Optimization of Salt Storage for County Garage Facilities

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16. Abstract

The Ohio Department of Transportation (ODOT) has identified two issues with salt storage at county garage facilities within Ohio: 1) an inability to maximize salt storage in dome structures and 2) an inability to maintain accurate salt inventory using visual estimates. To realize greater efficiency at salt dome facilities, research was performed to identify the state of the practice in salt storage, and evaluate modifications to ODOTs existing salt storage practices. At the conclusion of the first phase of the research, a diesel conveyor with 6-ton hopper was selected as the best option for maximizing salt storage in dome structures, while an acoustic scanning system was selected as the best option for improving salt inventory. During the second phase of the research, the diesel conveyor with 6-ton hopper and acoustic scanner system were evaluated through field trials over a four month period. The diesel conveyor was evaluated through comparison with a PTO conveyor configured in four different loading setups. The results indicate that the diesel conveyor outperformed the PTO conveyor setups when loading rate, cost, and the availability of garage resources are considered. In order to evaluate the acoustic scanner system, ground-based laser scanning was performed and the resulting volumes were compared. In addition, the daily volume of salt in the dome based on ODOT records was compared with the scanner volumes over the duration of the data collection period. It was concluded that the acoustic scanner system should be used in combination with another inventory method, such as visual estimates, for daily salt inventory. Based on the results of the research, ODOT will benefit by having tangible solutions that once implemented, can increase efficiency and safety at salt dome facilities, ultimately saving ODOT time and money.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(°F-32)/9 or (°F-32)/1.8	Celsius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2 or psi	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8°C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2 or psi

* SI is the symbol for the International Symbol of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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1. Statement of the Problem

The Ohio Department of Transportation (ODOT) is composed of 12 districts serving 88 counties. It maintains 42,090 lane miles of interstate, US and State Route, at an annual cost of $149.5 million (2009 US dollars) [ODOT, 2011]. As of 2007, ODOT stored approximately 400,000 tons of deicing salt at 222 locations statewide; typical annual tons of salt used range from 300,000 to 550,000. ODOT uses various structures to store salt; barns, coverall buildings, salt domes (Figure 1), etc. Proper salt storage is a best management practice that protects the invested money in the product, as well as equipment, infrastructure, personnel and the environment.

Figure 1. Photo of a salt dome. Photo taken from [http://www.wonderquest.com/SaltCones.htm].

The Environmental Protection Agency (EPA) has stated that salt storage presents a potentially greater environmental threat than salts that have been applied to roadways during winter maintenance operations because of the concentrated runoff that can occur from improper storage practices [ODOT, 2012]. Ohio has identified several salt storage piles as sources of chloride contamination to public and private ground water supplies [Pignolet, 2012]. Once affected, treatment of water sources can be difficult and expensive.

Ohio currently has no rules specific to storage of salt, but does prohibit "unauthorized discharge of pollutants" into waterways, including runoff from salt storage [Ohio, 2012]. Brine created from rainfall passing through salt piles is considered industrial wastewater that is subject to permitting requirements. The permit requires stored salt to be properly covered and enclosed.

ODOT has identified two issues with salt storage at garage facilities within Ohio: 1) an inability to maximize salt storage in dome structures and 2) an inability to maintain accurate salt inventory using visual estimates. To realize greater efficiency at salt dome facilities, identifying the state of practice for salt storage by other State DOTs and equipment necessary to accomplish these tasks is needed. Consequently, research is required to evaluate salt domes, identify the state of the practice for salt storage, identify available options and useful equipment, perform a cost-benefit analysis, provide recommendations based on the identified options, and perform field evaluations of approved recommendations. By completing this research, ODOT will benefit by having tangible solutions that, once implemented, can increase efficiency and safety at salt dome facilities, ultimately saving ODOT time and money.

2. Objectives and Goals

The objectives of this research were to conduct an analysis of the salt storage practices utilized by ODOT to store road salt for winter maintenance operations, identify alternatives to improve salt storage, and evaluate select alternatives through field studies. The focus of the analysis was on the various salt loading methods and inventory process used by ODOT for storing salt in dome structures. The analysis was restricted to five salt domes located at five different county garages in Districts 2 and 12. In accomplishing the project objectives, the following series of analysis tasks were completed: (1) review of the literature to determine the state-of-the-practice in salt storage (2) survey of state DOTs in order to identify best practices in salt storage (3) perform a cost-benefit analysis and matrix of findings for each identified practice, (4) analyze ODOT salt storage practices, and (4) field studies to evaluate alternatives for improving ODOT salt storage practices. Finally, based on the information collected throughout the course of the project, recommendations on potential changes in practices and or onsite modifications were made.

As a result of these tasks, the overall goal of this project was met: to identify practices and onsite modifications that can improve salt storage at ODOT salt domes while (1) providing safer conditions for maintenance staff that need to push the salt into the dome with a loader, (2) promoting cost savings and using less staff, and (3) using environmentally friendly alternatives.

3. Phase I Research

3.1 Literature Review

3.1.1 Salt Storage Facilities

Many of the salt dome facilities used by ODOT were built over 20 years ago, and require annual maintenance that consumes time and money. In some instances, replacing older structures may be the most cost-effective solution [Barbour et al., 2007]. In other instances, providing long term fixes for identified issues can extend the life of existing infrastructure. Storage facilities at other DOTs are discussed in the following section.

The Michigan DOT (MDOT) stores deicing salt in rectangular barn type (high gambrel, or trussed) buildings. These are typically built on four to ten foot high wood or concrete walls that are designed to resist the salt and impacts from loaders. These buildings allow indoor delivery of salt [Washtenaw County Road Commission, 2013].

The Saskatchewan Department of Highways and Transportation mainly stores salt in high gambrel barns similar to Michigan DOT. They also utilize raised steel silos (140-tonne and 90-tonne) in some rural areas that allow trucks to drive under the silo and fill the truck without having to use a loader or any other equipment. A gravity feed chute is operated using the truck's hydraulic system. A third alternative being considered at the time of the cited report is a "salt hopper bin with a conveyor belt auger system to load trucks". A small number of domes are also used, but future buildings will be the high gambrel type and will not include any domes [Lasic, Z. and Gerbrandt, R., 2004].

Indiana DOT (INDOT) is replacing old salt storage facilities with Legacy Tension Fabric Buildings. The structure of steel and fabric is built on eight foot high concrete walls to ensure all salt is retained within the structure. Standard widths are 120 ft, but lengths depend on annual salt usage. Buildings also allow indoor salt delivery and have drive-through capability for loading salt into trucks, as well as a vehicle wash facility that recycles wash water for use in brine making [Government Engineering, 2010].

The New York DOT (NYSDOT) replaced 72 salt storage domes in 2006 after several domes collapsed. The domes were replaced with fabric-covered buildings similar to those used by Indiana DOT [Government Engineering, 2006].

Pennsylvania DOT has replaced all fabric buildings that were in use with wood-framed structures after several fabric buildings collapsed under heavy winds and snow loads. The manufacturer of the buildings used by PennDOT is no longer in business [Roads and Bridges, 2010].

Proper siting, design and operation of salt storage facilities can increase efficiencies and reduce or eliminate salt laden runoff. Sealed storage and loading pads can prevent migration of stored salt off site. Examples of sealed pads include asphalt or high quality concrete with entrained air and treated with a sealant [OWRC, 2013]. The pads can be sloped slightly (1-2%) so water drains away from the salt pile and can be curbed to prevent the water from draining off site.

3.1.2 Mitigating Moisture and Corrosion

While the salt domes utilized by ODOT provide coverage of the stored salt, many lack the necessary door closure or adequate working space, and salt has corroded the salt dome structure. Because of these issues extraordinary maintenance and clean-up are required at these facilities and health and safety issues have been identified [Barbour et al., 2007].

Orienting storage buildings with the door facing away from prevailing winds helps prevent precipitation from entering, hence, reducing or eliminating the loss of salt by dissolution from precipitation [Salt Institute, 2006].

Adding doors to facilities that are currently open on one end or have an open doorway greatly reduces or eliminates precipitation from entering the structure and dissolving salt inside. New Jersey "strongly recommends that all storage buildings have a door or other means of sealing the access way" from precipitation [NJDEP].

An inspection of the Lucas County Garage and Salt Depot identified the same issues brought to light by this request for proposal, and made the following recommendations on site improvements [Barbour et al., 2007]:

- Adding a protective barrier door to the salt domes – such as a heavy weight curtain made of plastic or nylon with parts made of corrosion resistant materials (Figure 2a). This was found to have an estimated payback period of 1 year.
- Epoxy coating or using Fiberglass Reinforced Plastic gussets to minimize corrosion.

Figure 2 provides two examples of doors used on salt domes.

Figure 2. Photo of a salt dome with a) added heavy weight curtain to act as a door [Barbour et al., 2007] and b) a sliding door built into the original design (Oak Forest, IL) [http://www.oak-forest.org/news/article.asp?article_id=280&print=y].

3.1.3 Options for Salt Storage

For storage buildings that do not accommodate delivery trucks to dump salt inside the building, the salt is typically dumped outside the door and moved inside using loaders. This is very inefficient and can contribute to the loss of salt and pollution of the surrounding environment. The amount of salt that can be stored is also reduced due to loaders not being able to fill the building to capacity.

Where a loader is used for salt storage, the size of the loader may influence the safety and efficiency of the storing process. For example, a large capacity loader will be able to load the salt faster than a small capacity loader because it will require fewer loads. However, larger loaders will have more difficulty entering, exiting, and maneuvering inside the dome. Also, a larger loader may have difficulty accessing all of the storage area inside the dome, which would limit how much of the dome could be utilized for salt storage. Two possible solutions would be to modify the structure of the dome to accommodate a large loader, or using a smaller loader. To maximize salt storage in salt domes, a conveyor rather than a loader may be a more efficient way to store salt.

A storage facility that accommodates salt to be delivered indoors, rather than being unloaded outside and moved into the building, helps keep the salt dry and reduces salt loss due to spillage. A study done by the University of Massachusetts found that indoor salt delivery reduced the amount of salt spilled from 0.3% to 0.06% [Ostendorf et. al, 2012].

Using conveyors or elevators can increase the capacity of buildings by piling the salt from the top rather than from the side as a loader does. A conveyor may also be a safer alternative to the loader as it does not require maintenance staff to be inside the dome during the storing process. However, providing access for a conveyor may require a structural modification to the dome opening. A picture of salt being loaded into a dome in Butler County using a conveyor is shown in Figure 3, and demonstrates the type of equipment that is currently being used at some sites in Ohio.

Enclosed conveyor systems, traditionally used by fertilizer plants, have been shown to work effectively at placing salt in salt domes, increase efficiency and reduce costs while aerating the salt, and eliminating all lumps and clumps [PWJ, 1990]. Enclosed conveyors are in use at salt storage facilities in Illinois, New York, and New Jersey [NJDEP]. The systems were also noted to reduce clean-up efforts and be corrosion resistant. In Illinois, augers have been used to "fill domes to their utmost capacity" [Teichmann, 1990]. The augers used are 68 to 75 feet long and 8 inches in diameter and load at a rate of up to two tons per minute.

Figure 3. Salt being loaded into a salt dome using a conveyor in Butler County (http://www.bceo.org).

3.1.4 Salt Loading for Dispensing

Selecting the appropriate loading option for salt dispensing is influenced by salt demand. For instance, sites with high demand will require a process where salt can be loaded into trucks at a faster rate than those sites with lower demand. The vast majority of DOTs use front end loaders to load salt into trucks to be spread onto the road, increasing the likelihood of salt spillage, which contributes to salt loss, potential pollution, and time and labor for cleaning up spilled salt. Figure 4 shows salt being loaded into a truck outside a dome in Stark County. Another option used by the Virginia DOT to reduce salt spillage is to load trucks using a conveyor system [Goldman, 1999].

Figure 4. Salt being loaded into a truck using a loader outside a salt dome in Stark County (http://www.cantonrep.com).

3.1.5 Environmental Aspects

Salt storage structures should be large enough to allow for easy movement of spreaders and delivery vehicles, to provide the environmental benefits of delivery, mixing and loading undercover [OWRC, 2013]. Good housekeeping during stockpiling, mixing, loading onto spreaders and off-loading of unused salt from spreaders can prevent loss of salt and contamination [OWRC, 2013]. All maintenance staff involved with salt handing should receive training on these practices. Salt delivery into existing structures is preferred [OWRC, 2013], and has been found to reduce spillage five-fold [Ostendorf et al., 2012]. Washing equipment following exposure to salt will greatly increase its service life [TAC 2003]. Vehicle wash water can be recycled on site and reused in brine making processes [TAC 2003]. Meegoda et al (2004) discussed collection, treatment and recycle of the runoff from salt storage and maintenance facilities via oil-grit separation, sand filtration and storage. Improving the management of salt through training, good housekeeping practices, and storing and handling all salt under cover while ensuring all material is presented as a Code of Practice as part of the TAC Environmental Management of Road Salts [TAC, 2005].

3.1.6 Miscellaneous

The Salt Storage Handbook [Salt Institute, 2006] provides a one-page checklist for "safety features, proper access, legality, tidiness, economics and drainage". Review of the checklist by personnel at salt storage facilities may be useful. The handbook also provides tables for estimating space requirements for salt storage. Data presented are based on an assumed salt density of 80 pounds per cubic foot [Salt Institute, 2006].

Some groups have opted to share storage facilities and resources. An example is the Central Iowa Metropolitan Salt Storage Facility [Barbaccia, 2010] and one owned by McHenry County Illinois [DeVries 2004].

Outside the U.S., the country of South Korea has integrated an Analytical Hierarchy Process (AHP) and a Geographic Information System (GIS) to optimally locate salt storage facilities based on population density, snowfall amount, and managed road length [Yang et.al, 2011].

