 1, six tasks were to be accomplished, in two phases. The first phase, comprising tasks 1, 2, and 3, was to gather information and use that information to create a detailed outline of the guidebook. This work was to be reported in an interim report.

Task 1 required the collection and review of relevant domestic and foreign literature, research findings, and information that was pertinent to mechanical methods for snow and ice control operations. The research team collected this information from both published and unpublished documents, and through contacts with public and private organizations involved in snow and ice removal.

In task 2, the information collected in task 1 was used to develop an outline for the guidebook that addressed all aspects of mechanically methods that were used in snow and ice control operations, whether those methods were used on their own, or in conjunction with chemical or non-chemical products. Further, outlines were developed for chapters to provide guidance on selecting equipment and snow and ice removal strategies in the context of various climates, road geometries, and traffic conditions. The primary product of task 2 was a detailed outline of the proposed guidebook.

Task 3 involved the preparation and submission of an interim report, and a presentation to the NCHRP project panel. This was conducted, and after the presentation, authorization was given by the NCHRP to proceed with phase 2 of the research project.

The second phase of the project comprised three additional tasks (tasks 4, 5, and 6). Task four was developing the guidebook. This was done chapter by chapter, and as each chapter was finished, the draft version was submitted for NCHRP review. Task five required that the chapters be assembled into a coherent document that served as a draft version of the proposed guidebook. Task 6 required the preparation and submission of a research report documenting the work performed in the project, and a stand-alone guidebook for consideration by AASHTO (American Association of State Highway and Transportation Officials) for adoption.

CHAPTER 3: Findings and Applications

The material in the guidebook was developed by gathering information using a review of the literature, and through contacts with public and private organizations involved in snow and ice removal. This information gathering began with an examination of the equipment platforms upon which mechanical tools for snow and ice removal are mounted. This was followed by an examination of those tools in detail, together with an examination of the factors that mitigate for and against each tool in certain specific situations (considered as impacts of climate, road geometry, and traffic levels on winter maintenance operations). Finally, using all the data gathered to that point, key issues pertaining to safety were extracted and collected. This is discussed in Chapter 3.1 Information Collection, below.

Once the information was gathered, it was placed into appropriate chapters in the draft guidebook. As will be detailed below, certain of the chapters were designed to have a similar layout, so that users would be more able to access information critical to their needs as rapidly as possible. Many photographs were used, both to illustrate the text and to provide visual appeal to what might otherwise be a text-heavy document. This is presented in Chapter 3.2 Guidebook Creation, below.

Chapter 3.1: Information Collection

As discussed above, information was gathered from a variety of sources and then used to create the contents of the guidebook. This section of chapter 3 details the information found in each of the areas identified above.

Equipment Platforms for Snow and Ice Control

A wide range of vehicles are used for snow and ice control, as noted by Hunter (1998). Most common among these are heavy, medium, and light duty plow trucks, graders, snowblowers, loaders, tractors, miscellaneous small utility vehicles, and packers. Each has its benefits and drawbacks as discussed in Schacher (2020).

Trucks utilized for winter maintenance come in a multitude of various configurations, types, sizes, and horsepower. These various sized trucks, classified as light, medium, and heavy-duty, can serve multiple roles and can be equipped with a variety of plows and/or other equipment and attachments. Trucks are classified based on their Gross Vehicle Weight Rating (GVWR). GVWR is a vehicle’s maximum weight, which includes payload capacity. GVWR is the maximum amount of weight a vehicle can safely handle. Trucks are classified from Class 1 through Class 8 with Class 1-3 considered light-duty (GVWR less than 14000 pounds), Class 4 – 6 as medium-duty (GVWR 14001 – 26000 pounds), and Class 7 – 8 as heavy-duty (GVWR greater than 26001 pounds).

An agency, when considering the purchase of new or replacement equipment, may weigh a variety of factors to determine which approach will best meet the agency’s needs. These needs will change over time and will vary with location as well. Thus, agencies finding it difficult to recruit drivers with CDLs (Commercial Driver’s Licenses) may choose instead to expand the number of small and medium trucks in their fleet (with GVWR less than 26,000 pounds, thus not requiring a CDL), while reducing the number of larger trucks (Morreim, 2022).

Whatever vehicles an agency may select for their winter maintenance fleet, most of them will be purchased with the intent of being used in a wide range of tasks, not just in winter maintenance. Some specialty vehicles (e.g., a self-propelled snow blowing unit) are clearly not going to have this level of flexibility, which makes the use of such vehicles relatively rare in the field. For any specialty vehicle, there is an alternative approach which mounts a unit that can perform the task of the specialty vehicle on another sort of vehicle. Thus, a heavy snow-blowing unit can be mounted on a motor grader, thus replacing the need for (and the costs associated with) a specialty piece of equipment. Against this, for an agency which must (due to climate or geographic location) deal with heavy snowfalls on a regular basis, the purchase of a self-propelled snow blowing unit may be easily justified in terms of return on investment.

