Measuring the Efficiencies of Tow Plows and Wing Plows

Task 9: Final Report

FINAL REPORT

Prepared by:

Duane Bennett

Dr. Ty A. Lasky

Advanced Highway Maintenance and Construction Technology Research Center

Department of Mechanical and Aerospace Engineering

University of California at Davis

November 17, 2021

Published by:

Minnesota Department of Transportation

Research Services & Library

395 John Ireland Boulevard, MS 330

St. Paul, Minnesota 55155-1899

Acknowledgments

The authors thank the Clear Roads national research consortium for funding the work. The authors also thank Greg Waidley of CTC Associates LLC for his management and guidance on this effort. The authors would also like to thank the project subcommittee members along with member DOT personnel who tested the tools developed herein.

Table of Contents

List of Abbreviations

Abbreviation	Definition
AHMCT	Advanced Highway Maintenance and Construction Technology Research Center
CR	Clear Roads
DOT	Department of Transportation
DST	Decision Support Tool
MnDOT	Minnesota Department of Transportation
UCD	University of California, Davis

Executive Summary

Measuring the Efficiencies of Tow Plows and Wing Plows is a Clear Roads (CR) consortium Department of Transportation (DOT) pooled fund research project. This research is being performed by the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center at the University of California, Davis. This final report summarizes the information gathered in the following research tasks:

- Task 1: Literature and Product Review
- Task 2: Survey of Practice
- Task 3: Recommendations and Test Plan (Roadway Types/Geometries)
- Task 4: Simulations (Roadway Types/Geometries)
- Task 5: Peer Review of Simulation Results
- Task 6: Methodology for Efficiency Analysis
- Task 7: Decision Support Tool
- Task 8: Best Practices Guide
- Task 10: Decision Support Tool User's Guide

Because the Decision Support Tool (Task 7) and Best Practices Guide (Task 8) are the main deliverables of this project and the prior tasks have been documented in corresponding interim or summary reports, this final report is brief, focusing on documenting the methodology for creating those deliverables. AHMCT is also preparing a final closeout webinar and a PowerPoint™ file to support presentations at conferences or national and regional meetings by Clear Roads members regarding the findings and recommendations resulting from this project.

Task 1 and Task 2 reviewed literature, products, and surveys from participating DOT members. Task 3 developed recommendations and a test plan for the research effort. Task 4 began core tool development efforts, yielding a Microsoft Excel™/VBA tool to support simulation of cost efficiencies for varying allocations of plow types and road configurations. This tool was presented to the CR panel members who provided their review via teleconferences to AHMCT in Task 5. Task 6 yielded metrics to expand the simulation tool of Task 4 into the Decision Support Tool (DST) developed in Task 7. The DST, the primary product of this research, expands upon the plow efficiency methodology developed and reviewed by the CR subcommittee in the simulation and other preceding tasks, especially Task 6. The DST provides DOTs with an innovative method for quantifying plow configuration efficiencies and true costs throughout the life cycle of the equipment. These two cost analyses run together utilizing a common set of plow type and cost data in an Excel application. The DST output assists DOTs in calculating a return on investment of the designated plow types based on their state-specific costs and plow configurations. The DST incorporates modifications based on suggestions made by the subcommittee reviewers in Task 5. Task 8 provides background information on tow and wing plows, operational considerations of the target plow configurations, and most importantly, a guide to the use of the DST. Task 10, Decision Support Tool User's Guide, was added to the scope at the request of the Clear Roads subcommittee. The intent was detailed documentation on how to use the DST.

Overview

Problem

The fundamental tool used by DOTs nationwide to clear snow build-up on highways is a snowplow blade attached to a heavy-duty dump truck. The plow is most commonly mounted to the front of the truck, but underbody and even rear-mount plows are also used. The clearing width of these basic plows when angled is constrained by the legal width restriction for vehicles driving on the highway. Extending the clearing width of a plow truck is the obvious method to increase the efficiency and reduce the cost of highway snow clearing operations. A wide range of plow attachments have been developed that extend well beyond the legal width limit while operating in the plowing work zone and retract to legal width limits when the vehicle is out of the work zone. These extendable plow attachments add significant system cost and weight and further complicate the operation of the plow truck. Therefore a determination must be made whether the additional clearing capability justifies the costs of adding extendable plows to a standard plow truck, and, if so, what is the most appropriate attachment for the specific application. In the current research, the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center developed a Decision Support Tool (DST) and corresponding Best Practices Guide for snow-clearing DOTs to determine if, when, and where DOTs should procure and use more advanced variable-width plows.

Objectives

The objective of this research was to develop a guide for assessing the costs and benefits of investing in the addition of advanced plowing products to DOT plow truck configurations. This project had two primary goals. First, the research assessed the efficiency benefit of variable plow width equipment with respect to lane clearing capabilities for typical highway configurations. Second, this research developed tools for DOT decision-making and procurement, including a Decisions Support Tool (DST) and a Best Practices Guide, which will be helpful in procurement decisions and use of such plows. The DST and Best Practices Guide are the main deliverables of this project. These tools will support DOT procurement and operational planning with respect to the designated plow types. These tools will also assist in identifying the best road areas and geometries for deployment and in analyzing cost of ownership and return on investment.