3.2 Survey of Practice

3.2.1 Preliminary Survey

The second component of task 2 was to conduct a survey of users of salt domes from other DOTs to document their experiences, pros and cons, modifications, etc. in order to fill any knowledge gaps that were not be addressed by a review of the literature. A preliminary survey was prepared by the research team and distributed electronically by ODOT Central Office to other DOTs on the American Association of State Highway and Transportation Officials (AASHTO) Research Advisory Committee (RAC) listserv. The intent of the preliminary survey was to gather cursory information on salt storage along with information for a point-of-contact for each state. The topic of the survey was "Salt Storage Practices for Winter Snow and Ice Management". The intended audience was as follows: State Maintenance and Operations Administrators, District Deputy Directors, District Highway Management Administrators, County Transportation

Administrators (County Managers), and County Garage Managers. The survey was distributed on October 2, 2013 with a deadline for response back to the principal investigator by October 18, 2013. The following is the context that was provided to persons surveyed and then the questions that were posed. Appendix A1 provides a copy of the survey that was submitted.

Survey Context: Salt domes are widely used in the State of Ohio for storing salt for winter snow and ice removal. Difficulties accessing storage space in salt domes due to dome geometry and loading equipment (loaders) has resulted in a salt storage process that is inefficient and potentially unsafe to maintenance staff. Furthermore, inadequate protection of salt stored in dome structures from rain and snow may result in conditions that are unsafe to the environment. For these reasons, ODOT is investigating alternatives for loading and storing salt that maximize salt dome storage capacity while simultaneously providing for the safety of the maintenance staff and the environment. The purpose of this survey is to determine what other salt loading equipment, salt loading procedures, and salt storage facilities are being used by state DOTs throughout the country. The information from this survey will be used to evaluate alternatives to ODOT's current process with respect to cost, efficiency, and safety.

Preliminary Survey Questions:

1. What type(s) of storage facilities do you use to store salt for winter snow and ice removal?
2. What type(s) of equipment do you use to load salt into the storage facilities?
3. How is the volume of salt in the storage facilities determined for salt inventory?
4. What measure(s) do you use to protect the environment at the storage site from salt contamination?
5. Can you provide technical expert contact information in order to discuss your state DOT's salt loading and storing practices in more detail?

Summary of Responses: Twenty-four states and two Canadian provinces responded to the above survey. A summary of the responses is provided in Table A2.1 in Appendix A2. Note that some responses have been substantially reduced to accommodate the table format.

The results of the preliminary survey were analyzed with respect to the number of storage types, loading methods, inventory methods, and measures for mitigating the effect of stored salt on the environment, and are shown in Figures 5-8. Figure 5 summarizes the responses relative to question 1 on “What type(s) of storage facilities do you use to store salt for winter snow and ice removal?”. Domes and canvas/fabric covered buildings were cited the most frequently, each by 18 responders. Twelve DOTs listed wood –framed buildings, while 10 noted open- ended sheds. Open storage was cited by 4 while high gambrel barns/arch trussed buildings and other were cited by only three. Figure 6 presents the responses for question 2: “What type(s) of equipment do you use to load salt into the storage facilities?”. The majority (26) responded loader/dozer, followed by 14 using conveyors. Auger, blower and elevator were cited by less than 2 each. Figure 7 enumerates the responses to: “How is the volume of salt in the storage facilities determined for salt inventory?” The highest response (13) was “estimated based on amount ordered and load counts”. Seven responded “based on pile dimensions and other methods”. Survey of pile and loader with scale were cited by 3 and 2 responders, respectively. Figure 8 provides data on: “What measure(s) do you use to protect the environment at the storage site from salt contamination?”. “Use of an impermeable pad for storage” was noted by 18, followed by 16 listing runoff/control drainage. Seven said “keep open storage covered when not in use”, while three each noted “keep salt completely protected from weather and indoor delivery and loading”.

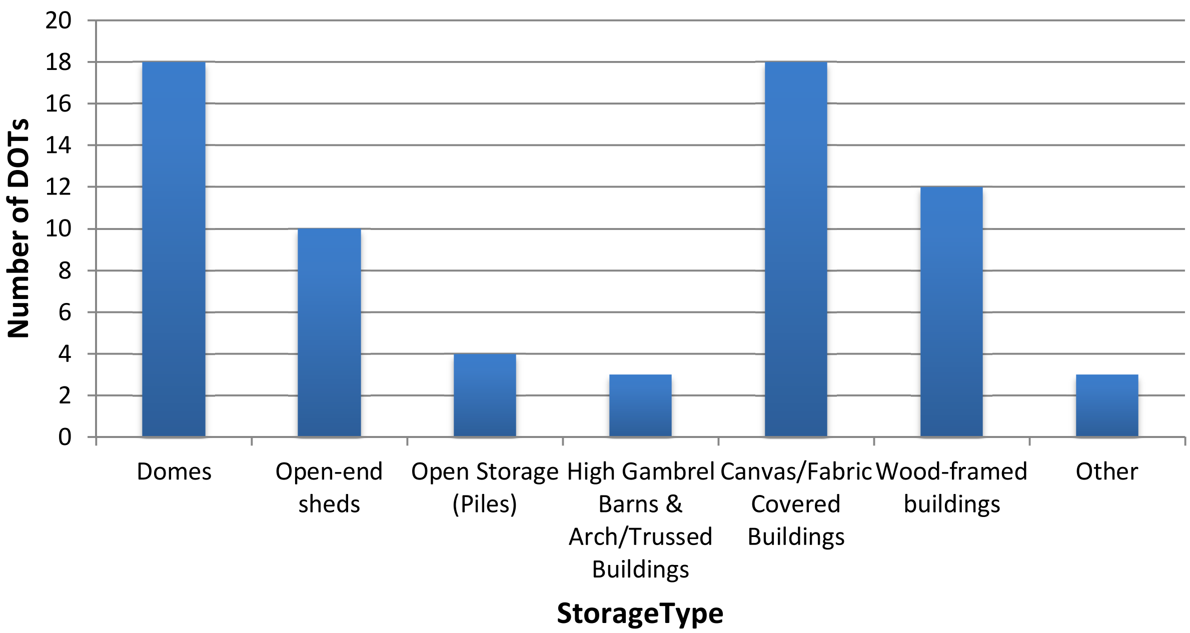


Figure 5. Enumerated responses to “What type(s) of storage facilities do you use to store salt for winter snow and ice removal?”

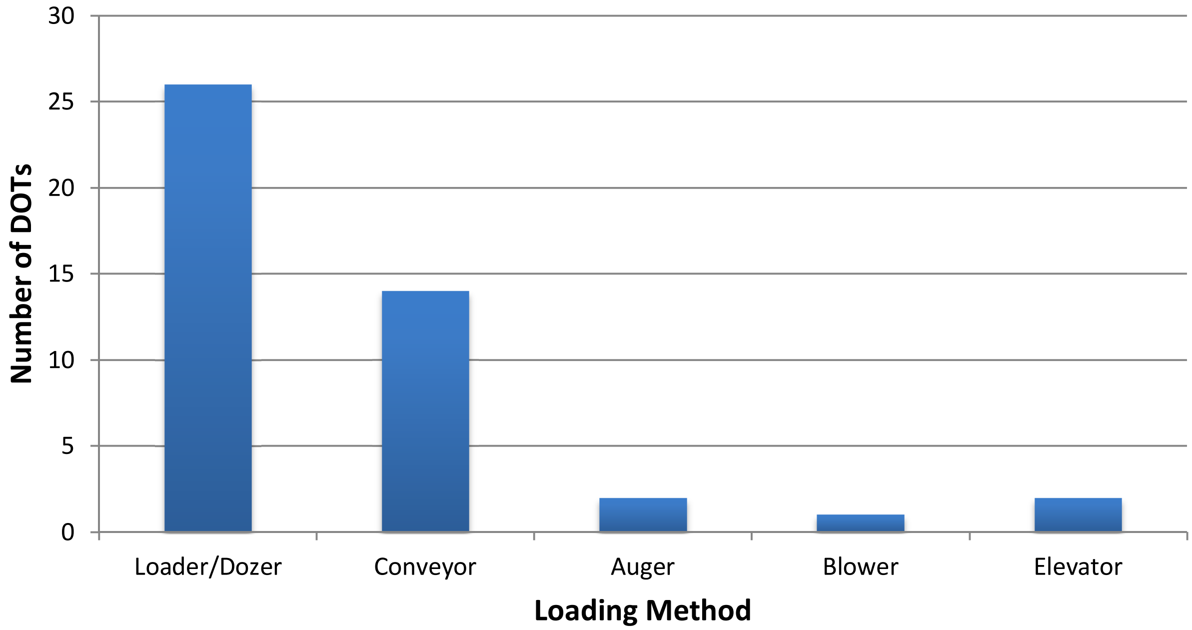


Figure 6. Enumerated response to “What type(s) of equipment do you use to load salt into the storage facilities?”

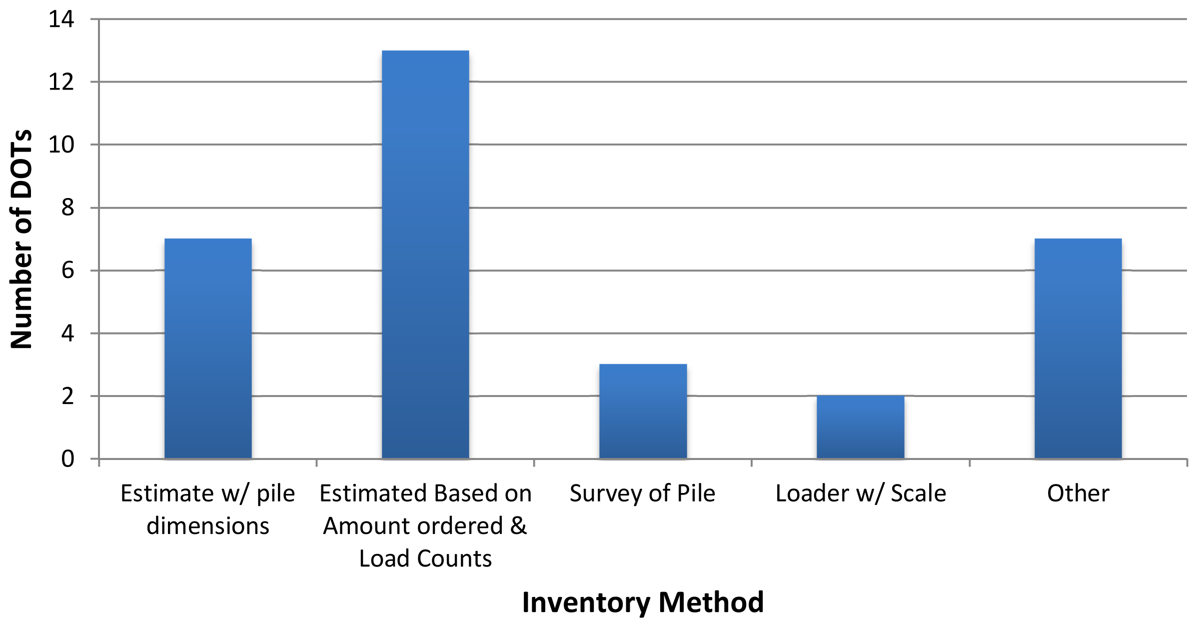


Figure 7. Enumerated response to “How is the volume of salt in the storage facilities determined for salt inventory?”

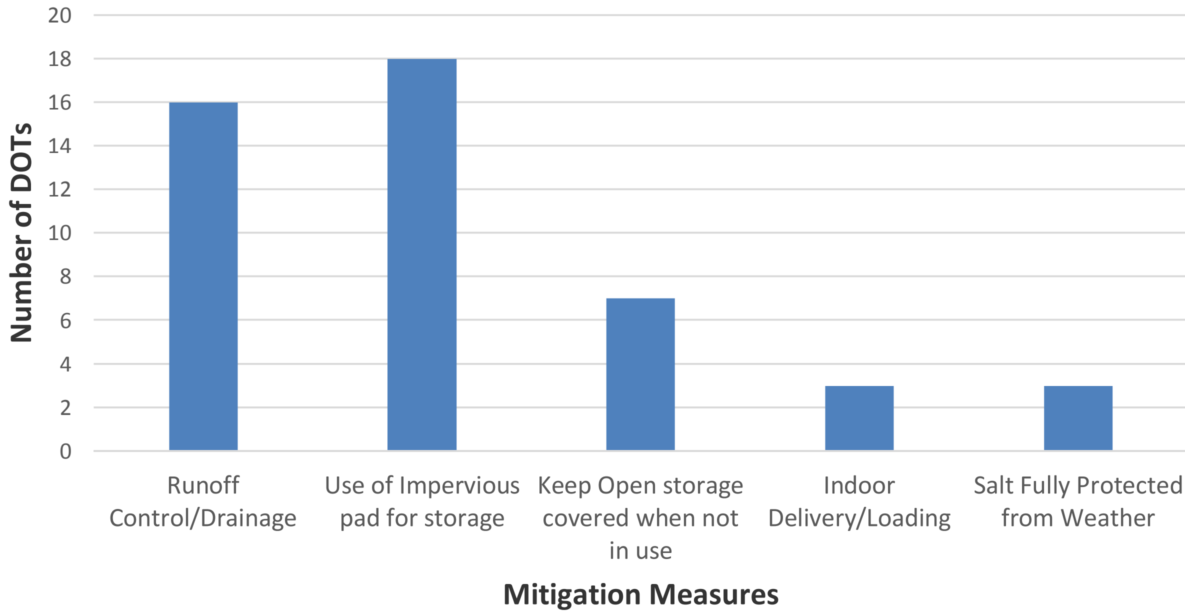


Figure 8. Enumerated response to "What measure(s) do you use to protect the environment at the storage site from salt contamination?"

3.2.2 Follow-up Survey

Based on the information collected during the preliminary survey, follow-up questions were developed to obtain more detailed information with regard to salt storage types, loading methods, and inventory. For storage types, information was collected on the percentage of each type, capacity, purchase cost, installation cost, annual maintenance, service life, staff training, salt loss per year, advantages, and disadvantages. For loading methods, information was collected on percentage of each type, loading rate, purchase cost, annual maintenance, service life, staff training, staff operating hours, advantages, and disadvantages. The information collected for salt inventory was how and when the pile was measured, associated cost, staff and training required, and the overall importance of salt inventory. Using the point-of-contact information collected for each state, a follow-up survey was administered. Twenty of the initial twenty-six DOTs surveyed provided information for the follow-up survey. They are as follows: British Columbia, California, Idaho, Illinois, Indiana, Iowa, Kentucky, Maryland, Minnesota, Missouri, Montana, New York, North Carolina, Rhode Island, South Carolina, South Dakota, Utah, Virginia, Washington and Wisconsin. A summary of the responses is provided in Appendix A3.

