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Winter maintenance fleet savings from implementing specialty winter maintenance equipment

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ABSTRACT

This research analyzed the probability of snow plow trucks exceeding a 120-minute cycle time and the benefit-to-cost ratio of implementing one specialty hopper and one specialty plow compared to standard trucks. Route optimization analysis was conducted for the Ohio Department of Transportation's winter maintenance routes to determine the number of lane miles maintained by each type of truck. The failure probability was evaluated in two ways: 1) the garage is considered to fail if any one truck exceeds the cycle time and 2) the garage is considered to fail if the summation of the time used by all the trucks in the garage exceeds the total cycle time. Both failure probabilities increase as the number of trucks in a garage increases. However, the specialty equipment has a lower failure probability than the standard plow truck, which results in greater service provided to the motoring public. Benefit–cost analysis was conducted to determine the payback period for specialty equipment. The initial cost of the purchase of the equipment is considered to occur in the first year followed by the lower operational costs for the specialty equipment thereafter. To generalize the results, the analysis area consisting of Ohio was divided into three regions based on weather. For Regions I and II, the specialty hopper will be paid off by the second winter season in which it is utilized, while for Region III, it will be the third winter season. For the specialty plow, the expected pay off time is year 6, year 18, and year 25 for Regions I, II, and III, respectively.

1. Introduction

With the rising costs of winter maintenance, agencies are evaluating the use of specialty equipment, optimizing routes, and developing innovative methods to analyze the benefits of equipment and materials by taking advantage of the increased prevalence of Global Positioning System and Automatic Vehicle Location (GPS/AVL) technology. The general goal of agencies is to increase the efficiency of maintenance operations while decreasing their overall costs. As a result of the increased demands on the transportation system and the increased winter maintenance costs, much research has focused on improving the efficiency of winter maintenance fleets.

Some research has focused on assessing the benefits and level of service provided by winter maintenance operations. A recent study assessed the benefits and costs of using weather information for winter road maintenance and found that winter maintenance costs could be reduced by improving the accuracy of weather prediction information (Ye et al., 2009). Researchers have developed speed recovery durations for the length of time required to return vehicle speeds to a baseline condition after a winter event (Lee and Ran, 2004). Carmichael et al. (2004) developed a weather index to estimate winter severity, and when combined with measures of transportation department infrastructure, the authors estimated the expenses that correlated with reported costs more accurately than other models (Carmichael et al., 2004).

Recently, many agencies, including the Ohio Department of Transportation (ODOT), have been evaluating specialty equipment such as specialty hoppers capable of spreading deicing material in up to three lanes and specialty plows capable of plowing two lanes in a single pass (Schneider et al., 2013, 2014). The specialty hopper, shown in Fig. 1 (left), reduces salt usage but increases the amount of liquid used. Specifically, salt is crushed into fine grains and liquid is added to reduce bounce and scatter compared to rock salt. Additionally, the specialty hopper tested by ODOT was capable of spreading material directly behind a truck, on either side, or on both sides of it. This allows the specialty hopper to treat up to three lanes in a single pass. The specialty plow, shown in Fig. 1 (right), is a tow behind trailer that can swing out a plow in a second lane in a single pass. The trailer is also equipped to apply dry and liquid material so that two lanes may be plowed and treated simultaneously.

While the material reduction and efficiency benefits of both types of specialty equipment are apparent, the impacts specialty equipment have on cycle times for an entire fleet and the benefit-to-cost ratio

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Fig. 1. Specialty hopper (left) and specialty plow (right).

need to be evaluated quantitatively. Determining where to implement specialty equipment is a difficult task faced by winter maintenance personnel. This research will aid with determining the extent of increase in efficiency and cost savings of specialty winter maintenance equipment. It evaluates the efficiency benefits and cost increases of implementing specialty winter maintenance equipment through reliability analysis and robust cost estimation. Essentially this research determines the savings of a winter maintenance fleet associated with implementing specialty winter maintenance equipment by evaluating the number of lane miles maintained obtained from route optimization, the probability of exceeding a given cycle time through reliability analysis, and benefit–cost analysis.