Scope

There are a wide array of innovative variable-width commercially-available plow products. This research applies to most of these products, but attention was focused on the effectiveness of six specific variable plow width configurations suggested by the Clear Roads (CR) project committee:

(1) Conventional-width front (head or underbody) plows (base case for comparison).

(2) Front plow with a right- or left-side wing plow.

(3) Single-direction tow plow.

(4) Bidirectional tow plow (assessing both right- and left-side deployments as well as operational efficiencies gained from the equipment's flexibility).

(5) Single-direction tow plow combined with a wing plow.

(6) Telescopic head plow.

The data sources used in this report, Best Practices Guide, and DST were based on a literature review, committee input, DOT survey, and product manufacturer recommendations. The DST is DOT-specific, interactive, and input-dependent for improved accuracy. The data relates to roadway classifications and geometries, operational considerations, and measures of efficiency including level of service and cost. The primary objective in the analysis was to optimize single-pass lane clearing capability.

Background

CR member DOTs, with Minnesota DOT (MnDOT) as the lead, are interested in examining the benefit/cost relationship of using advanced snowplows vs. the baseline standard front plow. The current research investigated this efficiency, including lane-clearing capabilities vs. equipment costs. While more expensive than conventional front (head) plows alone, the addition of telescoping plow, wing plow, and tow plow truck accessories allows more snow to be cleared for each pass, potentially providing an overall reduction in operating costs, better labor and equipment allocation, and increased level of service. There is presently an abundance of innovative commercially available products designed specifically to extend the lane-clearing capability of a conventional DOT plow truck. Each of these products has application-specific operational advantages and disadvantages. When DOTs select which plow attachments to deploy, they have a wide range of unique parameters to consider. Since the marketplace for snowplow products is expanding rather than converging on a small set of successful designs, a more sophisticated method of identifying the most efficient and appropriate plow equipment designs is essential for the foreseeable future.

Research Methodology

This research moved beyond current theoretical understanding of tow plow and wing plow efficiencies by gathering information on their efficiency in real-world application. A systematic approach was developed which characterizes the utility of advanced extendable plow equipment. The approach focused on the lane clearing capabilities of plow width products and not on the comparative effectiveness of the wide array of available products. The snow state DOTs include many different climate regions with distinct road conditions. Individual plow products and configurations are optimized based on snow/ice conditions, which vary widely depending on regional climate conditions. Accordingly, the plow performance and efficiency varies dramatically depending on the application. Examination based on a broad overall average efficiency rating, which ignores pavement and snow conditions, is not necessarily useful. Since the fundamental requirement is that a plow has to cover the roadway before the efficiency of that plow can be considered, examining the best means of covering the roadway with plows is the most important metric. Once the plow coverage has been optimized, specific performance enhancing countermeasures, such as blade type, plowing speed, blade down-pressure, and moldboard benching design can be augmented to meet specific regional requisites. State-specific issues like these could be examined in future research and surveys of DOT winter maintenance practitioners in multiple states. The current research focused on lane clearing capability based on analysis and modeling. The developed model was incorporated into a spreadsheet tool, the DST, which can assist in selecting which type of plowing equipment to deploy.

Report Structure

Tasks 1-6 have been documented in prior interim reports or summary internal CR panel reports. These tasks will be briefly summarized herein. More detailed information will be provided for the DST (Task 7), the Best Practices Guide (Task 8), and the DST User's Guide (Task 10).

Task 1: Literature and Product Review

Overview

AHMCT performed a literature search of domestic and international in-progress and completed research that describes relevant aspects of the use of tow plows and wing plows.

In the associated product review, AHMCT assembled basic information about each of the plow configurations to be tested, including any relevant documentation available from vendors (product specifications, guidance for use, manufacturer videos, etc.). AHMCT also identified key data needed for Task 7, including average purchase price and other costs.

Methodology

This task involved a literature search using Google Scholar and similar publication database search tools. AHMCT also visited manufacturer web sites for product information. The literature review included the following top-level topics:

- Snowplow Route Optimization
- Snow Clearing Best Practices
- Snowplow Benefit/Cost
- Plow Extension Equipment

Prior Report

Duane Bennett and Ty Lasky, "Measuring the Efficiencies of Tow Plows and Wing Plows - Task 1: Literature and Product Review," interim report, Clear Roads project 19-03, June 29, 2020

Task 2: Survey of Practice

Overview

AHMCT performed a survey of practice as part of the current research project sponsored by the Clear Roads Pooled Fund. The purpose was to gather information on advanced snow plowing technologies and evaluation of their plowing efficiencies. The study examined the costs of operation of six specific plow types. The six plow types included a conventional single plow truck, wing plows, three types of tow plows, and a telescoping head plow. The goal was to identify successful snow clearing application techniques to incorporate into a Best Practices Guide and to support development of a DST. The DST is a key project deliverable that enables DOTs to analyze and calculate optimum plow configurations for specific plowing routes based on the most efficient application of the six plow types.