3.3 Benefit-Cost Analysis and Matrix of Options

3.3.1 Equivalent Cost Analysis of Salt Storage Buildings and Loading Equipment

The initial goal of performing a benefit-cost analysis for the building structures used to store salt and for the loading equipment used to load salt into the structures was not feasible given the limited information available on costs and the total lack of information provided on benefits. Instead, using the available information, an equivalent annual cost analysis was performed for the salt storage structures and loading equipment where sufficient data was available. The analysis was performed by researchers at Montana State University's Western Transportation Institute.

An equivalent annual cost, or EAC, is a tool used in finance to assess the cost per year of owning and operating an asset over its service life. Equivalent annual cost is commonly used as a decision-making tool for "capital budgeting" when comparing investments in projects of unequal service lives. Assuming different types of facilities or equipment can be used to achieve a comparable level of performance, the ones with the lowest EAC are most desirable. The EAC is calculated by dividing the net present value (NPV) by the present value of an annuity factor, such that:

$$EAC = (NPV / A_{t,r}) + \text{annual maintenance costs,} \quad (1)$$

where EAC is equivalent annual cost, NPV = net present value, or initial investment cost (to build and install), and A = loan repayment factor given by:

$$A = ((1\text{-}1/(1+r)^t)/r \quad (2)$$

where t = expected service life and r = cost of capital in percent. The following assumptions were made in the EAC analysis:

- The cost of capital, r, was assumed to be the inflation rate in 2013, which is 1.5%, according to http://www.usinflationcalculator.com/ The data used in the analysis was acquired through a survey of state DOTs and provincial transportation agencies.
- Where service life values of indefinite or forever were provided by survey respondents, a service life of 100 years was used in the analysis.
- The year of purchase or construction was not provided by survey respondents, therefore the relative current value based on past inflation was not considered.
- The annual cost due to salt loss was calculated by multiplying the percent of salt loss by the building capacity, then assuming salt cost $35/ton, ignoring the potential effect of inflation on this unit cost.
- For all survey responses for each category, the median value was used in the calculations.
- Many, if not all, of the salt loss values were estimations and may not have been based on actual data collected.
- Installation costs were provided by some survey respondents, others stated that the cost was folded into the NPV, while others provided no information at all.
- It was assumed that staff training is repeated annually and the loaded labor cost of $21.42 per hour (which was taken from a case study in: Veneziano, D., Fay, L., Ye, Z., Williams, D., and Shi, X. Development of a Toolkit for Cost-Benefit Analysis of Specific Winter Maintenance Practices, Equipment and Operations. Final report prepared for the Wisconsin DOT and the Clear Roads Program. September 2010) was multiplied by the training hours reported in the survey so that annual training costs could be used in the analysis.

3.3.2 Building EAC Analysis

Sufficient information was available to calculate the EAC of the following structures; domes, canvas/fabric covered structures, wood-framed structures, open-ended structures, high Gambrel barns, arch/truss structures, and other (a combination of metal, wood, concrete structures). Table 1 provides the information gained from the surveys that was used to calculate EAC for the building structures. The final results of the analysis are reported as the Total Equivalent Annual

Cost (EAC) and the Total Equivalent Annual Cost (EAC) per Ton (based on building capacity). The lower the EAC the more cost effective the structure. Based on the total EAC analysis, the buildings that are most cost effective are the Open-ended structures, followed by dome and high Gambrel barns. Based on the total EAC per ton (based on building capacity), the most cost effective buildings are the Open-ended structures and high Gambrel barns, followed by domes.

3.3.3 Loading Equipment EAC Analysis

Sufficient information was available to calculate the EAC for loaders and conveyors. Table 2 provides the information gained from the surveys and used to calculate EAC for the loading equipment. The final results of the analysis are reported as the Total Equivalent Annual Cost (EAC) and the Total Equivalent Annual Cost (EAC) per ton per hour (based on building capacity and loading rate). The lower the EAC the more cost effective the piece of loading equipment. Based on the total EAC and total EAC per ton per hour, the conveyor is the most cost effective piece of equipment to load salt. One thing to consider, that the EAC calculations do not take into consideration, is that loaders are generally multi-use pieces of equipment and can be used for more tasks than just loading salt into buildings and trucks.

3.3.4 Data Collection Issues Encountered

While many state DOTs and provincial transportation agencies responded to the survey in some capacity, the amount of time required to provide responses for each category of the survey required more time than the practitioners had available to spend on the survey. For many respondents, the information was not available at all because the structures or equipment were built or purchased before information was easily stored on computers, information was archived in storage cabinets off-site, the organization did not have a statewide inventory, or a current inventory, of structures or equipment, etc. While the lack of available information made the analysis process challenging, for many of the state DOTs and provincial transportation agencies, it highlighted a need in their organization.

Table 1. Data used and total EAC and total EAC per ton.

Structure Type (1)	n (2)	NPV* (3)	Install. Cost (4)	A (5)	t (6)	r (7)	Annual Maint. Costs (8)	Staff Training † (9)	Salt Loss/ year‡ (10)	Total EAC (11)	Total EAC/ Ton (12)
Dome	8	$16,500	-	22.73	28	1.5%	$5,125	$43	$571	$22,239	$10
Canvas/Fabric covered	10	$41,265	$13,752	10.91	12	1.5%	$4,143	$0	$1,400	$60,551	$30
Wood-framed	7	$19,305	$26,545	20.72	25	1.5%	$6,470	$43	$0	$52,363	$26
Open-ended	6	$1,874	-	24.02	30	1.5%	$7,500	$0	$1,488	$10,861	$3
High Gambrel Barns	3	$17,697	-	24.02	30	1.5%	$4,750	$0	$2,555	$25,002	$3
Arch/Truss	3	$5,000	-	35.00	50	1.5%	$15,000	$857	$70,000	$90,857	$45
Other	3	$39,814	$4,684	13.34	15	1.5%	$500	$150	$0	$45,148	$77

*Purchase cost based on capacity in tons.

†This value is the staff training hours reported in the survey multiplied by the loaded labor cost per hour of $21.42 determined by (Veneziano et al., 2010).

‡This value is the percent salt loss reported in the survey multiplied by the estimated cost of salt of $35 per ton.

Table 2. Data used and total EAC and total EAC per ton per hour.

Loading Equipment (1)	n (2)	NPV* (3)	Install. Cost (4)	A (5)	t (6)	r (7)	Annual Maint. Costs (8)	Staff Training † (9)	Salt Loss/ year‡ (10)	Total EAC (11)	Total EAC/ Ton/ hour (12)
Loader	10	$7,281	-	17.17	20	1.5%	$4,650	$171	$0	$12,10 2	$179
Conveyor	5	$5,784	-	17.17	20	1.5%	$2,426	$171	$0	$8,382	$38

*Purchase cost based on loading rate in tons/hr.

†This value is the staff training hours reported in the survey multiplied by the loaded labor cost per hour of $21.42 determined by (Veneziano et al., 2010).

‡This value is the percent salt loss reported in the survey multiplied by the estimated cost of salt of $35 per ton.

3.4 ODOT Salt Storage and Loading Practices

The literature review and survey of state DOTs provided valuable information on the state-of-the-practice in salt storage around the country and the world. In order to evaluate the current salt loading and storage practices employed by ODOT county garages, site visits were conducted. The focus of the site visits was on collecting engineering data and interviewing maintenance staff. Engineering data was collected on the salt domes as well as the surrounding site. Data collected on the salt domes included structural layout, structure and foundation material, structure and foundation condition, dome and doorway dimensions, loading equipment type and dimensions, actual salt storage, and salt demand. In addition to collecting data on the salt dome, information was also collected on the surrounding site. The information included the location of the salt dome with respect to water wells, ditches, dry well streams, and flood plains; the existence and condition of an impervious storage pad, equipment washing, and the handling of brine equipment. This information was used to investigate the compliance of the garages with the recommendations for salt storage set forth by the Ohio Water Resource Council (OWRC 2013). A checklist for each garage is provided in Appendix A4. Generally, it was found that most garages were in compliance. Lastly, an ODOT staff member at each garage was interviewed by a member of the research team during the visits. The purpose of the interviews was to gather information on loading practices, the salt inventory process, and identify issues with regard to safety of maintenance staff during operation of the facility.

Prior to conducting the site visits, ODOT identified the locations of five salt domes with different storage capacities. The domes were located at five different county garages throughout Districts 2 and 12. These five garages also used all the salt loading methods that can be found throughout the state of Ohio: (1) loader, (2) PTO conveyor, (3) self-powered conveyor, (4) blower. All five salt domes were of similar construction and were only distinguished through variations in their geometry. The dome dimensions for all five domes that were visited are provided in Table A5.1 in Appendix A5. They all had the following features (Dome Corporation of North America):

1. Asphalt concrete base.
2. Cylindrical concrete riser wall supporting conical timber superstructure.
3. Large entrance canopies.
4. Vast clear-span unobstructed interior.
5. Floating concrete wall, founded at grade, acting as a retaining wall for the stored salt.
6. Superstructure made from modular panels consisting of rings of laminated lumber.
7. Panels covered with self-sealing asphalt shingles

A description of each dome, the loading methods used, the loading rates for each method, the safety of the loading methods, and the salt inventory process is provided in Appendix A5 for the five domes visited.

3.5 Analysis of Equipment and/or Structural Modifications

3.5.1 Comparison of Salt Loading Methods

Results of the survey of DOTs indicate that there are five methods used for loading salt into salt storage structures throughout the country, with the loader and conveyor representing the two most common of the five methods. Site visits to five ODOT garages in four different counties in Ohio revealed that storage practices in the state reflect the national trend, although Ohio also utilizes the blower as a loading method. A survey of the literature did not reveal any additional loading methods other than those identified through the DOT survey and site visits. The analysis of the two primary loading methods identified through the state survey indicates that the conveyor has the lowest equivalent annual cost (EAC) and would therefore represent the best solution for loading salt. Although not factored into the EAC, this method may be particularly appropriate for loading dome structures where dome geometry renders other loading methods (i.e. loaders) unsafe and less efficient.

The cost-benefit analysis of the five different loading methods considers factors such as loading rate, purchase cost, annual maintenance, service life, staff training, etc., using information that was obtained through the survey of DOTs. An analysis of the three salt loading methods currently employed by ODOT Districts 2 and 12 was also performed based on information gathered from the site visits. As described in Section 3.4, ODOT maintenance staff at each garage were asked to rate their loading methods in terms of quantity stored, loading rate, and safety. The rating for each method averaged over all five sites visited is shown in Figure 9. The results indicate that the self-powered conveyor was the best loading method for all three categories considered, with the exception of quantity stored, where it received the same average rating as the blower. Meanwhile, the PTO conveyor received the second highest rating in safety and quantity, but had the lowest rating in the category of speed. The low speed rating can be attributed to the configuration for this conveyor, which is powered by a tractor PTO and fed using a pigeon door on a truck (see Section 3.4). The blower received the highest rating for quantity stored (same as self-powered conveyor), second highest rating for speed, and the third highest rating for safety. However, as detailed in Section 3.4, the blower compromises the effectiveness of the salt for winter snow and ice removal and may lead to advanced deterioration of the salt dome in which it is stored. Finally, it may be observed from Figure 9 that the loader received the lowest average rating for the categories of quantity stored and safety, and the second lowest rating for speed. The results of the analysis suggest that the self-powered conveyor would be the safest and most efficient salt loading method.

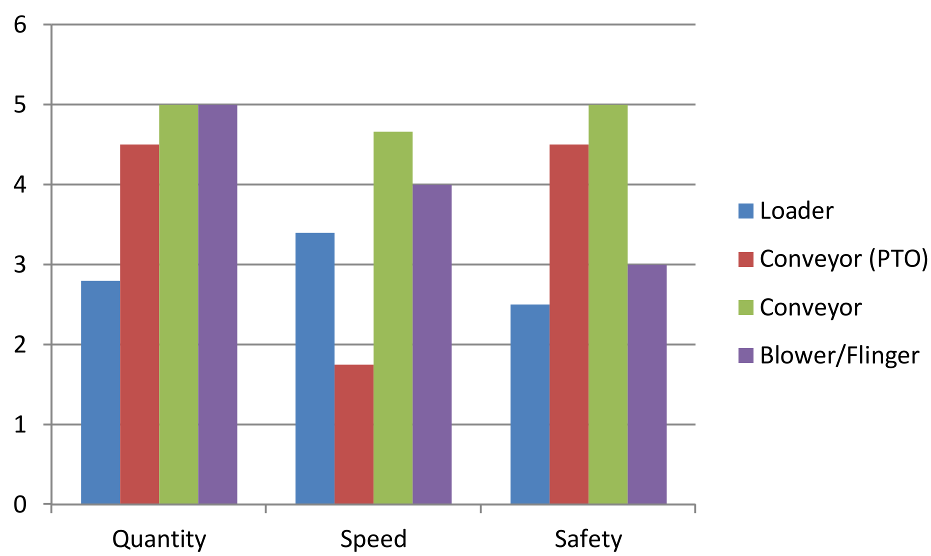


Figure 9. Average rating of loading equipment based on data collected during site visits.