When implementing specialty equipment to increase efficiency in winter maintenance operations, the routes maintained should be evaluated before and after the implementation. This is because the specialty equipment is capable of maintaining a larger number of lane miles than the standard plow truck. Determining the increase in lane miles is necessary to estimate the cost savings of the specialty equipment. To determine the routes, one can use snow plow route optimization, which has become a topic of interest for many agencies in recent years. A common method for optimizing routes is known as arc routing, where a network of routes is divided into areas with similar service times (Marks and Stricker, 1971; Bodin and Levy, 1991; Salazar-Aguilar et al., 2012). Another common route optimization method is known as the traveling salesperson problem where a road network is divided into arcs and nodes, and the input parameters include the types of vehicles, roadway attributes, and cost functions (such as travel time and distance) (Gupta et al., 2011). Perrier et al. (2006a,b, 2007a,b) conducted a comprehensive four-part survey of route optimization methods and algorithms for vehicle routing, fleet sizing, and depot locations. Several researchers (Golbaharan, 2001; Razmara, 2004; Sochor and Yu, 2004) have evaluated snow plow routing problems with multiple depots and time windows in which the problem routes snow plows from a start depot, covers every route once, and returns to the same depot, or essentially simulating one cycle of a plow truck.

ODOT sets a cycle time of 120 min for every truck in its fleet. This means that when a vehicle leaves the garage, it should be able to maintain the assigned route and return to the garage within 2 h. Having a cycle time of 2 h allows ODOT to know that a road segment will be treated roughly every 2 h during a snow event. The principle of setting a cycle time is to diminish the impact of snowfall on traffic such as vehicle delay. One of the methods to quantitatively assess the benefits of incorporating specialty equipment in the maintenance fleet is to evaluate the probability of exceeding a certain cycle time; which is known as failure probability. Specifically, the probability of one truck exceeding a cycle time as a component failure can be expressed in terms of two types of system failure: parallel system failure and series system failure. Particularly, we will compare four cases: no implementation of specialty equipment, implementation of one specialty hopper, implementation of one specialty plow, and implementation of one specialty hopper and plow. In addition, increase in efficiency that specialty equipment has on a fleet of vehicles is determined through benefit–cost analysis, where the equipment purchase costs and the operation costs are considered. Since the purchase price of specialty equipment is higher than standard equipment, benefit-to-cost ratio curves are developed and the break-even time when the extra initial cost is paid off due to lower operational costs is determined.

1.1. Research objective

With the rising costs of winter maintenance and the availability of specialty equipment, this research aimed to quantify the benefits associated with adding a specialty hopper or specialty plow to a fleet of winter maintenance vehicles. The benefits to the fleet are a result of the reduced treatment time and total lane miles traveled by the fleet when including specialty equipment. Such benefits were quantified based on lane mile changes from route optimization, the probability of exceeding a certain cycle time determined through reliability analysis with the use of data obtained from route optimization and ODOT operations, and the calculated benefit-to-cost ratio considering uncertainties. The failure probability and benefit–cost analysis will aid agencies in determining whether or not they should implement specialty equipment.

1.2. Study area

This study was conducted for three regions within the state of Ohio based on the amount of snowfall received and the number of snowfall events that occur annually. The average annual snowfall in the state of Ohio is shown in Fig. 2, where the black thick boarders define regions of Ohio based on snowfall. Three regions are defined based on the total annual snowfall. Region I includes northeast Ohio; Region II includes northwest and central Ohio; and Region III includes southern Ohio. Fig. 3 shows the number of snowfall events each winter for these three regions. For the purposes of this study, snowfall events are classified as 1) light snowfall (<2 in. for the storm), 2) moderate snowfall (between 2 and 6 in. for the storm), and 3) heavy snowfall (≥6 in. for the storm).

The average and standard deviation for the number of events in each region were determined by using 56 National Oceanic and Atmospheric Administration weather stations in Ohio. Snow storms were identified when a recordable amount of snowfall was detected by a sensor station, and the end of an event was identified when there were at least two consecutive hours without snowfall. The weather data used are from 2009 to 2014 in most cases; however, some stations reported data beginning in 2010. The number of events for each severity decreases as the total annual snowfall decreases from region to region as shown in Fig. 3, providing further justification for categorizing the ODOT districts into three regions.

2. Materials and methods

2.1. Changes in lane miles maintained

To evaluate the benefits of implementing specialty equipment on the winter maintenance fleet, one can examine the changes in snow