Methodology

AHMCT developed a 15-question survey, which was distributed on August 10, 2020. There were 15 responses, one of which was an internal test. The responders and quantities were:

- (1) Greg Waidley (CR project manager)
- (1) Montana
- (1) Pennsylvania
- (1) Delaware
- (4) Wyoming
- (1) Kansas
- (1) Nevada
- (3) Idaho
- (1) Connecticut

Prior Report

Duane Bennett and Ty Lasky, “Measuring the Efficiencies of Tow Plows and Wing Plows - Task 2: Survey of Practice,” interim report, Clear Roads project 19-03, September 1, 2020

Task 3: Recommendations and Test Plan (Roadway Types/Geometries)

Overview

A primary objective of the current research was to develop a Best Practices Guide for deploying tow plows and wing plows on specific roadway types and geometries. This study developed preliminary recommendations that identify the roadway types and geometries where the use of the six plow configurations could increase efficiencies beyond the use of a standard front plow and highlight limitations where these configurations may be less efficient. These preliminary recommendations were formed by surveying snow state DOTs then normalizing the responses to create a framework for the analytics developed to characterize plow efficiency metrics. The preliminary recommendations formed the basis for developing an analytical model for evaluating the efficiency of selected plow configurations on various roadway types and geometries.

Methodology

Based on the results from the literature search and the snow state DOT survey, preliminary recommendations and a test plan were developed for evaluating the efficiency of the six plow types when deployed of various roadway types and geometries. The literature search presented several state DOT empirical plowing efficiency reports based on seasonal plowing data. These reports are useful since they catalog how a successful agency fulfills their duty to maintain a passable highway system given available resources. However, these reports do not frame the data in any quantitative measure of efficiency that is comparable to alternative plowing methods or equipment, which is a goal of this study. Without a basis of systematic analysis, data from one case study is a poor predictor of any other slightly dissimilar operation. Consequently, the test plan for this study focused on the development of a systematic method of analyzing DOT snow plowing operational data and creating a framework for uniform quantitative plowing efficiency metrics. From this, agencies would be able to describe actual plowing routes of their choosing based on experience. Then, utilizing the analytical model, the agency can calculate a predicted plow cost efficiency for the prospective deployment of any combination of the six plow configurations of the agency's choosing. This enables an agency to evaluate cost efficiencies of various deployments of existing plow equipment and also investigate the potential performance of plow equipment not already in their fleet. In this way, an agency can determine what is the most cost efficient plow deployment configuration for a specific plowing route by calculating and comparing the cost of different plowing configurations.

One of the primary goals of this research was to develop preliminary recommendations of roadway types and geometries where the use of tow plows and wing plows is expected to increase and decrease plowing efficiencies. The test plan selected to best accomplish the evaluation plowing efficiencies for various plow types is based primarily on clearing a plow route consisting of various roadway geometries. One of the most consistent DOT survey responses received in this study was the importance of matching plowing equipment clearing width to roadway geometry. Clearing the width of the roadway is the primary concern, and plowing efficiency is a key dependent factor in any plowing operation. Deploying the minimum amount of resources to maintain the travel way is an essential best practice because it translates into more of the roadway being cleared with a given set of resources, thereby delivering a higher level of service. Good plowing practices may have less to do with how a DOT utilizes a particular plow type and more about constructing the most efficient snow clearing operations based on roadway geometry and using the six plow configurations. The test plan was to develop a methodology that provides a means for an agency to enter plowing routes consisting of various roadway geometries, plowing strategies, and plow types, after which the analytical model translates these parameters into a cost that can be compared to other deployment configurations to establish a quantitative measure of efficiency.

Prior Report

Duane Bennett and Ty Lasky, “Measuring the Efficiencies of Tow Plows and Wing Plows - Task 3: Recommendations and Test Plan,” interim report, Clear Roads project 19-03, November 19, 2020

Task 4: Simulations (Roadway Types/Geometries)

Overview

The goal of this task was to develop a computer simulation that calculates the plowing efficiency of the deployment of six plow types as related to clearing common roadway types and geometries. The measure of plow efficiency is based on the CR advisory subcommittee-approved comparative efficiency model described in detail in Task 3. The simulation tool enables DOT users to compare the capabilities of six plow configurations to clear a specific plow route ranked by their predicted operating costs (efficiency). The scope of this project is to develop a method of quantitatively comparing the efficiencies of the six designated plow types; the goal is not an expert system that recommends specifically how an agency should deploy plow equipment to clear snow from their highways. The subcommittee and the researchers agree the individual DOTs are best equipped to make such decisions.