3.5.2 Maximizing Storage Capacity of Salt Domes

Based on the results of the literature review, survey of state DOTs, cost-benefit analysis, and site visits, the self-powered conveyor is identified as a safe and efficient method for loading salt into salt domes at ODOT county garages. However, there are still several factors that must be considered to maximize the efficiency of the self-powered conveyor as a salt loading method. In particular, the quantity stored by the conveyor depends on the conveyor length, placement, and piling strategy. While conveyors may be ordered in a variety of lengths from manufacturers, the placement and piling strategy are determined by the operator. During the ODOT county garage site visits, it was observed that conveyed salt was typically stored inside the salt domes using two or more piles. However, this approach does not maximize the storage capacity of the dome structure, and instead salt should be loaded into dome structures as a single pile with the pile center concentric with the dome center. This can be easily verified through calculation and then observation. For instance, consider the two-dimensional representation of salt storage in a dome structure shown in Figure 10. The dome has a diameter D, and contains two salt piles (shown with solid line) each with diameter d, height at riser wall h_w, pile height h_p, and pile centers o_1 and o_2 located a distance x apart. The piles are assumed to be identical with constant angle of repose θ and height at riser wall h_w, while the distance between pile centers x may vary along with the pile diameters d. As the distance x decreases, the pile centers move closer together and the tops of the piles move along the dotted lines from point B toward C. Conversely, as the distance x increases, the pile centers move away from one another and the tops of the piles move along the lines from point B toward A. The total area of salt contained inside the dome may be determined by adding the areas of the two piles, and then subtracting the area of the pile intersection and the area of salt outside the dome, leading to:

$$A = \frac{1}{2} d \cdot h_p \cdot 2 - \frac{1}{2}\left(\frac{d-x}{2}\right) \cdot y \cdot 2 - \frac{1}{2}\frac{h_w}{\tan\theta} \cdot h_w \cdot 2, \tag{3}$$

where

$$d = D + \frac{2 \cdot h_w}{\tan\theta} - x, \tag{4}$$

$$h_p = \frac{d}{2} \cdot \tan\theta, \tag{5}$$

and

$$y = \frac{d-x}{2} \cdot \tan\theta. \tag{6}$$

Substitution of Equations 4-6 into Equation 3 and simplifying yields the following:

$$A = \left(\frac{D^2}{4} - \frac{x^2}{2}\right)\tan\theta + D \cdot h_w, \tag{7}$$

where $0 \le x \le d$ to avoid a negative height y, and for practical purposes $0 < \theta < 90°$. With the total area of salt contained in the dome A defined in Equation 7, calculus may be used to determine the distance x at which A is maximized. Taking the first derivative of A with respect to x yields:

$$\frac{dA}{dx} = -x\tan\theta. \tag{8}$$

Setting the function in Equation 8 equal to zero and solving for the distance between piles at which the area of salt is maximized gives $x_{max} = 0$. The result confirms that the maximum amount of salt is stored when a single pile is used with pile center concentric with the dome center. Substituting $x_{max} = 0$ into Equation 7 gives the maximum area of salt that can be stored as:

$$A_{\max} = \frac{D^2}{4}\tan\theta + D \cdot h_w \,. \tag{9}$$

Dividing the area of salt A for any distance between pile centers x in Equation 7 by the maximum area of salt in Equation 9 gives the salt storage efficiency as:

$$\varepsilon = \frac{A}{A_{\max}} \cdot 100\% \,, \tag{10}$$

or

$$\varepsilon = \frac{\left(\frac{D^2}{4} - \frac{x^2}{2}\right)\tan\theta + D \cdot h_w}{\frac{D^2}{4}\tan\theta + D \cdot h_w} \cdot 100\% \,, \tag{11}$$

which simplifies to:

$$\varepsilon = \frac{\left(D^2 - 2x^2\right)\tan\theta + 4 \cdot D \cdot h_w}{D^2 \tan\theta + 4 \cdot D \cdot h_w} \cdot 100\% \,. \tag{12}$$

It is observed that substitution of $x_{max} = 0$ into Equation 12 results in 100 % salt storage efficiency. The single pile concept may also be understood through simple observation. For instance, the two pile configuration in Figure 10 does not take advantage of the diamond-shaped empty space formed by the points B, C and the intersection point of the two piles. As the distance between pile centers x decreases, this empty space becomes stored salt. For $x = 0$, there is no empty space and the maximum amount of salt is stored.

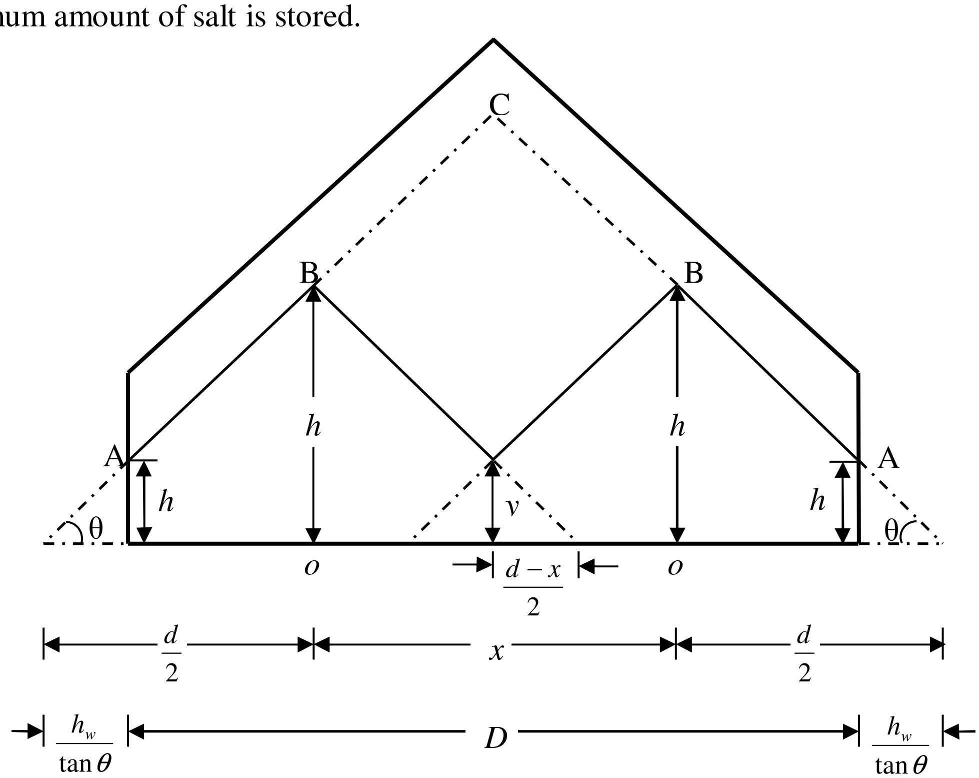


Figure 10. Two-dimensional representation of salt storage.

The previous result may also be shown for three-dimensional salt storage. However, the mathematical formulation is far more tedious, therefore a simpler approach is adopted. In lieu of a mathematical derivation of salt volume for one or more salt piles, CAD software capable of volume calculation is used to analyze the actual domes that were visited. For each dome, the volume of salt (V) is calculated assuming one, two, or three piles. For domes with one pile, the pile center is concentric with the dome center. For domes with two piles, it is assumed that the pile centers are located at quarter points along the dome diameter. When three piles are used, it is assumed that the pile centers are equidistant from each other and the dome walls. For all calculations, the height of the salt at the riser wall is assumed to be 1 ft below the wall height (H_w) and the angle of repose of the salt is taken to be 32° [Salt Institute, 2013]. Table 3 shows the results of the analysis. Columns 4, 5, and 7 give the maximum volume of salt stored in each dome for the one, two, and three pile configurations respectively. Columns 6 and 8 give the salt storage efficiency (ε) for the two and three pile configurations as calculated from Equation 8. A comparison of columns 4, 5, and 7 shows that the maximum amount of salt is stored in the domes when a single pile is used, regardless of dome geometry. Furthermore, comparison of columns 6 and 8 shows that the maximum salt storage efficiency for all domes and both the two and three pile configurations is 73 %, which occurs for the salt dome at the Cleveland garage. It should be noted here that this result still means that over 25 % of the storage capacity of the dome is not being used.

Table 3. Three-dimensional volume calculations for salt domes at ODOT County Garages.

			Number of Piles				
			1	2		3	
Garage (1)	***D* (ft)** (2)	**H_w (ft)** (3)	**V (yd^3)** (4)	**V (yd^3)** (5)	**ε (%)** (6)	**V (yd^3)** (7)	**ε (%)** (8)
Wood	60	6	1179	513	44	690	59
Sandusky	60	10	1598	895	56	1111	70
Unionville	60	10	1598	895	56	1111	70
Cleveland	60	12	1806	1102	61	1321	73
Independence	100	12	6229	3063	49	3985	64

It has been shown that in order to maximize the storage capacity of salt dome structures, salt should be conveyed into a single pile with the pile center concentric with the dome center. However, implementation of this loading approach presents some challenges. One of these challenges is containment of the salt at open doorways, which were observed at all five of the domes visited as part of this study. Without doors, it is expected that salt would spill out of the dome as the size (height and diameter) of the salt pile in the dome increases. The spilled salt would then be exposed to moisture and other contaminants that may compromise its quality and the safety of the surrounding environment. As a result, implementation of the single pile approach would require a means for containing the spilled salt. Possible alternatives for containment would be to retrofit salt domes with load bearing doors, covered entrances that extend the length of the spillage, or a combination of both.

One factor that could affect the selection of a containment strategy is the quantity of the spillage. The amount of salt spilled is a function of the dome geometry, and can be easily determined for the five domes visited as part of this study. If it is assumed that each dome is loaded using the single pile approach, and that the height of the salt at the riser wall is 1 ft below the top and the angle of repose is 32° [Salt Institute, 2013], then the radial distance (d_r) the spilled salt would extend from the doorway may be determined using trigonometry. The results for the five salt domes visited in this study are provided in Table 4, and it is clear that domes with higher riser walls will result in more salt spilled. This is important, as containing large amounts of salt with a door may not be feasible due to the large load exerted on the door. The magnitude of the load (*P*) is easily determined using the height of the salt at the doorway along with its unit weight [Washington State Department of Transportation, 2012]. The loads that would be exerted on the doors for the five domes in this study are provided in column 5 of Table 4, and may be used along with the load capacity of the door to determine its feasibility as a containment method. Where doors are not feasible, a covered entrance may be constructed that extends the length of the spill. Such an entrance should be constructed to be wider than the dome doorway to avoid restricting movement of the loader during loading of the salt trucks. Furthermore, any addition to the existing structure should comply with all existing ODOT requirements for salt storage.

Another alternative for containing the salt that would spill out of the dome while using the single pile approach is considered. Rather than use a permanent solution such as a door or covered entrance, it may be more cost-effective to just cover the spilled salt with a tarp. While this is not the preferred method for long-term storage of salt [OWRC, 2013], the spillage that would result at fill-up during the winter period would only be temporary, as it could be used to load the first salt truck(s) at the start of the next winter storm. One drawback to this containment strategy is that ODOT county garages typically load the salt domes for the next winter season during the summer months, thereby leaving the spilled salt covered with a tarp for an extended period of time. To address this issue, it may be possible to delay off season fill-up until closer to the winter season, or install a temporary structure to block the door during the months between summer fill-up and the next winter season.

Table 4. Distance salt spills and force at doorway using single pile approach for loading domes.

Garage	***D* (ft)**	**H_w (ft)**	**d_r (ft)**	***P* (lb)**
(1)	(2)	(3)	(4)	(5)
Wood	60	6	6.5	10114
Sandusky	60	10	13	32769
Unionville	60	10	13	32769
Cleveland	60	12	16	48951
Independence	100	12	16	48951

Another challenge in implementing the single pile approach is the placement of the conveyor such that the salt pile center is concentric with the dome center. It was observed during the site visits that portable conveyors were positioned at or inside the dome doorway with the conveyors extending into the dome for loading salt. Typically, the domes were filled from back-to-front with multiple salt piles by changing the conveyor position and angle. With salt conveyed in a single pile, the conveyor would have to be positioned at or outside the dome doorway and extend into the dome so that it didn't occupy any of the storage space. The conveyor would need to be long enough, and positioned at a steep enough angle, to pile salt to its maximum height based on the dome geometry. At the same time, the conveyor would need to fit within the height of the dome doorway, which is not always proportional to the dome size as is shown in Table A5.1. These two conflicting requirements would complicate using a single portable conveyor for domes of varying sizes. If the conveyor is selected based on the largest dome, it is likely not to work with the smaller domes. It is obvious that a conveyor selected based on the smallest dome would not be capable of piling salt to the maximum height at the larger domes. Therefore, each dome would need a custom size conveyor in order to maximize its salt storage. The exception would be counties with domes of similar sizes where conveyors could be shared.

While portable conveyors would allow domes of similar size to share resources and save money, issues may arise when multiple domes within a county require loading at the same time. During the peak of the winter season, transporting a conveyor around the county may be too inefficient to meet all of the garages' salt loading demands. Another issue with using portable conveyors inside salt domes to load a single pile is removal of the conveyor. Assuming the conveyor meets all the criteria for accessing the dome and maximizing the pile height, it may not be possible to remove the conveyor without significantly disturbing the salt pile once loading is complete. To further examine this issue, each of the salt domes visited as part of this study were analyzed for an ideal conveyor. The ideal conveyor at each dome was positioned at the dome doorway and extended into the dome. The length and angle of the conveyor were selected so that it could pile the salt to the maximum allowable height based on the dome geometry. The domes and conveyors were drawn in CAD software using the actual dome geometries. The results for all five domes are shown in Figure A6.1 in Appendix A6. It can be seen that for each dome and conveyor, there is very little room to maneuver the conveyor once the dome has been filled.

The use of a portable conveyor inside the salt domes with the single pile approach is further complicated by the spillage of salt that would occur at the doorway. Whether the spillage was contained using a door, a covered entrance, or covered with a tarp, the accessibility of the dome interior via the doorway would be significantly reduced. An alternative to using a portable conveyor inside the dome would be to use a permanent conveyor and load the dome from the exterior. With this alternative, the storage space could be accessed through a structurally modified opening in the dome. The opening would need to be covered to keep out moisture. It would also be likely that additional support would have to be provided to the dome to ensure the dome's structural safety. At ground level the conveyor should be trough fed. Finally, the conveyor should be corrosion resistant to protect it from the salt, and covered to protect the salt from moisture during loading. An example of domes loaded using permanent external conveyors is shown in Figure 11.

Figure 11. Salt domes loaded using permanent external conveyors (courtesy of Wisconsin DOT).