A key factor to consider in vehicle selection is the power of the engine of the vehicle. This is especially important in the selection of dump trucks since they need sufficient power to manage whatever slopes they may face in their operational area, while being fully loaded with salt or other materials. In addition, they need power to operate the various hydraulic systems that are typical on a plow truck (the plow itself, the sander/spreader unit, and any additional equipment such as wing plows and underbelly plows). Further, some units may require additional power upgrades if it is intended that they should be used with, for example, tow plows (Bennett and Lasky, 2018).

Since winter maintenance vehicles will need to operate in the most severe of winter weather conditions, it is important that they be prepared for such operations appropriately. An overview about appropriate preparation of fleet vehicles for winter is given in McIver (2020) who reviews the various fluids needed and the requirements that those fluids have depending on climate region.

Plows

Plows are the primary tool for removing snow and ice from the roadway. Pell (1994) provided a detailed description of the process whereby a front mounted plow operated at an angle to the direction of travel compresses and displaces snow. However, as Pell noted, there is insufficient linkage between theory and experiment for the theoretical models to be particularly useful in terms of designing optimal plow moldboard shapes or geometries. At the most basic level, plows are simply tools to move material (snow and ice) from one location (in the road) to another (off the road) (Nixon, 2017). They can operate without any use of freeze point depressant chemicals, but when used properly with chemicals (i.e., with the chemicals being used to break or prevent the bond between the snow and the pavement) they are most effective. It should be noted though that the primary snow and ice removal tool is the plow itself, and not the chemical – the chemicals serve only to enhance the plow performance and not to replace it. Primarily, the chemicals serve to break or prevent the bond between the snow and ice and the pavement (Nixon, 2016). In the absence of this bond (whether broken or prevented) the plow can remove the snow and ice most efficiently.

There are four basic types of plows - front plows, wing plows, underbody plows, and towplows (Nixon, 2017). While in the past (Minsk, 1998) use has been made of drag plows (plows pulled directly behind the truck) this usage is not current in North America. Each of the four plow types has variations, as summarized in table 3.1. While it is possible to speak in general terms describing how certain plow types are used, it must be noted that these usages are not universal. As an example (Nixon, 2017) underbody plows in most of North America are used to deal with compacted snow and ice on the road and in some cases to reduce snow fog. However, in Michigan, underbody plows are the standard plow types and are used instead of front mounted plows.

Wing plows and towplows are being used as “force multipliers” for agencies conducting winter maintenance (Schacher, 2020). With a large wing, or with a towplow, a single truck can plow snow from more than one lane of road, and towplows are being used on multi-lane roads to allow a single truck to plow two lanes of highway in one pass. This is particularly helpful when team plowing is being conducted, since using towplows and wing plows it will be possible to clear multi-lane highways in a single pass using fewer trucks than if all trucks were mounted with front plows only.

Wing plows are often used to increase snow storage on the roadside, by “benching” snow back from the travelled way. In those parts of North America where frequent snowfalls occur without the opportunity for significant snowmelt between the storms, the issue of snow storage is a major concern and must be addressed either by hauling all snow to snow dumps or by increasing roadside storage where that is possible.

Table 3.1 Typical Variations on Standard Plow Types

Plow Type	Typical Variations
Front Mounted Plow	One-way, two-way, vee plow, extendable plow
Wing Plow	Left side, right side, benching, front mount, mid-mount, rear mount
Underbody Plow	Fixed angle, variable angle, with or without down-pressure
Towplow	Left lane clearance, right lane clearance, with solid material hopper, with liquid application system

Of the four plow types, the most recently developed is the towplow, so much so that it was not referenced in Minsk’s (1998) text. Thus, there are several recent studies available on the towplow, with one of the earliest reports being Lannert (2008). Bennett and Lasky (2018) provided a detailed investigation into towplow performance, with emphasis on how it might be made ready for use by the California Department of Transportation. The towplow was also the focus of an AASHTO Technical Implementation Group study, with the final report (Chojnacki et al., 2012) providing insight into the benefits and challenges of the new plow type. The following bulleted list shows the benefits identified by Chojnacki et al (2012) in their study.

- Decreased cycle time due to one pass clearing and wider clearing path.
- Higher operating speed potential.
- Quickly position or relocate snow removal equipment.
- Improved equipment reliability.
- Extended plow blade life due to reduced down-force.
- Efficient clearance means fewer vehicle trips to resupply treatment materials.
- Benefits rural and urban areas.
- Builds clearing capacity while not increasing on-road equipment fleet size.

In terms of plow usage, various state Departments of Transportation provide materials in their maintenance manuals (or equivalents). These manuals typically cover plow types, usage methods, good practices to use, and poor practices to avoid, and safety tips. Alaska DOT&PF (2014); Minnesota Local Road Research Board (2022); and the Idaho Transportation Department (2021) provide this sort of information.

Cutting Edges

Cutting edges are attached to the bottom of the plow moldboard, to serve as a wearing surface between the road and the vehicle, and to remove the snow and ice as efficiently as possible. Every sort of plow (front mounted, wing, towplow, etc.) has a cutting edge. In addition to plows, cutting edges were also a focus of the Strategic Highway Research Plan investigations into winter maintenance (Nixon, 1993). At the time of that research, the options for cutting edges were only three. There were rubber (squeegee type) edges, there were high-speed steel edges, and there were edges (made of steel) with tungsten carbide inserts. The rubber blades were used primarily for handling slush, or when objects in the pavement were sufficiently fragile that they would be damaged by harder blades (for example, on some airports). Rubber blades were typically used with shoes or casters on the plows to avoid rapid wear of the rubber.