Methodology

The simulation analysis is plow type and plow route-specific. A plow route, in general, consists of an innumerable amount of independent variables, but from the perspective of snow clearing efficiency, the user need only define a few key attributes. The plow route can be represented simply as a set of key roadway geometrics (Nodes) to be cleared, connected by uniform sections of roadway (Segments). The simulation algorithm solves for the necessary plow type(s) or a combination of plow types to clear the entire width of the route at its widest and calculates the corresponding operating cost. The plow operating cost is based on procurement and daily operating costs. The simulation tool links to data libraries that define the plow equipment performance and cost parameters for the six plow types as well as specific plow route roadway geometries. The libraries contain default data for all six plow types and important roadway geometries, all of which can be customized to correspond with DOT-specific parameters. The simulation tool was developed in Microsoft Excel™/VBA.

Prior Report

Duane Bennett and Ty Lasky, “Measuring the Efficiencies of Tow Plows and Wing Plows - Task 4: Simulation (Roadway Types/Geometrics),” plow efficiency simulation report, Clear Roads project 19-03, January 28, 2021

Task 5: Peer Review of Simulation Results

Overview

AHMCT provided a copy of the completed simulation tool program to the Clear Roads project subcommittee DOT members for review on March 4, 2021. AHMCT also conducted an online demonstration of the simulation program to instruct the subcommittee on how to use the program and to provide an overview of program's outputs. Several subcommittee DOT state representatives volunteered to serve as peer reviewers to confirm that the simulation results represent what would be expected to occur under real-world operating conditions. AHMCT provided individualized demonstration sessions to each of three requesting state DOT expert groups. AHMCT worked to resolve any concerns identified during these peer review sessions and incorporate acquired information into continued plow measurement of efficiency program development.

Methodology

The three individualized simulation tool demonstrations conducted with subcommittee DOTs included representatives from the Montana Department of Transportation (MDT), the Idaho Transportation Department (ITD), and the Rhode Island Department of Transportation (RIDOT). The Task 5 report includes a list of comments received that related directly to simulation program development. The list in this report is not the full set of generalized questions or comments discussed in the initial presentation and the individualized DOT demonstration sessions. The simulation tool demonstration review comments can generally be categorized as being related to simulation program use issues, simulation program output methodology, or the overall project objective expectations.

Prior Report

Duane Bennett and Ty Lasky, "Measuring the Efficiencies of Tow Plows and Wing Plows - Task 5: Peer Review of Simulation Results," plow efficiency simulation report for completed Tasks 5-7, Clear Roads project 19-03, April 1, 2021

Task 6: Methodology for Efficiency Analysis

Overview

The goal of this task was to expand the fundamental plow efficiency methodology to incorporate as many identified key operational considerations of plow efficiency as possible into the efficiency analysis. As defined in this study, plow efficiency is characterized as a comparison between the six designated plow types often referring to a standard 12-foot front plow as a baseline value. Comparing actual or hypothetical plowing efficiencies enables DOTs to easily visualize their most efficient strategies to deploy plow resources, which could then be translated into cost savings.

Methodology

Task 6 focused primarily on ensuring the four project designated plowing metrics were incorporated into the efficiency analysis:

1. Time
2. Level of service
3. Labor allocation/optimization
4. Width of pavement cleared in a single pass

Prior Report

Duane Bennett and Ty Lasky, “Measuring the Efficiencies of Tow Plows and Wing Plows - Task 6: Methodology for Efficiency Analysis,” plow efficiency simulation report for completed Tasks 5-7, Clear Roads project 19-03, April 1, 2021

Task 7: Decision Support Tool

Overview

The primary deliverable in Task 7 was the development of a Decision Support Tool (DST) in the form of an Excel program that calculates both plowing efficiencies based on real world plowing data and the life cycle costs of plow configurations. The DST expands upon the plow efficiency methodology developed and reviewed by the CR subcommittee in the simulation and other preceding tasks, especially Task 6. The DST provides DOTs with an innovative method of quantifying both plow configuration efficiencies and the true costs of plow configurations throughout the equipment life cycle. These two cost analyses run together using a common set of plow type and cost data in an Excel application. The DST output assists DOTs with calculating a return on investment of the designated plow types based on their state-specific costs and plow configurations. The DST also incorporates modifications based on suggestions made by the subcommittee reviewers in Task 5.

Methodology

The DST combines two algorithms: (1) the measure of plow efficiency algorithm that calculates cost efficiency by the plow configuration required to clear the full width of a user-specified plow route, and (2) the life cycle cost algorithm that evaluates the cost of plow types throughout the equipment life cycle.

The DST outputs two related calculations. The primary output is the measure of plow efficiency in relation to clearing a specific plow route. The secondary output calculates an Average Life Cycle cost categorized by plow type. These calculations share data contained in plow equipment cost and performance libraries, but some of the data in these libraries is specific to one calculation or the other. The User Interface (UI) home screen of the DST application displays the outputs and various key data values to provide a quick reference to the calculation basis.