3.5.3 Salt Storage Options and Cost Analysis

Salt Storage Options

The results of the analysis above indicate that the maximum amount of salt may be stored when it is conveyed into a single pile with pile center concentric with the dome center. Furthermore, the results indicate that the safest and most efficient means of loading salt is to use a self-powered conveyor that is hopper fed, and load the dome from the exterior through a structurally modified opening. Based on the results of the analysis, the research team contacted two companies in the materials conveyance and storage industry to explore salt loading and storage options and obtain cost estimates for the equipment and site modifications for each option. The two companies that were contacted were Kimco and Dome Corporation of North America. Each company was provided with site drawings of the Wood County Garage along with drawings of the dome and asked to provide an itemized cost estimate for the following:

1. Self-powered conveyor (gas or electric).
2. Hopper (w/ vibrator) for feeding the conveyor.
3. Installation of a dormer in the dome superstructure.
4. Installation of a sub-grade pit for temporarily storing salt during loading.

Based on feedback from the companies, several options for loading and storing salt were identified. The different options, along with their itemized costs, are provided in the following for each supplier.

Kimco

The itemized costs for each option provided by Kimco are shown in Tables A7.1-3 in Appendix A7. In the first option, a portable conveyor is used in a permanent loading and storage setup. Along with the conveyor cost are the costs for a hopper, vibrator, installing a dormer, and delivery, installation and training. Note that the portable conveyor option uses a portable conveyor in a permanent loading and storage setup. The portable conveyor uses a diesel engine, whereas a fixed conveyor uses an electric motor. The diesel engine will require more routine maintenance compared with the electric motor. The portable conveyor also has more moving parts that will need to be maintained. Finally, it was not recommended by the supplier to use the portable conveyor with a dump pit.

In the second and third options provided by Kimco, a fixed conveyor is used instead of a portable conveyor. For both options, the cost for a hopper, vibrator, installing a dormer, and delivery, installation and training are provided. The only difference between the two fixed conveyor options is that the third option includes the price for installing a dump pit to temporarily hold the salt during loading. The dump pit represents the most efficient loading method, as delivery trucks can dump directly into the pit and then salt is conveyed into the dome. As a result, there is no need for a loader as with the hopper fed conveyors, and the equipment and manpower required for loading salt is reduced. The efficiency of the pit increases along with the number of salt storage facilities it serves.

Dome Corporation of North America

The itemized costs for each option provided by Dome Corporation of North America (DCNA) are shown in Tables A7.4-6 in Appendix A7. They are comparable to options 1-3 for Kimco in Tables A7.1-3.

Kimco vs Dome Corporation of North America

Some of the differences between the options specified by each supplier are in the equipment that is used in the loading setup. For instance, Kimco uses a diesel engine in their portable conveyor while DCNA uses an electric motor. As stated previously, a diesel engine will require more routine maintenance than an electric motor. On the other hand, Kimco uses stainless steel for the body of their conveyors while DCNA uses galvanized steel. Galvanized steel is more prone to corrosion over time, and Kimco has reported that it has replaced DCNA conveyors with their stainless steel conveyors at several sites due to corrosion issues. Other differences in equipment are the loading rates of the conveyors. The rates of all of the Kimco's conveyors (portable and fixed) are reported to be 300 tons/hr. DCNA's reported that its portable conveyors were 300 tons/hr while its fixed conveyors are 225 tons/hr. Another difference between the options specified by the suppliers is the price. For the first option using the portable conveyor, the cost estimates for the two companies are comparable. However, for the second and third options using the fixed conveyors, the cost estimates from DCNA are substantially higher than that of Kimco.

Cost Analysis

Maximizing salt storage at salt dome structures using one of the above options will require an initial investment by ODOT in terms of equipment and dome modifications, along with a continued investment in equipment maintenance. The alternative to purchasing and installing one of the loading setups identified above is to contract the conveying services through a salt supplier. A direct comparison of these two alternatives is required to identify the most cost-effective means for loading salt. If it is assumed that the total cost to purchase and install one of the options identified above is paid up front, then the total lifetime cost may calculated by simply adding the purchase and installation cost to the maintenance cost adjusted for inflation over time. The adjusted maintenance cost may be determined using the Equivalent Annual Cost (EAC) method. For the analysis performed herein, it is assumed that the service life of the salt loading setups is 10 years, the annual cost for maintaining the equipment will be $1,000.00 (provided by Kimco), and the inflation rate is 1.5%. It is further assumed that the cost to contract the conveying service is $3.50/ton, the rate of inflation applied to this service is 1.5 %, and that the conveyor is the only loading method used to load salt. The analysis is performed for the Wood County garage, which stores an average of 4,500 tons of salt per year. The results of the analysis are included in Table 5, and indicate significant savings can be realized by purchasing a conveyor system compared to contracting the service through the salt supplier.

Table 5. Comparison of cost to purchase conveyor and cost to contract conveyor

Company (1)	**Option** (2)	**Purchase & Install** (3)	**Annual Maintenance** (4)	**Service Life** (5)
Kimco	Portable	$81,408.56	$1,164.91	$93,057.66
	Fixed w/o Pit	$108,765.00	$1,164.91	$120,405.10
	Fixed w/ Pit	$142,765.00	$1,164.91	$154,414.10
DCNA	Portable	$85,000.00	$1,164.91	$96,649.10
	Fixed w/o Pit	$160,000.00	$1,164.91	$171,649.10
	Fixed w/ Pit	$185,000.00	$1,164.91	$196,649.10
Salt Supplier	Contracted	-	-	$170,783.83

3.5.4 Salt Inventory

While the salt loading strategy and equipment are important for maximizing salt storage, proper salt inventory also plays a vital role in winter snow and ice management. As discussed in Section 3.2, the importance of proper salt inventory was typically rated very high in the survey of DOTs. A similar response was obtained during the site visits to ODOT county garages (see Section 3.4). In all, it was found that proper inventory of salt is considered to be important to effective management of winter snow and ice operations. However, the survey and site visits also revealed that current methods for determining the quantity of salt were slow and/or inaccurate. One of the objectives of this research project was to identify more efficient methods for determining salt quantities for inventory purposes. Specifically, methods that could determine quantities quickly, accurately, and autonomously were considered. A thorough search of the state-of-the practice in stockpile measurement concluded with two different volume-measuring technologies: laser and acoustic scanners. A description of each technology is provided in the following.

Laser Scanner

Laser scanner technology operates on the principle of reflected infrared light. The distance between a laser scanner and target object is determined by measuring the time of flight for a laser pulse to travel from the instrument to a target and back (distance = 0.5 x speed of light x time of flight). In order to determine the volume of a stockpile using a laser scanner, a point cloud is created by measuring the distance to many different points on the pile. The data in the point cloud includes the x, y, and z coordinates of each point. The coordinates are then post-processed to create a surface of the pile, which along with a baseline surface, may be used to determine the volume of the pile. Even though modern laser scanners are capable of measuring the distance to thousands of points per second, the accuracy of the pile volume estimation relies on data from many points, and data collection can be time consuming (~45 minutes). Furthermore, developing the point cloud requires that the scanner be physically aimed at each point on the pile where data is to be collected, which requires motorization of the scanner. The presence of moving parts increases the likelihood that the scanner will require maintenance. Another potential maintenance issue with laser scanners is keeping the sensor free of dust, which can reduce the effectiveness of the device. This is sometime addressed by incorporating a tube that extends from the laser to protect the lens. However, regular maintenance may still be required.

Acoustic Scanner

Acoustic scanner technology is similar to that of laser scanner, except that acoustic scanners emit sound rather than light. They work by bouncing sound waves off an object and then measuring the time of flight and direction of the resulting echo. In order to determine the volume of a stockpile, three or more sources with known position send and receive sound pulses in sequence. Then, a triangulation algorithm is used to process the data and analyze the reflected sound (time and direction). From this, the volume of the pile may be computed relative to a predetermined baseline volume. Some features of the acoustic scanning systems are that the scanners are stationary and the volume calculation only takes a few minutes. They may also be self-cleaning, as the emitted sound waves can cause vibrations that prevent the build-up of dust on the device.

Laser vs Acoustic Scanner for Measuring Salt Volumes in Domes

In order to compare the laser and acoustic scanning methods for measuring the volume of salt in a dome structure, several cost estimates for each system were obtained. For the sake of conducting a direct comparison between the two systems, all estimates were requested for the salt dome at the Independence garage. The details of this dome are provided in Table A5.1 in Appendix A5. The results of the research are provided in Table 6, and include information such as the system cost, accuracy, and scanning time. Other entries in the table are related to system maintenance, motorization, and access to data. It may be observed from Table 6 that the Contour and 3DLevelScanner acoustic systems offer accuracy within 4-5 % of the volume for the four scanner configuration, while the laser scanner systems can compute the volume of the pile to within 0.25% or 2 % depending on the system. However, the cost of the Site Monitor laser system is almost twice as much as the most expensive acoustic system. Meanwhile, the cost of the VM3D laser system is comparable to the acoustic systems; however, this system must be installed by the customer (with guidance from the manufacturer). Furthermore, volume measurements for the VM3D system are accessed from a secure website via the Internet within 24 hrs of completion of the scan. It may be further observed from Table 6 that the acoustic scanning systems are capable of completing a scan in only a fraction of the time (5 minutes) it takes the fastest laser system (30-45 minutes). Finally, it can be seen that the acoustic systems are self-cleaning and have no moving parts, thereby reducing the need for maintenance. The data analysis is also performed on site which provides the user with the resulting volume measurements in a convenient and timely manner.

It should be noted that while both laser-scanning systems only specify a single scanner, there is some doubt on behalf of the research team as to whether a single scanner system will be able to achieve the reported level of accuracy. The laser technology requires the scanner to ‘see’ the entire volume of salt in the dome in order to obtain an accurate measurement. As shown in Figure A5.6 for the Independence garage, salt is often piled high near the walls where it could block the line of sight of the laser from measuring the back side of the pile. To account for this, additional lasers would have to be installed in the dome. The cost of a single additional laser for each system is $10,000-$12,000. However, if the salt was stored in a single pile in the center of the dome the effects of shadowing would be reduced, and the use of a single laser system could be feasible.

Scanner Maintenance

One issue with installing a scanning system (acoustic or laser) in a salt dome is maintenance. Although the acoustic scanners are marketed as having a self-cleaning feature, it is still possible for salt to build up on the scanner antennas over time. The laser scanners do not claim a self-cleaning feature and would therefore require routine cleaning to keep them functioning properly. Accessing the scanners for cleaning would be difficult, as they would be mounted near the top of the dome. Elevating ODOT staff for scanner cleaning would require special equipment and could place the staff safety in jeopardy. As a result, the criteria for the purchase and installation of a scanning system should include a means for raising and lowering the scanners for cleaning.

In order to gather more information on the required maintenance, warranty, technical support, additional costs, etc. for the acoustic and laser scanning systems identified in Table 6, a list of questions was developed by the research team and distributed to the scanner suppliers. It should be noted that the VM3D laser scanner by ABB was not included in the survey as this scanner was eliminated from consideration due to the lengthy scanning time, off-site analysis, and customer self-installation. The questions distributed to the other four scanner suppliers were as follows:

Q1. How often will the system need to be cleaned if it is mounted in a highly corrosive environment where salt dust and moisture are present?

Q2. How is the system cleaned? Can it be lowered from its mounting position for cleaning, or will maintenance staff need to be elevated to the height of the scanner?

Q3. What other routine maintenance will be required other than cleaning of the scanner? What is necessary to perform the maintenance?

Q4. Is there a warranty for the system? If so, how long is the warranty and what does it cover? When the warranty has expired, and the system needs repair, will you provide a technician to do the repairs? If so, what is the cost to have the technician come to the site and perform the repairs?

Q5. What type of customer support do you provide during the warranty period and beyond?

Q6. After the system has been installed and is running, will there be any additional fees (software license, technical support, etc.)?

Q7. What is the service life of the system that you have specified?

Q8. Can the scanners be recycled for use in other structures in the future?

Table 7 provides a summary of the responses. From column 2, it can be seen that two of the three acoustic scanner suppliers (FCX Performance and Measurite Inc.) indicated that the acoustic scanners do not require any cleaning, even in the corrosive environment of a salt dome. This response is reflective of the self-cleaning feature of the acoustic scanners that results from the noise-induced vibration of the antennas. Meanwhile, the third acoustic scanner supplier (Henry M. Wood Company) and the laser scanner supplier (3D Laser Mapping) suggested annual and quarterly inspection of their scanners, respectively. From column 3 of Table 7, all of the surveyed scanner suppliers reported that cleaning of the scanner will require ODOT staff to be elevated to the height of the scanner, either for cleaning the scanner at the mounted location or for lowering the scanner for cleaning. Based on the results of this survey, and in the interest of ODOT staff safety, the research team approached each scanner supplier about the possibility of installing a system for raising and lowering the scanners for cleaning. Of the four scanner suppliers under consideration, only Henry M. Wood Company and FCX Performance responded positively to this request, with additional costs for installation of the raising and lowering systems of $16,800.00 and $10,000, respectively. The remaining two suppliers, Measurite Inc, and 3D Laser Mapping, responded by providing costs for on-site cleaning.

Table 6. Cost and features of volume measurement technologies.

Scanner Type (1)	**Product Name** (2)	**Distributor** (3)	**No. of Scanners** (4)	**Maximum Error (%)** (5)	**Scanning Time (minutes)** (6)	**Motorized (Y/N)** (7)	**Self-Cleaning (Y/N)** (8)	**On-Site Data Analysis (Y/N)** (9)	**Cost ($)** (10)
Acoustic	3DLevelScanner	FCX Performance	4	3	5	N	Y	Y	$29,100
		Measurite Inc.	3	6	5	N	Y	Y	$21,125
			4	4	5	N	Y	Y	$26,300
		Henry M. Wood Co.	4	5	5	N	Y	Y	$30,700
Laser	SiteMonitor	3D Laser Mapping	1	0.25	30	Y	N	Y	$54,452
	VM3D	ABB	1	2	45	Y	N	N[1]	$17,550[2]

[1]Volume measurements are accessed from a secure website via the Internet within 24 hours of completion of the scan.
[2]Cost does not include installation, which must be performed by the customer.

Table 7. Summary of responses from scanner suppliers.