Additional work suggests (Nixon et al., 1993; Nixon, 1994; Nixon and Frisbie, 1993) that the shape and material in the cutting edge are as important as the dynamics of the plow itself. This earlier work indicated that the processes involved in a plow cutting edge removing snow or ice on the road were like the processes involved in cutting metal on a lathe or milling machine.

One of the challenges of the high-speed steel cutting edges was that they wore down very quickly. In many cases, a single shift of plowing was sufficient to wear out a cutting edge. This had obvious drawbacks not only in the cost of new cutting edges, but also in the time required to change out the cutting edges. The cutting edges with tungsten carbide inserts were an attempt to obtain better wear characteristics for the cutting edges, so that they would last longer than a single event. The challenge at that time was that the carbide was often damaged by the inevitable shock loading that a plow edge will see during operations.

The design of a cutting edge is thus a balance between two competing requirements: shock resistance, and wear resistance (Nixon et al., 1993, Nixon et al., 2017). In general, the harder a material is, the more wear resistance it has but the less shock resistance it has. In recent years, designs for cutting edges have been developed that allow hard wearing materials (tungsten carbide and other ceramics) to be protected within a matrix of more shock resistant materials such as rubber. However, as noted by Nixon (2012) several other factors need to be considered as well:

> *"The choice of a cutting edge is a function of a number of variables. Key among these are price and longevity of the cutting edge, which ideally should be combined into a form of life-cycle cost analysis, and the overall performance of the cutting edge (the degree to which it clears snow and ice from the road surface), but other factors also must be considered. These include the type of pavement and pavement markings in use on the road system for which the cutting edges are being purchased. Additional factors to be considered in the selection of a cutting edge are noise and vibration, and ease of installation."*

Road surface type is a particular concern for selection of cutting edges. It is not only the possible presence of raised pavement markings that must be considered, but also the propensity for the type of pavement to impact the cutting edge to a greater or lesser degree. Nixon (2002) reported on the potential for damage from cutting edges on thin pavement overlays, also noting that certain (very hard) overlays could damage cutting edges. In addition, road surfaces are typically not flat, and so there are also several cutting edge systems that are sufficiently flexible to conform to the pavement surface. This improves the removal of the snow from the pavement surface and thus reduces the need for chemicals and enhances operational efficiency.

Schacher (2020) provides a brief introduction to the newer, longer-lived cutting edges now being used and discusses the benefits and drawbacks of these new products. The primary drawback is the high initial cost, which as Schacher discusses is offset by much longer lifespans and superior performance at snow clearing. Schacher's observations make clear that life-cycle cost analysis is critical when selecting cutting edges especially (because the cost differential between the cheapest and the most expensive cutting edges are so high). Certainly, life-cycle cost analysis is important in any equipment selection, and the Clear Roads consortium developed a tool for such analysis in winter maintenance (Veneziano et al., 2010; Veneziano et al., 2013).

Since the material in the cutting edge itself is so critical to the performance of the cutting edge, effort has been expended to provide tests to measure critical material properties of the cutting edges (for example, hardness of carbide inserts) that could be used as quality control measures. Studies by Wei et al. (1998) and Kruse and Kirchner (2010) provide guidance in this regard, and Clear Roads developed a sample specification for carbide insert cutting edges (Minge et al., 2020).

There was some interest in recent years in using cutting edges with multiple blades. These might be two or three bladed systems, with one blade designed to break ice or compact snow, one to plow loose snow or ice fragments, and one to remove slush. A Clear Roads report (CTC & Associates, LLC. 2010) reported on field tests conducted in five states. The report indicated that the multibladed systems worked, and when used in the correct configuration could improve plow performance from the point of reducing remnant snow and ice material on the road after plowing.

The following bulleted list shows factors, collected from the literature, which need to be considered in selection and use of cutting edges.

- Harder cutting edges last longer than softer ones (so need to be changed less often).
- Harder cutting edges are typically more expensive than softer ones.
- Harder cutting edges are more easily damaged than softer ones, so greater care will be needed when using them.
- In general, the more sophisticated a cutting edge system is, the more care will be needed in its operation. Cutting angles will need to be carefully set and monitored.
- Having a cutting edge system that does not need to be changed as often provides increases in efficiency (less time in the shop, more on the road).
- Matrix type systems (combining hard materials in a soft matrix) often provide much less vibration than more traditional systems, which reduces operator fatigue.
- Flexible systems provide more conformity to pavement surfaces but are typically more complicated to install than non-flexible systems.

Front-mounted plows often include trip mechanisms that are designed to protect the cutting edges from shock loading when the plow hits an obstacle such as a raised manhole cover (Pell 1994). One of the challenges for trip mechanisms is that they do not necessarily automatically reset after being triggered, and while they may protect the cutting edge, they can, in doing so, provide a significant shock loading to the truck and the operator. Pell reported on attempts to develop self-resetting trip mechanisms and indicated that while such developments were possible, they faced many issues to become fully deployed, including both the mechanisms by which they might be reset, and the need for them not to trigger under too low a load (otherwise they would simply trigger too often.