The DST program uses the same methodology and algorithm as the Simulation Tool program. The extended capabilities of the DST consist primarily of program modifications that incorporate new requisite features from Tasks 5, 6, and 7. The program modifications requested in Task 5 comments included adding two additional wing plow configurations and adding a double wing plow type to the multi-directional plow configuration and cost data libraries. The primary program modification required by Task 6 was calculating plow route loop times. This change required the addition of average plow speed data in the plow performance data library. Together with the defined plow route combined segment length, the DST computes the average plow route loop time for the user-defined route. The primary program modifications required in Task 7 was the addition of a plow life cycle comparison calculation to the UI.

The plow life cycle comparison automatically estimates the average life cycle cost of each plow type for a user-customizable time period. The plow life cycle cost is useful when calculating a DOT's return on investment as to where to deploy the six designated plow types, and provides an estimate of any practicable efficiencies related to the investment. To make life cycle (LC) cost comparisons between plow types that may have different service lives, a common frame of reference needs to be established. The DST uses a time-of-use reference frame. This assumes the different plow types are used the same amount over the season, which will not typically be the case. However, generally when DOTs make comparison judgements to decide between purchasing and/or deploying one plow type over another, they often make that judgment in respect to its utility to clear the same plow route(s) assuming the service time interval. The DST program uses the same approach. The LC analysis is based on a common time-of-use reference frame represented as the total number of days used in a normalized equipment life. In this way, the calculated LC average cost values for each plow type can be directly compared.

Prior Report

Duane Bennett and Ty Lasky, “Measuring the Efficiencies of Tow Plows and Wing Plows - Task 7: Decision Support Tool,” plow efficiency simulation report for completed Tasks 5-7, Clear Roads project 19-03, April 1, 2021

Task 8: Best Practices Guide

This chapter provides a Best Practices Guide to aid state DOTs in determining where to best deploy various plows and configurations to optimize cost-effectiveness and other efficiencies. This Best Practices Guide, a key deliverable for this research, incorporates the DST from the previous chapter.

Background Information on the Use of Tow Plows and Wing Plows

Tow plows and wing plows are two of the six plow types designated in this study. All six can be characterized as accessories that are attached to conventional plow trucks as a means of increasing the plow truck's single-pass snow clearing width capability. These accessories are maintained in a retracted position within highway legal vehicle width requirements for transportation to and from work zones. While plowing, these accessory plow(s) can be hydraulically extended to widen the plow clearing width. The plow operator controls the width of plowing up to the maximum combined width of the plow configuration to account for factors such as snow water content and tire traction, and to avoid roadside obstructions. The plow accessories can be attached to the base plow truck in three different locations. The head plow on the front of the plow truck can be extended laterally (telescope, front wings), an accessory plow can be mounted to the side of the plow truck and swung out (side wing), or trailered and steered out laterally (tow plow). These plow accessories usually clear snow in a single direction. Some are bi-directional, enabling the plow operator to select the clearing direction. In some less common plowing operations, some plow accessories can even be configured to clear snow in both directions simultaneously.

Given the wide array of plow accessories readily available to DOTs, choosing how best to configure and deploy plow equipment requires a careful examination of many variables. These variables tend to fall into one of the following three main categories: plow equipment considerations, plow operational considerations, or roadway plowing considerations. Since all wing plow, tow plow, and any other plow accessories share in common a conventional plow truck, the truck forms the baseline of equipment configuration and performance characteristics. As such, in the following discussion of plow accessories, all equipment configuration and/or performance differences begin from a common basis of a conventional plow truck. Also it should be noted here that the choice of selecting and deploying plow equipment is heavily influenced by the capability of applying winter materials such as sand, salt, and deicers. This study focused solely on plow clearing efficiencies as the first consideration in the plow configuration and deployment metric, since clearing the roadway is the primary job to enable traffic to pass. The application of abrasives and deice treatments are secondary considerations and were not considered in the tool.

Plow Accessory Equipment Considerations

A common consideration when attaching a wing and/or tow plow accessory to a plow truck is accounting for the additional forces generated by pushing the additional snow. The increased forces act to slow the plow truck. In the specific case of asymmetric wing plows clearing snow generates a moment force that acts to spin the plow truck. The plow weight benefit/reduction relationship is complex, but on flat roadways the weight factor is significantly more influenced by abrasives application than plow weight alone. The plow truck standard requirements must be increased to account for installation and operation of any type of plow accessory. Common plow truck upgrades include increased engine power, increased engine cooling capacity, additional hydraulic power and circuits, visibility aids, frame stiffening, additional electrical wiring, additional lighting, and additional controls and data collection. The required plow truck upgrades add significant cost to the plow truck procurement. This additional cost, along with the benefit of the additional snow clearing width capability, is incorporated in the DST plow data libraries. The DST analysis uses this data on a per-plow-route basis, and the data can be used to estimate the time necessary to justify the additional expense of the plow truck upgrades.