Distributor (1)	**Q1** (2)	**Q2** (3)	**Q3** (4)	**Q4** (5)	**Q5** (6)	**Q6** (7)	**Q7** (8)	**Q8** (9)
FCX Performance	never	lower unit	none	1 yr (entire unit)	phone, on-site service	no	decades	yes
Measurite Inc.	never	rinse cones with water	none	2 yr (material and workmanship)	phone, on-site support	no	indeterminate	yes
Henry M. Wood Co.	annually (inspection)	elevate staff	none	2 yr (electronics and transducers)	phone, on-line support	no	10 yrs (minimum)	yes
3D Laser Mapping	quarterly (minimum)	elevate staff	dust tube, lens, external	1 yr (entire unit)	phone, on-line support	yes	unknown	yes

3.6 Conclusions and Recommendations

From an analysis of the data collected through a review of the literature, survey of other DOTs, and field visits to five ODOT county garages, it was determined that the loader and self-powered conveyor are the two most common methods of loading salt. Of these, the conveyor was identified as the faster and safer method for loading salt, and the more effective method at maximizing the amount of salt stored in a dome structure. Furthermore, the results of a cost analysis of the two loading methods showed that the conveyor is also a more cost-effective piece of equipment. Analysis of the conveyor and dome structure for salt storage demonstrated that the maximum amount of salt will be stored when salt is conveyed into a single pile with the pile center concentric with the center of the dome. However, this loading practice will result in spillage of salt for domes with open doorways. To contain the spillage, domes may be retrofitted with load bearing doors or extended covered entrances, or spillage may be temporarily covered with a tarp. The presence of any one of the three containment strategies will make loading with a conveyor through the open doorway difficult. As an alternative, the dome may be retrofitted with a structurally modified opening to provide the conveyor access to the dome interior from outside the dome.

A survey of DOTs along with field visits to ODOT county garages identified salt inventory as a very important component in the management of winter snow and ice operations. Furthermore, all of the ODOT county garages identified accurate volume measurement as an important factor in proper salt inventory, and four out of five reported deficiencies in volume measurement at their site. As a result, there is a need for a fast, accurate, and autonomous method for measuring salt volume as part of the salt inventory process at ODOT county garages. A thorough search of the state-of-the practice in stockpile measurement concluded with two different volume-measuring technologies: laser and acoustic scanners. A comparison of the cost and features of the two technologies for a large salt dome located at one of the ODOT garages indicates that the acoustic technology is faster, more cost-effective, more robust, and more convenient than its laser counterpart.

Based on the results of the research described herein, the following is recommended for maximizing salt storage at salt domes in Ohio:

1. Salt should be loaded using a self-powered conveyor (gas or electric) from outside the dome and the storage space should be accessed through a structurally modified opening.
2. The conveyor should be hopper fed.
3. The conveyor should be corrosion resistant and covered.
4. Salt should be loaded using a single pile with pile center concentric with the dome center.
5. Spillage at the doorway should be contained using one of three options: load bearing door, extended covered entrance, or tarp and temporary structure. The method of containment will likely vary based on conditions at the site.
6. For inventory purposes, the volume of salt should be determined using an acoustic scanner system.
7. The acoustic scanner system should be installed with a system for raising and lowering the scanners for cleaning.

These recommendations are based on research performed during phase one of the research project, and should be evaluated after implementation at select ODOT county garages as part of a second phase. Selection of the field study sites should be done in consultation with the ODOT technical panel and liaison, and will likely influence the implementation costs. It is suggested that the evaluation period be no less than one winter season, where a longer evaluation period will provide more data and more reliable results. Successful implementation could lead to statewide changes in salt storage and inventory, and overall improvement in the management of winter snow and ice operations at ODOT county garages.

3.7 ODOT Review and Phase 2 Implementation

The recommendations summarized in Section 3.6 were presented to ODOT for review. For salt storage, it was decided that the Kimco portable diesel conveyor (Table A7.1) used in a portable setup would be the most cost-effective solution for the salt loading and storage needs at county garages where multiple storage facilities are used to store salt. The Kimco diesel conveyor has a loading rate of 300 tons/hr and only requires a single ODOT staff member with a loader to operate. This is a significant increase in speed and efficiency compared with the PTO conveyor, which has an approximate loading rate of 57 tons/hr and requires four ODOT staff members to operate. Furthermore, the portable conveyor will allow ODOT staff to quickly and easily load multiple storage facilities at the same garage, or at different garages throughout a county. The increase in speed and efficiency of the portable diesel conveyor will also allow ODOT to use the conveyor as the primary loading method. As a result, it will no longer be necessary to use a loader for loading salt, and the safety of ODOT staff will be improved.

When using the portable conveyor in the portable setup, salt is loaded into the dome structure by placing the conveyor through the dome entrance. As a result, it was decided that neither the structurally modified opening on the exterior of the dome, nor the method for containing spillage at the doorway, would be necessary. The adjusted cost of the Kimco portable conveyor system without the dome modifications is $76,408.56. It was decided that Phase 2 evaluation of the Kimco portable conveyor will take place at the Wood County Garage in Bowling Green, OH.

For salt inventory, ODOT selected the acoustic scanner system supplied by the Henry M. Wood Company for Phase 2 evaluation. The acoustic system was selected over the laser system due to the faster scanning time, reduced cost, and reduced required maintenance. Of the three acoustic systems identified in Phase 1 of the research, only the suppliers that offered a means for raising and lowering the scanners for cleaning, the Henry M. Wood Company and FCX Performance, were considered for Phase 2 evaluation. The Henry M. Wood Company system was selected over that supplied by FCX Performance due to the diligence of the sales representative in preparing the cost estimate, who visited the installation site several times to collect information for installing the scanners with the raising and lowering system. The total cost for the system supplied by Henry M. Wood Company, including the cost for the raising and lowering system, is $47,500. It was decided that Phase 2 evaluation of the acoustic scanner system would take place at the Riveredge Garage in Cleveland, OH, which is the same size and has identical capacity to the Independence Garage in Independence, OH.

4. Phase II Research

4.1 Field Analysis of Salt Loading Modifications

4.1.1 Equipment Installation

A 24 in, 70 ft stainless steel diesel conveyor and 6 ton hopper with vibrator was purchased from Kimco for $76,409 (price includes delivery, installation, and on-site training). The loading rate of the conveyor specified by Kimco is 300 tons/hr. The conveyor was delivered to the Wood County Garage in Bowling Green, OH on August 4th of 2014. Kimco provided an operation and maintenance manual along with on-site training for ODOT staff members. A picture of the installed conveyor with hopper is shown in Figure 12.

Figure 12. Kimco diesel conveyor installed at Wood County Garage in Bowling Green, OH.

4.1.2 Data Collection

The diesel conveyor described above was purchased to address inefficiencies with the PTO driven conveyor previously used by the Wood County Garage. In order to evaluate the diesel conveyor, it was compared with a PTO driven conveyor configured in a variety of loading setups. Data collected for each conveyor setup included the loading rate (tons/hr), number of pieces of equipment used, and the number of ODOT staff members required for safe operation.

PTO Conveyor with Dump Truck

The research team visited the Wood County Garage to collect data on the PTO driven conveyor configured with a loader and dump truck. In this setup, shown in Figure 13, the loader supplies salt to the dump truck, the dump truck feeds the conveyor, and a tractor is used to drive the conveyor belt. This setup required four pieces of equipment and used four ODOT staff members. The loading rate was determined by counting the number of loader buckets of salt conveyed in one hour of time, where the weight of one loader bucket of salt was determined prior to starting. The loading rate for this conveyor setup was determined to be 101 tons/hr.

Figure 13. PTO driven conveyor with loader and dump truck.

PTO Conveyor with Hopper

During the same field visit to the Wood County Garage, the research team also collected data for the PTO driven conveyor configured with a loader and hopper. In this loading setup, shown in Figure 14, the dump truck was replaced by the 6 ton hopper for feeding the conveyor. However, the loader was still used to fill the hopper, and a tractor was still used to drive the conveyor belt. This conveyor setup required three pieces of equipment and used three ODOT staff members. Again, the loading rate was determined by counting the number of buckets conveyed in one hour of time. The loading rate for this setup was determined to be 140 tons/hr.

Figure 14. PTO driven conveyor with loader and hopper.

PTO Conveyor with Trough Conveyor

An alternative to using a loader and dump truck, or loader and hopper, is to dump the salt from the delivery trucks directly into a trough conveyor. The trough conveyor then conveys the salt onto a conventional conveyor, which then loads the storage facility. The advantage to using this setup is a reduction in the equipment and personnel required for the salt loading process. In order to collect data on this setup, the research team visited the Gallia County Garage in Bidwell, OH. The salt loading setup at the Gallia County Garage, as shown in Figure 15, consisted of a PTO driven conveyor, a trough conveyor (Kimco LoadMaster), and loader. The loader was kept on-hand to allow for a delivery truck to occasionally dump into a temporary bin. From there, the salt was loaded into the trough conveyor using the loader. This is sometimes done in order to expedite the loading process and reduce delivery truck waiting times. The setup at the Gallia County Garage used three pieces of equipment - PTO Conveyor, trough conveyor, and tractor - and two ODOT staff members. The loader is not included in the required equipment due to its infrequent use in the loading setup. The loading rate was determined by using the weight of salt from seven delivery trucks along with the total time it took for the trucks to offload their salt directly to the trough conveyor. The loading rate for this conveyor setup was determined to be 101 tons/hr.

Figure 15. PTO driven conveyor with direct dump trough conveyor.

Diesel Conveyor with Hopper

The research team returned to the Wood County Garage to collect data for the diesel conveyor with six-ton hopper. In this setup, shown in Figure 16, the loader supplies salt to the hopper, which in turn feeds the conveyor. This setup requires 3 pieces of equipment and two ODOT staff members. Data collection for the diesel conveyor was performed in a manner similar to that of the PTO driven conveyor. The only difference is that the number of loader buckets of salt conveyed was only determined for a half hour rather than one hour of time. During the half hour of time, two to three times the number of loader buckets were conveyed compared to the PTO driven setups, and it was determined that enough salt had been conveyed in order to establish the loading rate. The loading rate for the diesel conveyor was determined to be 345 tons/hr.

Comments on Data Collection

It should be noted that data was collected only one time for each loading setup, and took place during salt fill-up prior to the beginning of the winter season. Furthermore, loading at the Wood County garage was arranged specifically for the purpose of collecting data on the diesel conveyor and the PTO conveyor with dump truck and hopper, while data collection on the trough conveyor at the Gallia County Garage took place during normal garage operations. It is also important to point out that slight modifications in the loading equipment will affect the loading rate of a given setup. For instance, the research team observed an increase in the loading rate of the PTO conveyor at Wood County when the conveyor belt was tightened. Also, an ODOT staff member at Gallia County reported that the PTO conveyor with trough conveyor system was capable of unloading a delivery truck in five minutes (~300 tons/hr), and that the efficiency of the setup was highly dependent on the angle of the PTO conveyor used in the setup.

Figure 16. Diesel conveyor with hopper.

4.1.3 Loading Setup Analysis

A summary of the data collected for each loading setup is provided in Table 8 for comparison. Based on the data collected in this study, the diesel conveyor with hopper has the highest loading rate and uses the least number of ODOT staff members and equipment (same as PTO conveyor with LoadMaster). As a result, the diesel conveyor represents the most efficient loading setup of all the setups studied. A closer look at the data summary also reveals some clues as to the inefficiencies within the other setups. For instance, a comparison of the PTO driven conveyor with the dump truck and hopper shows a 40 % increase in the loading rate when the dump truck is replaced by the hopper. As there are no other equipment changes between these two setups, the data suggests that using the dump truck to feed the conveyor is slowing down the loading process. This can be attributed to the time it takes to raise and lower the dump truck bed between loader buckets, and the inconsistent flow rate through the pigeon hole in the gate. The latter must be maintained in order to maximize the efficiency of the PTO driven conveyor. If the salt flows too slowly, then the capacity of the conveyor isn't realized, and less salt is conveyed into the storage facility than is possible. If the salt flows too fast, then the conveyor won't be able to keep up with the salt supply, and the tractor driving the belt will stall. Maintaining a constant flow rate of salt through the pigeon hole requires frequent modifications to the truck bed angle by the driver.

A comparison of the PTO driven conveyor with hopper and the diesel conveyor reveals a 150 % increase in the loading rate for the diesel conveyor. As both are used with the same six ton hopper, it can be concluded that the PTO driven conveyor is causing a reduction in the loading rate. This is not unexpected, as the loading rate of the PTO driven conveyor is limited by the power of the tractor driving the belt, which often gets 'bogged down' when too much salt is fed onto the conveyor. During data collection for the PTO driven conveyor with the hopper, the loader supplying the hopper had to wait for the hopper to empty before dumping each bucket to avoid 'bogging down' the conveyor and stalling the tractor. Therefore, the loading rate for this setup represents the maximum rate for the PTO driven conveyor studied at Wood County. This insight further highlights the decrease in efficiency caused by using the dump truck in the loading process.

The loading rate for the PTO conveyor with trough conveyor was the lowest of all the loading setups studied. Similar to the PTO conveyor setups studied at the Wood County Garage, it was observed that the flow of salt to the PTO conveyor had to be maintained carefully to maximize the conveyor capacity while also avoiding bogging down the conveyor and stalling the tractor. This required modifications to the delivery truck bed angle feeding the trough conveyor. These modifications were achieved through coordination between the delivery driver and ODOT staff members. It should be pointed out that a limit on the loading rate of the trough conveyor was also observed, as the conveyor would overflow when too much salt flowed from the truck. Another factor contributing to the low loading rate of the PTO conveyor with trough conveyor was the delay associated with the time it took for the delivery trucks to enter and exit the dump location. Several attempts were often required in order to line-up the delivery trucks with the trough conveyor.

Table 8. Comparison of conveyor setups.