Icebreakers

Icebreakers, also called penetrating drums, are attachments that utilize a freely rotating spiked roller system that uses metal spikes (teeth) or blades to break the packed snow or ice bonded with the pavement into relatively small pieces that can then be plowed off the roadway by following blades and/or plows (Bennett, 2016).

As noted by Bennett (2016) the pressure of the spikes (teeth) on the drum penetrates and breaks up hard, compacted ice layers on the road surface. A variation on the penetration drum is an icebreaker with rolling wheel sets with rotating teeth sets. All icebreakers create holes in the compact snow and ice that can then be removed by traditional mechanical methods. There are several commercially available icebreakers that can be attached to a heavy-duty plow truck, wheel loader, grader, and utility type vehicles (UTVs). Four manufacturers of this technology were identified from the US, Canada, Finland, and China. In addition, Fairbanks International Airport (FAI) built their own icebreaker specified for use on airport runways, called the Yeti, and won an award for innovative design. It is based on a gang of standard carbide tipped planer drums mounted on an articulating frame.

The icebreaker uses high pressure under a series of teeth to fracture the compacted snow or ice on the road. Once the snow and ice are fractured, then it is easier to remove with traditional plows, and any application of salt or other chemicals will be more easily able to penetrate to the road surface, thus eventually breaking the bond between snow/ice and the pavement. Bennett (2016) notes that they can be used in free floating mode (only their own weight acting on the ice) or with down-pressure applied, depending on the mounting used for the icebreaker. When used in a down-pressure mode, there is a risk of pavement damage.

The following bulleted list shows a summary of operational findings gathered in Bennett (2016) as noted by various State Departments of Transportation.

- Turning should be kept to a minimum when the icebreaker is being used. The icebreakers cannot turn, and must be lifted around turns, but they do work on super elevation.
- Use caution when crossing railroads and bridge expansion joints.
- Agencies have found that the optimal speed is approximately 15-17 mph.
- Multiple passes (2 or 3) have been shown to be beneficial in pulverizing ice and snowpack.
- Icebreakers work better on thicker ice and hard pack. Operating on ice and hard pack of at least ½ to ¾ inch helps to minimize any damage to the underlying pavement.

Snow Blowers

Snow blowers, also known as rotary snowplows, are a snow removal apparatus that is primarily used to cast heavy concentrations of snow collected on the road and shoulders (Minsk, 1998). The equipment, which may be self-propelled or attached to a carrier vehicle, uses one or more rotating elements (single or two-stage units) to disaggregate a snowpack. The disaggregated snow is then broken into particles small enough to pass through a casting mechanism and directional chute. All snow blowers have the same basic operation. They scoop up the snow from the ground with an auger and discharge it through the snow chute, with or without the help of the impeller. Some high-speed snow blowers can discharge up to 5,000 tons of snow per hour. Snow can be cast up to two hundred feet depending on conditions.

The Alaska Department of Transportation and Public Facilities Highway Maintenance and Operations Handbook summarizes the use of snow blowers very effectively:

> *"Using a snow blower is a very effective method to get rid of large amounts of snow. As long as you have room to do so, blowing snow off the road into open areas is the quickest and most efficient way to get rid of it. If you are in a confined area and you are able to windrow the snow, loading trucks with a snow blower is much quicker than a loader."*

In summary, snow blowers are a key component of the snow removal strategy on highways that travel across mountains and in areas that receive substantial amounts of snow. Rotary plows are used to clean up deep berms of snow left on the shoulders and to open seasonal and mountain pass roads that are allowed to close in the winter. Occasionally, drifts and avalanches are deep enough that rotary plows are required. Snow blowers can be used during storm conditions but work at slower rates than snowplows and are normally used for post-storm snow removal outside of very heavy snowfall areas.

Other Non-Chemical Techniques

Over time, there have been several proposed alternative methods of removing snow and ice from the pavement mechanically (Pell, 1994). Two methods still under consideration today are heated pavements (Akin et al., 2013, provide a summary of these methods) and ultra-flexible pavements (Takeichi et al., 2001). However, currently neither of these two methods are in full operational deployment. As such they are not currently suitable material for a guidebook, although that might change in the future.

Other countries also make use of different removal techniques. The use of brooms on pedestrian and bike path facilities is extensive (Tremblay, 2017) and similarly brooms are used for clearing loose snow from airport runways (Minsk, 1998) but Minsk also notes that their use on roads and highways in the United States is limited because of the relatively low speed of brooms when clearing snow. Likewise, in Japan in certain locations (Ohashi, 2022)) air blowers are used to remove loose snow from roads, and they are used in certain circumstances on runways as well. While their use in a fixed road location is an interesting solution to a specific problem, their use on roads in the United States is not current practice.