Plow Accessory Operational Considerations

Life cycle costs of plow accessories by plow type can be quantified with the DST based on DOT-specific plow operating costs. The use of plow accessories to increase plow width clearing capabilities generates additional common plowing operational issues. Operator training and experience are much more essential when operating plow accessories. The plow driver must possess a higher level of skill to account for the additional plowing force, constantly monitor for obstructions including where the trailing type accessory plows are extended and headed. As the snow load on the plow surfaces increases, the plow operator retracts the accessory plow to maintain speed. The plow driver has an increased number of variables to control simultaneously, which requires a much higher skill level than operating a standard plow truck.

The additional plow accessories obviously contribute to an increase in seasonal and operational maintenance, consumables, and storage costs. However, viewed from the perspective of the required equivalent plow capacity of additional plow trucks and/or plow runs, the cost difference would be minimized. The harsh environment of highway snow plowing with cold temperatures, high salinity, and extreme wear shorten the service life of a standard plow truck. Plow accessories operate in this same environment, so the service life of plow accessories would typically be equivalent to that of a standard plow truck.

Plow Accessory Roadway Considerations

Deploying plows with accessories is an efficient means of providing the additional clearing capacity necessary to clear a route at its widest points and reducing the need for additional plow trucks. Examples of roadway widening points include intersections, lane increases, wide shoulders, and ramps. Plow accessories can also provide reserve clearing capacity to more cost-efficiently clear roadway geometries that involve departure lanes, such as ramps and merges. Since a roadway split requires a group of plows to separate to clear separate roadway sections, deploying reserve plow capacity with plow accessories is a more cost-efficient strategy than using additional standard plow trucks that are redundant over the remainder of the plow route. The primary objective of deploying plow trucks with plow accessories is to maximize clearing width of a plow truck, but another advantage is the support for variable clearing width. When clearing variable-width roadways with geometric features, the ability to retract large plow surfaces is a great benefit when navigating restricted road segments. As opposed to multiple standard plow trucks that need to queue-up to pass choke points, retractable plow accessories can fold up, and the plow trucks can pass through without adding to traffic congestion. Common choke points include roundabouts, lane reductions, and structures.

Specific Plow Type Considerations

The six plow types, together with the addition of a double wing plow type, can be logically grouped into four plow accessory configurations with similar attributes. Each of the four configurations has advantages and disadvantages related to cost, application, route specifics, and operational requirements. The following are generalized best practices that can be taken into account when making plow type comparisons.

Wing Plow-Specific Considerations

Wing plows are moldboard attachments attached to a host plow truck via a swing mounting. Wing plows are mounted either to the side or front of the host plow truck.

- Wing plows can be used on single and multi-lane highways.
- Wing plows are the most basic and least expensive plow accessory type.
- Wing plows are less useful in heavy snow due to the inherent snow force moment that acts to spin the plow truck.
- For side-mounted wing plows, the plow operator has limited visibility of the wing plow moldboard, especially in white-out conditions.

Telescopic Head Plow-Specific Considerations

Telescopic plows are head plows that consist of several nested plow moldboard segments that can be hydraulically extended laterally to form an exceptionally wide telescopic moldboard. Telescopic head plows are a relatively new and innovative plow type with limited DOT field deployment experience.

- The telescopic plow can be purchased from the manufacturer for a variety of clearing widths. The widest model can clear two full lane widths in a single pass.
- The telescopic plow is mounted in front of the plow truck providing a direct line of sight for the plow operator.

Tow Plow-Specific Considerations

Tow plows are typically used on relativity flat multi-lane roadways. The following describes the best features and limitations of tow plows.

- Tow plows can be configured with wider head plows to clear up to two full lanes in a single pass.
- Tow plows are adept at plowing heavy snow loads. Due to the rotational joint (hitch) connection to the plow truck and steep rake angle of the tow plow, heavy snow loading does not fully transfer to the conventional host plow truck.
- Tow plows are well adapted for snow clearing applications that require large amounts of granular or brine spreading.
- Tow plows are highly configurable by the manufacturer.
- Tow plow trailer models can be purchased with left, right, or bi-directional clearing capabilities.
- A tow plow can be purchased configured for granular spreading with one or two hoppers of various sizes. The brine version tow plow can be purchased with one or two brine tanks of various sizes or with a combination of granular hopper and brine tank for pre-wet applications.
- The tow plow trailer is a fleet item that has limited potential for non-winter use.
- Tow plows, when connected to the host plow truck, are much longer than any other plow configuration which often requires special equipment storage facilities to be parked inside during snowstorms.
- Tow plows performance diminishes when plowing up steep grades due to their relatively large weight-to-plow surface ratio.
- The plow operator has limited visibility of the tow plow moldboard, especially in white-out conditions.

Multi-plow-Specific Considerations

A multi-plow can plow in multiple directions at once. The combination of right-clearing tow plow with left-clearing wing plow mounted to the host plow truck was one of the project-designated plow types. By request of one of the CR subcommittee member DOTs, a head plow with double wings was added to the DST program and the multi-plow type was created to consolidate both multiple direction plow configurations into the existing designated plow type category. The double wing plow is unique in that it can be configured with a bi-directional or multi-directional head plow. In the case of the bi-directional head plow configuration two separate configurations must be defined and only one configuration of the plow can be entered in the allocation table at a time.