Setup (1)	**No. of Operators (2)**	**No. of Pieces of Equip. (3)**	**Loading Time (minutes) (4)**	**Loading Amount (tons) (5)**	**Loading Rate (tons/hr) (6)**
PTO conveyor, dump truck	4	4	60	102	101
PTO conveyor, hopper	3	3	56	130	140
PTO conveyor, trough conveyor	2	3	104	174	101
Diesel conveyor, hopper	2	3	30	175	345

In order to identify the most cost-effective salt loading setup, the cost for each alternative is required. In the present study, a simplified cost analysis was performed in which the cost for each loading setup was determined over a ten year period. The total cost included the cost to purchase the equipment required for each setup (see Table 8), the cost to maintain the conveyance equipment, and the cost to compensate the staff during operation of the equipment. The equipment purchase costs were provided by ODOT staff at the Wood and Gallia County garages and are provided in Table 9. The maintenance cost for the conveyance equipment was taken to be \$0.40/ton for the traditional conveyors and \$0.28/ton for the trough conveyor (provided by Kimco USA). The staff cost is calculated using the loaded labor cost, the loading rate of the equipment (see Table 8), and the total salt usage over the ten year period. A loaded labor cost of \$43.56/hr is assumed as reported by the Bureau of Labor Statistics for the month of September 2014. The total salt usage was based on the Wood County garage, which stores an average of 4,500 tons of salt per year. The cost to maintain the non-conveyance equipment (i.e. loader, tractor, dump truck) in each setup was not incorporated as this equipment is used for a variety of garage operations throughout the year.

Table 9. Cost of equipment used in loading setups.

Equipment (1)	**Cost** (2)
Diesel Conveyor	$62,427
PTO Conveyor	$44,040
Trough Conveyor	$27,934
6-ton Hopper	$10,716
Vibrator	$1,685
Loader	$140,868
Dump Truck	$155,102
Tractor	$36,242

The cost breakdown for each loading setup over a ten year period is provided in Table 10. The highest total cost is for the PTO conveyor with the dump truck, mainly due to the multiple pieces of equipment used in the setup. This setup also had the second highest staff cost, although this cost contributes to less than 5 % of the total cost. The high staff cost is directly related to the loading rate for the setup, as a slower loading rate results in more time required to load a given amount of salt. For this reason, the staff cost is also high for the PTO conveyor with trough conveyor. However, this setup has the lowest equipment cost, leading to the lowest overall cost of all the setups considered. The next lowest overall cost is for the diesel conveyor with the hopper, which has the second lowest equipment cost and the lowest staff cost. This is followed by the PTO conveyor with the hopper, which is roughly $25,000 more expensive than using the setup with the diesel conveyor.

In order to evaluate the overall cost-effectiveness of a particular setup, both cost and loading rate should be considered. To this end, a rating index (R_i) is introduced that includes both of these parameters and allows for direct comparison of the cost-effectiveness of the loading alternatives. The index is a calculated as follows:

$$R_i = \frac{\min\left(\frac{TC_i}{LR_i}\right)}{\frac{TC_i}{LR_i}}, \tag{13}$$

where TC_i is the total cost ($), and LR_i is the loading rate (tons/hr), for the i^{th} loading setup. A value of 1 corresponds to the most cost-effective loading setup. A value less than 1 indicates the relative cost-effectiveness of a particular option compared with the most cost effective setup. The ratings are provided in column 6 of Table 10, and indicate that the loading setup with the diesel conveyor and hopper is the most cost-effective alternative of all the setups studied. This can be attributed to the high loading rate compared with the other setups, along with second lowest total cost. The PTO conveyor with trough conveyor is the second most cost-effective loading setup, following by the PTO conveyor with the hopper, and the PTO conveyor with the dump truck.

Table 10. Cost breakdown for different loading setups including ODOT standard equipment.

Loading Setup (1)	**Equipment** (2)	**Staff** (3)	**Maintenance** (4)	**Total** (5)	**Rating** (6)
PTO conveyor, dump truck	$376,252	$19,345	$18,000	$413,597	0.17
PTO conveyor, hopper	$233,551	$13,984	$18,000	$265,535	0.37
PTO conveyor, trough conveyor	$108,216	$19,378	$12,600	$140,194	0.50
Diesel conveyor, hopper	$215,696	$5,690	$18,000	$239,386	1.00

One of the factors influencing the ratings presented in Table 10 is the inclusion of the costs for the standard ODOT equipment used in each loading setup. These costs were included based on the assumption that any standard garage equipment used in the loading setups would be unavailable for other jobs during loading. Or vice versa, if the equipment was required for other jobs during loading then dedicated equipment would have to be purchased. However, the validity of this assumption may vary depending on the equipment and/or garage. For instance, the tractor required to drive the PTO conveyor may only be used in a limited capacity during the winter season, thereby making it available for use in a loading setup. On the other hand, the dump truck used in the PTO conveyor setup is typically used all year round, although some garages may have a sufficient number of trucks so that one truck can be dedicated to salt loading without compromising winter operations. It is also possible, depending on the garage, that a particular piece of equipment can be used for multiple jobs without affecting the salt loading process.

For cases where including the standard ODOT equipment is not appropriate, the ratings in Table 10 can be re-calculated based only on the purchase of the conveyance equipment. The results are presented in Table 11, and indicate that the loading setup with the diesel conveyor and hopper is still the most cost-effective alternative from all the setups studied. Again, this can be attributed to the high loading rate compared with the other setups, along with second lowest total cost. However, the comparative ratings reveal that the PTO conveyor with trough conveyor is now the least cost-effective alternative. This can be attributed to the large reduction in equipment cost of the other setups when the standard equipment is excluded, compared to a relatively small reduction in cost for the PTO conveyor with trough conveyor setup. That is to say, the setup with the trough conveyor becomes less cost-effective when excluding the standard equipment because it requires a larger initial investment, but has one of the lowest loading rates.

Table 11. Cost breakdown for different loading setups excluding ODOT standard equipment.

Loading Setup (1)	**Equipment** (2)	**Staff** (3)	**Maintenance** (4)	**Total** (5)	**Rating** (6)
PTO conveyor, dump truck	$44,040	$19,345	$18,000	$81,385	0.36
PTO conveyor, hopper	$56,441	$13,984	$18,000	$88,426	0.45
PTO conveyor, trough conveyor	$71,974	$19,378	$12,600	$103,951	0.28
Diesel conveyor, hopper	$74,829	$5,690	$18,000	$98,518	1.00

The use of cost-effectiveness versus total cost in selecting a loading setup will depend on the garage. For garages with a high salt demand, where salt is delivered throughout the winter season, both the cost and loading rate should be considered. For this case, the setup with the diesel conveyor and hopper will provide the most cost-effective solution, regardless of whether the ODOT standard equipment is considered. For garages with low salt demand, where salt is only delivered during the summer fill-up, the loading rate may not be as significant and only the total cost may be important. In this case, selecting the best setup will depend on the available resources at the garage. For instance, the availability of standard equipment, or the number of staff, that can be dedicated to the loading process without affecting normal garage operations.

If it is appropriate to consider ODOT standard equipment in the cost, then the PTO conveyor with trough conveyor will have the lowest total cost and require the least number of staff (see Table 10), and should therefore be selected as the loading setup. However, if cost of standard equipment can be excluded, then the decision can be made based considering the tradeoff between cost and staffing requirement. If sufficient staff is available and minimizing cost is a priority, then the PTO conveyor with dump truck setup may be selected. If minimizing the staff is a priority over minimizing the cost, then the diesel conveyor with hopper may be selected. In the end, the decision to select a particular setup will be garage dependent, and should be made on a garage-by-garage basis.

4.1.4 Issues Encountered

As part of the field study on the diesel conveyor with hopper at the Wood County garage, information on mechanical issues encountered by ODOT staff was collected. The conveyor was delivered on 8/4/2014, and the following issues, and the resolution, were reported:

1. Clutch went out on diesel motor (8/27/2014). Kimco contacted motor manufacturer, who sent mechanic on-site to diagnose. New clutch installed 9/2/2014 at no cost to ODOT.
2. Vibrator on the hopper stopped working (12/16/2014). Garage mechanic diagnosed the problem as a loose wire and fixed it on-site.
3. Bearing in drum seized (1/16/2015). Kimco was contacted, and suggested greasing damaged bearing. Normal conveying operations resumed.

It was also noted by ODOT staff that the lifting points on hopper are substantial, and a way of using the forklift to move hopper around is needed.

4.2 Field Analysis of Salt Inventory Modifications

4.2.1 Scanner Installation

An acoustic scanner system for measuring the stockpile volumes was purchased from the Henry M. Wood Company for $47,500. The price includes the cost of the hardware, software, and installation of the system. The primary system components include four acoustic scanners (70º beam angle), a controller, two serial modems, and a raising and lowering system for performing maintenance. The latter was specifically requested by ODOT to avoid potential safety issues with bringing staff to the level of the scanners for maintenance. The system was installed at the Riveredge Garage in Cleveland, OH on September 11th of 2014. Three of the four scanners were installed around the perimeter of the dome at a height of approximately 38 ft, while the fourth scanner was installed closer to the center at an approximate height of 54 ft. The number and position of the scanners are determined so that the entire contents of the dome can be captured during the scan. Figure 17 shows a picture of a single scanner installed on a wood frame that can be raised/lowered for scanner maintenance.

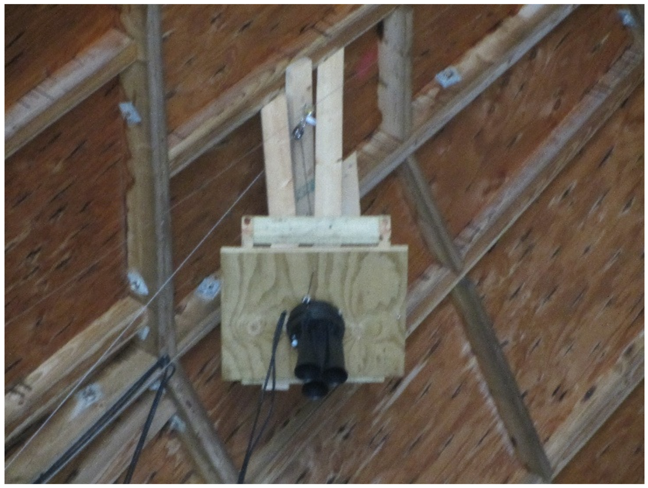
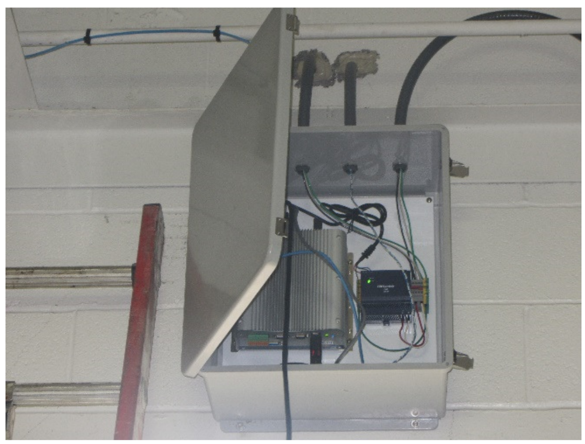


Figure 17. Picture showing a single scanner with raising/lowering system.

The four scanners are wired to a serial modem installed on the exterior wall of the dome. A second serial modem is installed on the exterior wall of the garage located approximately 165 ft from the dome. The second serial modem is then hard-wired to the controller located on the inside wall of the garage, which is then connected to the local network. Pictures of the serial modems and controller installation are shown in Figure 18. In this installation configuration, raw data from the scanners is transferred wirelessly to the controller, which then processes the data to determine geometric information about the stockpile. The processed data can then be accessed using the vendor-supplied software from any computer connected to the local network. At the Riveredge Garage, the software was installed on the garage manager's computer located in the front office.

(a)

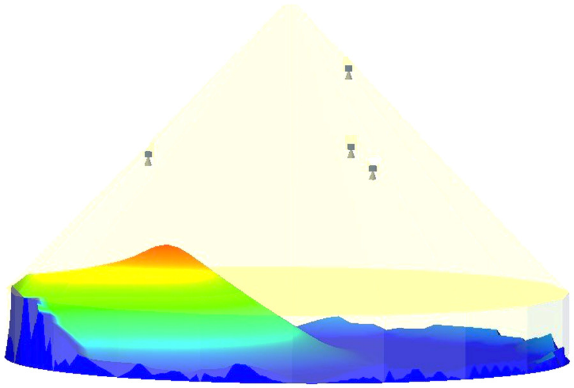
(b)

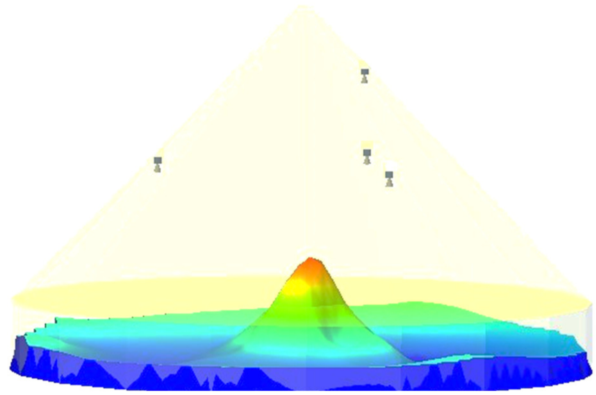


(c)

Figure 18. Pictures showing the installation of the (a) serial modem on the exterior wall of the dome, (b) serial modem on the exterior wall of the garage, and (c) the controller on interior wall of the garage.

An initial test of the scanner system yielded volume readings that were well above the amount of salt estimated to be in the dome. After consultation with technical support, it was determined that the error was due to the slow transfer speed of the raw data between the serial modems, which resulted in gaps in the data required by the controller algorithm for determining the pile geometry. To improve the system accuracy, it was decided that the installation would have to be reconfigured so that the transfer of raw data to the controller occurred using a hard-wired connection. Prior to reconfiguration of the setup, this solution was tested by temporarily running cable from the dome to the garage and hard-wiring the scanners to the controller. Figure 19 shows a three-dimensional (3D) image of the salt in the dome produce by the software before and after the system was hard-wired. Figure 20 shows pictures that were taken of the salt at the same time the images were produced. Comparison of the 3D images with the pictures indicated that an improvement in the system performance was achieved using the hard-wired connection, although the new scanner image was still not entirely representative of the salt in the dome. As a result, the original system was reconfigured so that the controller was mounted at the dome and hard-wired to the scanners, and the processed data was sent via Wi-Fi to the garage for access by ODOT staff.





(a) (b)

Figure 19. Image of the dome (a) before and (b) after hard-wiring the scanners to the controller.

(a) (b)

(c)

Figure 20. Pictures showing the salt at the (a) left side, (b) right side, and (c) center of the dome.