Snow Removal Strategies for Different Climates

Mewes (2012) demonstrated how much winter weather varies across the United States, developing a series of maps indicating how winter severity varied across the country. This series of maps was further refined into sets of five maps for twenty-eight states, showing hours of blowing snow, freezing rain, and snowfall, as well as total snowfall accumulation and winter severity for each state (Clear Roads, 2014). There are many differences between states, suggesting that each state needs different strategies for addressing the most prevalent types of winter weather that they face.

Table 3.2 summarizes the equipment that is optimal for regions of heavy snowfall (total accumulation of 12 or more inches of snow in one storm), lighter snowfall (less than the heavy snowfall), freezing rain, and ice and compacted snow accumulations. The information is compiled from Minsk (1998), Bennett (2016), Nixon (1994, 2017), Pell (1994), and Schacher (2020) and the references are given also in table 3.2.

Table 3.2 Summary of Equipment Types for Different Winter Storm Types

Type of Winter Storm	Suggested Equipment
Heavy total snow accumulation	Snowblowers, front mounted v-plows (Minsk, 1998)
Lighter snow accumulation	Front mounted plows (Pell, 1994; Minsk, 1998), wing plows (Schacher, 2020), towplows (Bennett, 2016; Schacher, 2020), and for accumulations less than 4 inches, underbody plows (Nixon, 2017)
Freezing rain	Icebreakers (Schacher, 2020), underbody plows (Nixon, 1994)
Ice and compacted snow accumulations	Icebreakers (Schacher, 2020), underbody plows (Nixon, 1994), serrated cutting edges (Nixon, 1994)

Snow Removal Strategies for Different Road Geometries

Highway geometries of concern for winter maintenance operations can be considered in two parts – issues involved with intersections, and issues involved with the main part of the traveled way between intersections. The geometries of intersections have become more complex as the intersections are designed to manage higher levels of traffic within constrained space footprints (AASHTO, 2018). Qi et al. (2018) developed a manual of best practices for clearing these more complex intersection geometries but did not discuss how different equipment was suited to specific geometries. However, their listing of intersection types (they identify ten distinct types), while not exhaustive, allows for consideration of all major intersection types. The primary

A primary concern for clearing intersections is the turning radius of the equipment conducting the clearing. Thus, graders are often used for residential circles in urban developments (Schacher, 2020) because of their tight turning radius. Likewise, tools such as towplows or wings may not be ideal in geometries with tight curves, although both tools can be moved into a "non-deployed" position as needed.

For the traveled way between intersections, the primary concern is again, turning radius. Certain roads in mountainous terrain may have very tight curves (e.g., hairpin turns) and in such circumstances it might be appropriate to consider using graders rather than dump trucks (Schacher 2020) because the slower speed of a grader is less likely to be an issue on such steep and curvy roads.

Snow Removal Strategies for Different Traffic Levels

Heavy traffic conditions place an extra constraint on winter maintenance operations, and in some winter storms roads may become completely blocked for a time due to a combination of snow and traffic (Hammond, 2022). Winter maintenance vehicles stuck in such congestion will not be able to clear snow from the roads because they will not be moving. This is the extreme case of the interaction between traffic and winter conditions, but if such situations are to be avoided, specific approaches are needed for such high traffic volume roads.

One of the most effective ways of clearing high traffic roads is using team plowing, in which several plow vehicles (often equipped with towplows and/or wing plows as well as front plows) plow in echelon to clear snow from the road (and apply materials as needed) in a single pass (Minsk, 1998). This method may require coordination with state patrol or other local traffic enforcement agencies to ensure safety during the operation (Nixon et al., 2023). When using such an approach, the greater the width of highway that can be cleared by a single truck, the better. This approach therefore lends itself to using both wing plows and towplows as available.

Lower traffic volume roads pose fewer concerns regarding traffic control during snow clearing operations, but they are not without their own issues. Such roads are often in more remote areas, and thus while traffic levels might be low, traffic speeds are not necessarily low. It is important in such cases, as far as possible, that operations on low traffic volume roads be conducted in the best possible visibility conditions. Given that such roads are often lower priority (because of their lower traffic volumes), it should be possible to schedule such operations during daylight hours. If the roads in question are unpaved, the use of graders is a common approach for winter maintenance operations.

Combining Mechanical and Chemical Snow Removal

The primary tool for removing snow and ice from the road is the plow (Nixon, 2017). Chemicals can enhance the ability of the plow to remove snow and ice from the road by breaking or preventing the bond between snow and the pavement (Schacher, 2020). Thus, apart from anti-icing (and specifically, the pre-storm application of chemicals part of the anti-icing operational strategy, Nixon, 2016) chemical methods should not be used without also employing mechanical methods at the same time.

There will be situations where conditions (most typically low pavement temperature, but also high wind situations) are such that the use of chemicals is not appropriate (Akin at al., 2013). In those situations, the mechanical methods are not augmented by the use of chemicals. Akin et al. (2013) examined strategies for snow removal at very cold temperatures. Under such conditions, traditional road salt is less effective (and sometimes may be totally ineffective) and thus mechanical methods might be paramount, but the study focused on alternative chemical usage and methods to make abrasives more effective and longer lasting (as a friction enhancer) at cold temperatures, rather than examining mechanical methods in detail. However, in most circumstances, chemicals can be used to enhance the performance of mechanical methods.