- The double wing plow trucks can be configured to clear two full lane widths in a single pass while clearing in two directions.

- The tow plow with wing configuration can clear up to two and a half lanes in a single pass while clearing in two directions.
- Multi-direction plows can only plow their full width on separated roadways with large shoulders on both sides of the roadway.
- Plow operators cannot monitor both wing plows at the same time. The driver will need to continuously shift focus between left, right, and center while plowing.
- Multi-plows have limited visibility of the wing plow moldboards, which increases impact risk in congested metropolitan areas.

Best Practices for Where and How to Use Different Plow Configurations to Achieve the Greatest Efficiencies

As the state highway duty plow truck equipment market continues to expand with manufacturers commercializing new and innovative plow designs and features, the DOT job of deciding which plows to purchase, configure, and deploy becomes more complex. DOT best practices are a good starting point for simplifying these complex decisions and provide some consistency. Best practices are usually a record of how methods succeeded or failed in current or past experience. With the continuous introduction of innovative, new plow equipment functionality and capabilities, relying on historical experiences alone as a guide can delay the adoption of new methods that could provide near-term increases in efficiency and level of service. Therefore, the Best Practices Guide in this study seeks to assist DOTs in their examination of new plowing types and assist with the analysis of increasing the efficiency of existing plowing operations.

The DST developed in Task 7 enables DOTs to quantitatively compare cost and efficiency analyses based on their actual cost and performance data. The DST standardizes data sets to reduce variables and provide accurate quantitative comparisons. These comparisons establish best practices for plow type procurement, and assist with plow equipment deployment decisions. The DST can be used in different ways depending on the user’s known data, key variables, and, most importantly, a firm understanding of the ultimate goal. Two primary analyses are plow efficiency comparison and plow life cycle cost comparison. As previously discussed, the DST focuses on comparative analysis as opposed to specific cost and performance calculations which are dissimilar to be accurately compared across different plow types. Comparative analysis allows DOTs to visualize cost and performance trends across a wide spectrum of plow types and configurations at specific geometric locations. The comparative analysis is directly compatible with purchase justification for purchasing additional plow equipment, unique plow equipment, and plow equipment distribution.

Best Practices - Plow Efficiency

The plow efficiency comparison analysis can be used in various ways depending on the outcome the user is seeking. The plow efficiency calculation algorithm uses plow equipment cost, performance, and plow route data to quantify plow efficiencies. To use the DST as a best practices predictor for plow type configuration, the user creates a specific plow route as a fixed basis to conduct plow type efficiency comparisons. The best practice is the most cost efficient plow type configuration or combination of plows, giving an indication of the best choice for deployment. Other factors such as surface treatments are involved in the actual selection process. To account for these ancillary DOT factors, the DST calculates all combinations of the plow configurations that provide the needed plow width, and ranks the combinations by ascending cost. The user can use the cost ranking to move down the list and select a plow or plow group that may be slightly less cost-efficient but better meets additional DOT-specific deployment or procedure criteria.

To use the DST as a best practices tool to predict where best to deploy a specific plow type, the user allocates a fixed specific plow type configuration or group of plows, and then runs multiple calculations with different plow routes to determine which roadway geometrics result with the allocated plow(s) being calculated as the most cost-efficient selection(s). Once again, the user can consult the full cost ranking list to take into account DOT-specific ancillary deployment or procedure factors when conducting this analysis to qualify selections. Other best practice factors, such as route time, labor allocation, clearing direction, and various maintenance costs, can similarly be quantified for comparison analysis. The DST provides an additional best practices resource for DOTs to consult when faced with complex decisions regarding which plows to purchase, configure, and deploy. The DST has many uses to help DOTs visualize complex decisions by creating quantitative comparisons to help simplify complex choices.

Best Practices - Plow Life Cycle

A plow life cycle estimate on its own has little significance. Plow life cycle estimates only become meaningful when compared to the life cycle estimates of other plows. Therefore, a fundamental best practice for plow life cycle cost analysis must calculate life cycle cost estimates on a common basis. Different plow types and configurations of plow types have varying service lives and use profiles, so plow cost data cannot be directly compared accurately. Instead, a common frame of reference must be established and the plow type configuration data must be averaged by plow types. Only then can the plow types cost data be normalized to the life cycle frame of reference. This allows meaningful comparison between calculated plow type life cycle estimates. The life cycle analysis is based solely on equipment costs, plow operating costs, plow usage, and plow service life. Unlike the efficiency analysis, the life cycle cost analysis is not directly related to plow route or plow performance. A more detailed explanation of the life cycle cost analysis was presented in the Task 7 report.