The optimal use of chemicals is to apply them to prevent or break the bond between snow and ice and the pavement. Of these two approaches, it is better to prevent the bond than to break it. Prevention can be achieved by applying materials (typically but not always in liquid form, as a brine) prior to the start of the storm, and then after any fallen snow is removed, additional chemical is applied as needed to continue to prevent bond formation. If the bond has formed already, then the first required operational step is to remove as much loose snow and ice as possible by plowing. Then, chemicals are applied to get through any bonded snowpack or ice layers and reach the interface or bond between the snow and ice and the pavement. Once at the bond, the chemicals will weaken and break that bond, and the excess snow and ice can then be removed.

There is much guidance available on appropriate chemical application rates (Nixon and DeVries, 2015) and suitable rates of application should be used in conjunction with mechanical methods as conditions of pavement temperature, precipitation rate and type, and cycle time require.

Chapter 3.2: Guidebook Creation

This guidebook has been created to provide information on the mechanical methods of snow removal for all agencies and others involved in the process of providing winter maintenance on roads, streets, and highways. The emphasis on mechanical methods does not imply that non-mechanical methods (such as the use of ice control chemicals) are inappropriate – they have a central part to play in good winter maintenance practice. However, there are circumstances (most often, but not always, associated with very low pavement temperatures) where mechanical methods are the only or the primary “tool” available in the winter maintenance toolbox. It is the types and uses of these mechanical methods that is the focus of this guidebook.

The guidebook is not intended to be proscriptive or to be any sort of standard methods document, but rather to provide guidance as to when and how various mechanical methods of snow removal have been used and can be most effectively used by an agency. The guidebook is intended to be a resource for agencies, laying out the various mechanical methods currently in use in the United States, with information on the benefits and drawbacks of each method and tool that has been used.

The guidebook is aimed at all personnel involved in the practice of winter highway maintenance, from senior management, supervisory staff, and front-line operators. It is expected that these groups will use the guidebook in different ways. Senior management may view the guidebook as more of a reference document, upon which they may call as needed. Supervisory staff may use the guidebook to assist in training the frontline staff in the specific usage of different mechanical tools, while for the frontline staff, the guidebook may serve as a ready reference of useful information.

Most of the chapters in the guidebook look at specific pieces of mechanical snow removal equipment, from front mounted plows, through wing plows, towplows, cutting edges, snow blowers, and ice breakers. These chapters have a common structure, covering the benefits and limitations of the specific pieces of equipment, their typical operational usage, a general description of the piece of equipment, and a discussion of operation techniques. Each of these chapters ends with comments on safety factors specific to the piece of equipment, and to a listing of additional resources available on the internet. Since some may be using this guidebook in a printed rather than online version, QR codes are included for each of the internet resources. Appendix A lists the links used at the end of each chapter of the guidebook.

There are three cross-cutting chapters, addressing how issues of climate, traffic levels, and highway geometry may impact the selection of specific mechanical snow removal tools. In these chapters, the intent is to allow an agency to explore whether their current mix of equipment is appropriate for the specifics of the climate, the traffic levels, and the various highway geometries for which they must provide winter maintenance services. As appropriate for a guidebook, the chapters do not define specific solutions, but rather present options that an agency might consider.

The remaining chapters of the guidebook are more general material. One addresses the various equipment platforms that are available to which the various tools described may be attached.

This includes trucks but also other equipment likely to be available to agencies, such as front-end loaders, graders, and so forth. This chapter describes which tools may be used with which equipment platforms. There is a chapter dedicated to safety in winter maintenance operations. The equipment described in the guidebook is typically heavy, and often driven by powerful engines, and as such can be hazardous if not operated appropriately and with due attention to safety. Further, the conditions under which the equipment is used (during winter storms) are often hazardous in and of itself, and thus safety needs to be a prime consideration in all aspects of winter maintenance operations. Finally, there is an introductory chapter and a conclusory chapter at the end of the guidebook.

Agencies will determine how the contents of the guidebook best serves their needs, but the chapters are arranged to provide information in a readily accessible form. Thus, the material in the guidebook could be used as a whole, on a chapter-by-chapter basis, or in briefings, as part of annual training for regular employees, as part of the onboarding process for new employees, or as training for seasonal employees as appropriate. Much of the information is provided in bullet list form to make it straightforward to extract pertinent data for whatever use an agency might require.

CHAPTER 4: Conclusions

This report details the work performed to create the Guidebook for Mechanical Methods for Snow and Ice Control Operations. The project comprised the collection of information from available literature, and from contacts with public and private organizations involved in snow and ice control operations. This information was then organized into the chapters of the guidebook. The guidebook provides information on the equipment platforms (e.g., trucks) to which typical mechanical snow and ice control tools are attached, the tools most typically used for mechanical snow and ice control operations, the impacts of climate, road geometry, and traffic on the selection of various tools, and the safety concerns that should be considered when using such tools. The guidebook is structured so that chapters stand on their own and can thus be used independently, depending on an agency's specific needs for the information contained in the guidebook.