The common best practice method for justifying plow procurement is to select a plow type and configuration that meets the needs of the required plowing application. If multiple plows can perform the same described task, then cost typically becomes the leading deciding factor. Low bid procurement favors the plow with the lower initial procurement price, but the cost of the plow over its service life is a better true cost. The DST life cycle cost program can estimate the life cycle costs for all six of the designated plow types and allows for DOT-customized cost and performance data to generate valid estimates. To run a life cycle analysis, the user need only enter a common plow deployment duration. The DST program then calculates life cycle estimates for the plow types defined in the plow data libraries. An explanation of the life cycle cost methodology is presented in detail in the Task 7 report. The DST life cycle comparison values are also useful for evaluating a return on investment for plow types and identifying efficiencies a DOT can expect from the related investment.

Task 10: Decision Support Tool User's Guide

Overview

As the DST was developed and presented to the Clear Roads subcommittee, it became clear that a detailed user's guide would be essential for successful widespread deployment of the DST to multiple Clear Roads DOTs. Consequently, the project subcommittee added a Task 10 to the project scope that creates a DST user guide. The intent of the user's guide is to enable a DOT user to easily understand the utility of the DST and provide a step by step example of how to utilize the DST to analyze the plowing efficiencies of their specific plowing operations. The Task 10 user's guide consists of an interactive PowerPoint presentation that concisely describes the plow efficiency measurement algorithm, the use of the DST, and how the DST can be utilized to benefit DOT plowing operations. A detailed examination of the DST is available in the Task 7 report: Duane Bennett and Ty Lasky, "Measuring the Efficiencies of Tow Plows and Wing Plows - Task 7: Decision Support Tool," plow efficiency simulation report for completed Tasks 5-7, Clear Roads project 19-03, April 1, 2021.

Methodology

The Task 10 DST user's guide was developed to enable a DOT user with highway plowing operations knowledge and access to a specific DOT's plowing operational cost information to conduct various plow route plowing efficiency analyses. The user's guide is a PowerPoint application that uses an interactive multimedia format with action buttons that enables a user to select the areas and depth of information they are interested in viewing. The guide provides a brief overview of the DST, including motivation and benefits. The core of the guide provides text-based description and, where appropriate, accompanying detail videos, for the following aspects of the DST:

- Installation guide
- Adding or revising plow configurations*
- Entering cost information*
- Creating a route*
- Executing a plow route analysis*

AHMCT developed an outline of the user's guide, as well as scripts for the anticipated video segments needed in the user's guide. This draft material was reviewed by the subcommittee, and their feedback was incorporated into the final approach for the user's guide. The subcommittee provided feedback on the draft user's guide. Following this, the subcommittee performed testing of the user's guide efficacy by providing it to uninitiated DOT staff to see if they could install and use the DST. With the resulting feedback from the subcommittee, AHMCT then finalized the user's guide.

Prior Report

Duane Bennett and Ty Lasky, “Measuring the Efficiencies of Tow Plows and Wing Plows - Decision Support Tool User’s Guide,” detailed user’s guide for completed Task 10, Clear Roads project 19-03, December 31, 2021

Conclusions and Future Research

The fundamental objective of this research was to develop a quantitative measure of plowing efficiency by plow type. A literature search of related research revealed several studies that evaluated a specific DOT's current winter highway maintenance operations. However, references could not be found that attempted to define either a comprehensive measure of plowing efficiency by plow type or establish a methodology for evaluating plowing efficiencies by plow type. Therefore, this research proceeded by creating a suitable measure of plow efficiency by plow type and developing an innovative methodology to quantify the plow efficiencies of dissimilar plow types. The methodology needed a common basis to construct accurate comparisons. Comparisons and trade-offs are key factors to consider when making complex multi-variable decisions, such as deciding which plow type to procure and deploy.

The plow efficiency methodology developed in this study was based on DOT expert subcommittee input. Through a series of program demonstrations, the DOT experts helped to guide the iteration of the methodology into an Excel program that automates the efficiency calculation based on DOT-customizable plow cost and performance data. The final result is the DST, which produces a quantitative comparative measure of plow efficiency for the six designated plow types and a comparative life cycle cost calculation for the four distinct plow types. The DST accuracy is founded on the principles of customizable plow data and normalized comparisons, yielding genuine results that provide a high level of credibility to justify DOT-specific procurement and deployment decisions. A companion Best Practices Guide was also created that describes potential uses of the DST by DOTs to help guide their decision process to enhance their plowing operational efficiencies. When used together, these tools can assist DOTs in qualitatively and quantitatively identifying best road areas and geometries for deployment of tow plows and wing plows and in analyzing their return on investment. Finally, the DST User's Guide will facilitate successful widespread deployment of the DST to multiple Clear Roads DOTs.

Future development of the DST would benefit by the inclusion of roadway surface treatments into the plow efficiency methodology. The application of granular and deice roadway treatments are key factors that DOTs consider when configuring and deploying plow equipment. Some plow types include the capability of transporting and spreading surface treatments, some do not. Vehicle weight, traction, and policies like diminishing loads can guide selection of which plow types to include in the DST efficiency analysis. The scope of this research did not include this key variable. In future work, the DST program could be extended to include a surface treatment metric.