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APPENDIX A

LINKS PROVIDED IN THE GUIDEBOOK

Links from Chapter 2: Safety

http://www.iml.org/file.cfm?key=2993#:~:text=Always%20stay%20on%20the%20proper%20side%20of%20the%20road.&text=PLOWING%20GUIDELINES%20(cont.)&text=When%20plowing%20snow%20or%20applying,another%20driver's%20ability%20to%20see.&text=Never%20plow%20with%20your%20head,cause%20head%20and%20neck%20injuries Quick reference guide on snowplow safety. Accessed online on February 28th 2024.

https://clearroads.org/training-resources/ Training resources developed by the AASHTO Clear Roads Pooled Fund consortium. Accessed online on February 28th 2024.

https://clearroads.org/project/18-01/ Guide developed by the Clear Roads Pooled Fund on Defensive Driving for Snowplow Operators. Accessed online on February 28th 2024.

https://www.youtube.com/watch?v=W0IDdyip-mM High-speed snowplow safety training including multiple attachments by Alaska Department of Transportation and Public Facilities. Accessed online on February 28th 2024.

Links from Chapter 3: Equipment Platforms

https://www.roadsbridges.com/technological-advances-winter-maintenance-field-found-reliably-increase-safety a review of all the tools available for winter maintenance operations. Accessed online on February 28th 2024.

Links from Chapter 4: Front Plows

https://professionalsnowfightersassociation.org/2023/12/minnesota-dot-snow-and-ice-control-handbook-for-snowplow-operators-2022/ (Minnesota Snow and Ice Control Handbook, in particular see page 11).

https://professionalsnowfightersassociation.org/2023/12/alaska-dot-pf-highway-maintenance-operations-handbook/ (Alaska Highway Maintenance and Operations Handbook, in particular Chapter 7, and appendices). Accessed online on February 28th 2024.

https://professionalsnowfightersassociation.org/2023/12/idaho-transportation-department-operations-manual-2022/ (Idaho Transportation Department Operations Manual, in particular Chapter 7). Accessed online on February 28th 2024.

https://www.youtube.com/playlist?list=PLurY2WfsVWKn9ismDC4Uz3IbRivAnf0Ld (Iowa DOT Winter Operations Training Series of videos, particularly videos 8 and 9). Accessed online on February 28th 2024.

https://www.youtube.com/watch?v=6RTam4qXIus (Iowa DOT video explaining what tandem or team plowing is). Accessed online on February 28th 2024.

https://www.youtube.com/watch?v=W0IDdyip-mM (Alaska High Speed Snowplow Training video). Accessed online on February 28th 2024.

https://www.youtube.com/watch?v=3XHtB4ChZtg (Ohio LTAP Center, Winter Operations Training Program volume 4). Accessed online on February 28th 2024.

Links from Chapter 5: Wing Plows

https://www.youtube.com/watch?v=Zm9DVBCQCCA (Iowa DOT training video on wing plow usage). Accessed online on February 28th 2024.
https://www.youtube.com/watch?v=CA8xBDJmFG4 (Kansas DOT training video on wing plow usage – specifically mid-mounted). Accessed online on February 28th 2024.
https://professionalsnowfightersassociation.org/2023/12/alaska-dot-pf-highway-maintenance-operations-handbook/ (Alaska Highway Maintenance and Operations Handbook). Accessed online on February 28th 2024.

https://www.youtube.com/watch?v=W0IDdyip-mM (Alaska DOT & PF training video). Accessed online on February 28th 2024.

Links from Chapter 6: Underbody Plows

https://sicop.transportation.org/wp-content/uploads/sites/36/2017/07/CA-Ice-Breaker-Report.pdf (a report from Caltrans that discusses a variety of tools for ice breaking, including underbody plows). Accessed online on February 28th 2024.
https://www.lrrb.org/pdf/200619.pdf (A report from MNDOT on underbody plows). Accessed online on February 28th 2024.
https://www.youtube.com/watch?v=W0IDdyip-mM (Training video from Alaska DOT & PF on using plow trucks, including information on using underbody blades). Accessed online on February 28th 2024.
https://professionalsnowfightersassociation.org/2023/12/clear-roads-manual-of-environmental-best-practices-for-snow-and-ice-control-2015/ (report from Clear Roads including discussion of underbody plows). Accessed online on February 28th 2024.

Links from Chapter 7: Towplows

https://ops.fhwa.dot.gov/publications/fhwahop12046/rwm07_colorado1.htm (report from Colorado DOT on their use of Towplows). Accessed online on February 28th 2024.

http://aii.transportation.org/Documents/TowPlow/TowPlow-training-manual.pdf (Towplow training manual from Missouri DOT). Accessed online on February 28th 2024.

https://professionalsnowfightersassociation.org/2023/12/caltrans-report-on-towplows-2018/ (Report from Caltrans on their evaluation of the Towplow). Accessed online on February 28th 2024.

https://vtrans.vermont.gov/sites/aot/files/vttc/documents/Tow_Plow_Manual.pdf (Michigan DOT Towplow training guide). Accessed online on February 28th 2024.

Links from Chapter 8: Cutting Edges

https://www.dot.nd.gov/divisions/materials/research_project/mr201003final.pdf This is a report on a study on four different cutting edge types from 2010. Interesting information about the different types. Accessed online on February 29th 2024.

https://professionalsnowfightersassociation.org/2023/12/minnesota-dot-snow-and-ice-control-handbook-for-snowplow-operators-2022/ This is the Minnesota DOT Snow and Ice Control guidebook from 2022, which includes some interesting information on cutting edges. Accessed online on February 29th 2024.

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/preliminary-investigations/ice-breaker-pi-a11y.pdf A report from CalTrans on testing conducted on several different cutting edges (and other ice removal tools from 2016. Accessed online on February 29th 2024.

https://www.iowadot.gov/research/pdf/tpf218.pdf A Clear Roads report from 2010 on multiple cutting edge blade systems, with testing conducted over three winters. Accessed online on February 29th 2024.

Links from Chapter 9: Snow Blowers

https://www.youtube.com/watch?v=gEH4Ke3xY-k (Long video showing snow removal in Montreal, including the use of snow blower to transfer plowed snow to a truck for hauling). Accessed online on February 29th 2024.

https://www.youtube.com/watch?v=2rufo38MsDY (Snow blower mounted on a front-end loader, showing operation of cutting blades and throwing of snow). Accessed online on February 29th 2024.

https://www.youtube.com/watch?v=EAKRsuh_AOU (Snow blowers cutting through heavy snow in Japan). Accessed online on February 29th 2024.

https://www.youtube.com/watch?v=fehNWKMceig (Several different snow blowers in operation). Accessed online on February 29th 2024.

https://vimeo.com/3539062 (Large snow blower in operation). Accessed online on February 29th 2024.

Links from Chapter 10: Ice Breakers

https://professionalsnowfightersassociation.org/2023/12/caltrans-report-on-mechanical-ice-breakers-2016/ (Caltrans report on ice breakers). Accessed online on February 29th 2024.

https://professionalsnowfightersassociation.org/2023/12/clear-roads-alternative-methods-for-deicing-2020/ (Clear Roads report that discusses the use of ice breakers among other technologies). Accessed online on February 29th 2024.

https://www.youtube.com/watch?v=XJiWOByFMiI (video on the Alaska DOTPF ice breaker). Accessed online on February 29th 2024.

https://ckpgtoday.ca/2021/01/14/new-icebreaker-demolishes-compact-ice-on-roadways/ (Story, including a video, of the Finnish-made ice breaking unit). Accessed online on February 29th 2024.

https://www.youtube.com/watch?v=LPgHKh1tpkw (Video of the MN DOT ice breaker in operation). Accessed online on February 29th 2024.

Links from Chapter 11: Climatic Concerns

https://professionalsnowfightersassociation.org/2023/12/clear-roads-mapping-weather-severity-zones-2012/ - a report on weather severity zones across the United States. Accessed online on February 29th 2024.

https://clearroads.org/project/14-08/ Weather severity maps for individual States. Accessed online on February 29th 2024.

https://clearroads.org/project/16-02/ A report on a tool that provides an index for a location that measures the severity of winter storms and winter seasons. This allows agencies to track how their winters (or their winter climates) are changing over time. Accessed online on February 29th 2024.

https://clearroads.org/project/16-05/ This report provides a tool that allows agencies to reconstruct winter weather events, with the intent that they might use that reconstruction to better describe the conditions they faced during the specific event. Accessed online on February 29th 2024.

https://link.springer.com/article/10.1007/s10584-020-02662-0 An article on how climate change has impacted winter maintenance in one particular city. Accessed online on February 29th 2024.

https://www.epa.gov/climateimpacts/climate-change-impacts-transportation EPA report on Climate Change Impacts on Transportation. Accessed online on February 29th 2024.

https://www.cbsnews.com/news/winter-getting-warmer/ A news report on changing winter weather. Accessed online on February 29th 2024.

https://journals.ametsoc.org/view/journals/wcas/9/3/wcas-d-16-0103_1.xml An article on planning winter road maintenance in the context of climate change. Accessed online on February 29th 2024.

Links from Chapter 12: Constraints Related to Geometry

https://professionalsnowfightersassociation.org/2023/12/clear-roads-manual-of-best-practices-and-techniques-for-clearing-intersection-layouts/ This is a manual on best practices for clearing various intersection geometries. Accessed online on February 29th 2024.

https://professionalsnowfightersassociation.org/2023/12/clear-roads-reference-cards-for-intersection-and-interchange-clearing-and-instructions-2018/ This is a series of reference cards with information on various exchange geometries that provides methods of plowing those intersections for operators. Accessed online on February 29th 2024.

Links from Chapter 12: Constraints Related to Traffic

https://www.wric.com/news/virginia-news/review-released-of-snowstorm-that-stranded-drivers-on-virginia-i-95-spanning-2-day-period/ media story on multi-day closure of I-95 in Virginia. Accessed online on February 29th 2024.

https://www.sciencedirect.com/science/article/abs/pii/S0001457521004796 a research paper discussing the relationship between maintenance operations, weather variables, surface condition, and traffic safety. Accessed online on February 29th 2024.

https://www.sacbee.com/news/traffic/article272593060.html a media report on winter storm related closures in February 2023. Accessed online on February 29th 2024.

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