4.2.2 Scanner Operation

The acoustic scanner system determines the volume of a stockpile by mapping points on the pile and then using the points to calculate the pile geometry. The distance from the scanners to the pile points is determined by continuously emitting sound waves, and then measuring the time it takes for the waves to return to the scanners. The travel times are then used to calculate the travel distances based on the speed of sound. When the system is used within a confined vessel, there is the possibility for sound waves to bounce off other objects (e.g. walls) in addition to the target material prior to returning to the scanners. These 'multi-path echoes' result in distance measurements that are not representative of the actual distance to the pile points, and therefore cause errors in the pile geometry.

To account for multi-path echoes, and other features that may cause errors in the distance measurements (e.g. noise), the measurements are averaged over a time interval referred to as the damping time (typically measured in minutes). Despite the use of the damping time, errors in the distance measurements will result in fluctuations in the pile geometry and corresponding volume measurements over a very small time scale (minutes). Another feature that is used to address errors in the distance measurements are the vessel fill and empty rates. These application-dependent parameters are used to distinguish between true changes in stockpile volume and those due to errors in the distance measurements. This is done by neglecting volume changes that are not consistent with the predefined rates.

4.2.3 Data Collection

After the final installation of the acoustic scanner system was completed, the research team collected data to evaluate the system in terms of the accuracy of volume measurement. Data was collected during the winter season from November 2014 through March 2015, and included volume readings from the acoustic scanners, weight of salt delivered, bucket loads of salt dispensed, and daily visual estimates of the salt weight by garage staff. Volume readings from the acoustic scanners were collected on an hourly basis using the reporting feature in the scanner software. Meanwhile, data on salt delivered and dispensed was collected by event and typically included the time of day. Visual estimates were only reported once daily and were taken at the beginning of the morning shift.

4.2.4 Data Analysis

Total Volume - Acoustic vs. Ground-Based Laser Scanner

In order to evaluate the scanner accuracy, the volume of salt reported by the acoustic scanners was compared with the volume of salt determined using ground-based laser scanning. The first comparison was performed by the research team using a hand-held laser scanner in early November (11/4/2014). At this stage of the research, the team was trying to determine a rough estimate of the actual volume to compare with the initial readings from the acoustic scanners. To determine the volume, a hand-held laser distance finder was mounted on top of a protractor and fitted to the top of a short pole. The device is capable of measuring distances as well as angles from a horizontal reference plane. The pole was erected on the top of the salt pile by partially burying the base. The laser was then rotated in a horizontal reference plane, and for each angle of rotation, both the distance and vertical angle (measured down from horizontal reference plane) were recorded for multiple points on the pile. The number of points recorded for each horizontal angle depended on the topography of the salt, where more points were measured for more complex topography. The data was used to create a digital image of the salt pile, from which the volume of the salt was calculated. Two views of the pile image are shown in Figure 21, where arrows have been used to indicate the location of the dome doorway. Figure 22 shows pictures that were taken from the top of the pile in order to compare with the digital pile image. The pictures in Figure 22 were taken as the camera was rotated in the clockwise direction starting at the right, and ending to the left, of the dome doorway.

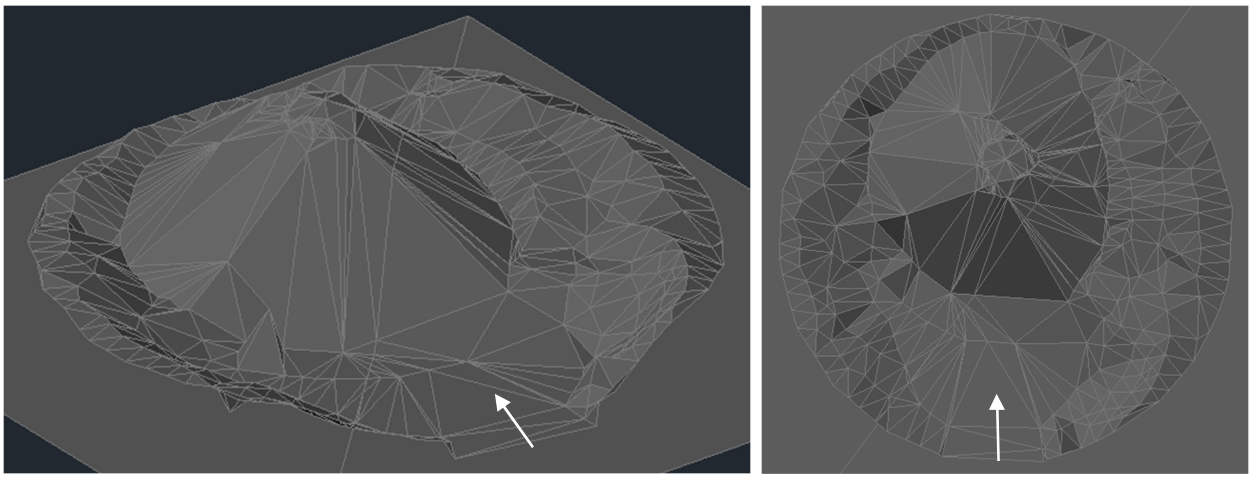


Figure 21. Digital image of the salt pile at Riveredge (11/4/2014).

Figure 22. Pictures taken from the top of the salt pile at Riveredge (11/4/2014).

Comparison of the digital image with the pictures of the pile shows that the major features of the salt pile were captured. The volume calculated from the digital image was determined to be approximately 63,000 ft^3, while the volume reported by the acoustic scanner during this time was approximately 42,000 ft^3. Comparison of the acoustic scanner readings and the ground-based laser scanning showed that the acoustic scanners underestimated the volume by around 30 %. The underestimation in volume can also be observed by comparing the 3D images of the salt pile produced by the scanner system with the pictures of the salt pile (see Figure 22). The 3D images, shown in Figure 19, indicate that height of the salt at the wall is well below the top of the wall. However, the pictures of the salt pile reveal that the height of the salt at the wall is close to the top of the wall around most of the perimeter. It was also determined that the scanner system was reporting the pile height to be around 4 ft shorter than the height measured using the laser distance finder. The research team took the area of the salt footprint, multiplied by 4ft, and added it to the scanner reading of 42,000 ft^3, the resulting volume was 68,000 ft^3.

Two additional ground-based laser scans were performed during the winter season in order to provide additional comparisons with the acoustic scanner. The scans were performed by a company that specializes in stockpile volume measurement using industry standard 3D laser scanning technology. The first of the two additional scans took place in mid-February (2/10/2015), when the dome was at approximately 25 % of its 5500 ton capacity. The scan data was used to create a digital image of the salt pile, from which the volume of the salt was calculated. Two views of the pile image are shown in Figure 23, where arrows have been used to indicate the location of the dome doorway. Figure 24 shows pictures that were taken from the dome doorway in order to compare with the digital pile image. The pictures in Figure 24 were taken as the camera was rotated in the clockwise direction starting at the left of the dome doorway.

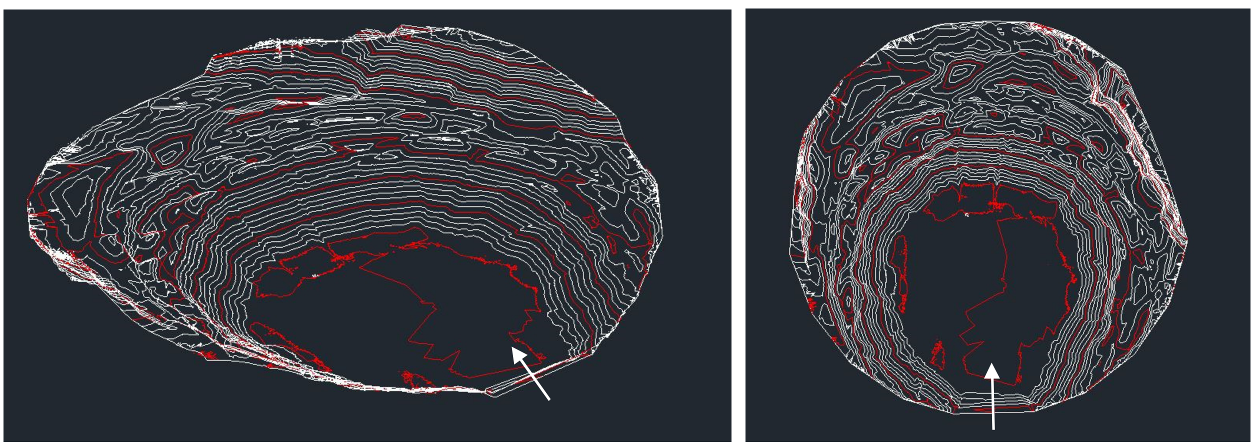


Figure 23. Digital image of the salt pile at Riveredge (2/10/2015).

Figure 24. Pictures taken from the dome doorway at Riveredge (2/10/2015).

Comparison of the digital image with the pictures of the pile shows that the major features of the salt pile were captured, where the salt is located mainly around the walls of the dome. The volume calculated from the digital image was determined to be approximately 42,000 ft^3, while the volume reported by the acoustic scanner during this time was approximately 45,500 ft^3. Comparison of the acoustic scanner readings and the ground-based laser scanning showed that the acoustic scanners overestimated the volume by around 8 %.

The second third-party scan took place in mid-March (3/19/2015), when the dome was at approximately 50 % of its 5500 ton capacity. Again, the scan data was used to create a digital image of the salt pile, and the volume of salt was calculated. Two views of the pile image are shown in Figure 25, where arrows have been used to indicate the location of the dome doorway. Figure 26 shows pictures that were taken from the dome doorway in order to compare with the digital pile image. The pictures in Figure 26 were taken as the camera was rotated in the clockwise direction starting at the left of the dome doorway. The volume calculated from the digital image was determined to be approximately 64,000 ft^3, while the volume reported by the acoustic scanner during this time was approximately 72,000 ft^3. Comparison of the acoustic scanner readings and the ground-based laser scanning showed that the acoustic scanners overestimated the volume by around 13 %.

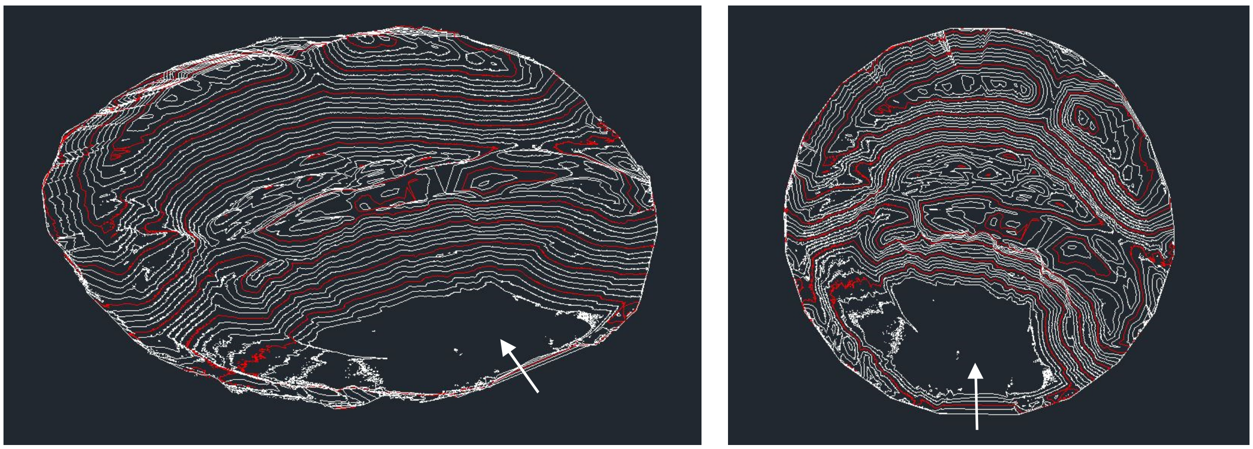


Figure 25. Digital image of the salt pile at Riveredge (3/19/2015).

Figure 26. Pictures taken from the dome doorway at Riveredge (3/19/2015).

Change in Volume vs. Time

Another way to evaluate the accuracy of the scanner system is to look at changes in volume over time. This can be done by comparing the volume from the acoustic scanners with the volume determined from the salt records kept at the garage, over the course of the winter season. The garage records include the weight of salt delivered to the garage, buckets of salt dispensed, and daily visual estimates of the salt. The weight of salt in the dome determined by visual estimates, and that determined by salt delivered and dispensed, was compared with the volumes reported by the acoustic scanner system. The weight of salt in the dome determined by salt delivered and dispensed was calculated by adding and subtracting salt from the weight at the beginning of the winter season. The latter was calculated by subtracting the salt delivered during the final pre-season fill-up from the post fill-up visual estimate.

In order to determine the weight of salt dispensed, it was necessary to convert between loader bucket volume and weight, which requires making an assumption about the salt density. The density of deicing salt varies depending on the gradation, moisture content, and compactness. The Salt Institute (2013) reports that the density of salt varies from 72 lb/ft^3 for loose salt to 84 lb/ft^3 for compacted salt, and suggests that a value of 80 lb/ft^3 be used for stored salt. The research team used a value of 74 lb/ft^3 for all conversions between weight and volume in the acoustic scanner study. This value is consistent with that used at the Riveredge garage. It should be noted that there will be an error in the volume of salt dispensed based on the assumed density value, and the magnitude of the error will vary depending on the true density of the salt in each loader bucket.

Figure 27 shows the volume of salt versus time for the acoustic scanners, salt delivered/dispensed (in-out), and the visual estimates. Figure 27 also shows the volumes reported by the three ground-based laser scans performed on November 4th, February 10th, and March 19th. The volumes reported for the acoustic scanners were taken at 11:59 pm, the visual estimates at 6:00 am, and the in-out volume was calculated for a 24 hr period ending at 11:59 pm every day. Some visual estimate data was missing from the garage records, and there was missing data for the acoustic scanners during a period when the acoustic scanner system was offline. In both cases, only the available data is shown. Figure 27 shows that all three volumes follow the same general trend over the data collection period. There are large spikes in all three volumes around November 12th that correspond with the pre-season fill-up, and then an immediate drop as the Riveredge garage responded to its first winter event. The volume readings level off around December 1st and remain steady through December 31st, which is consistent with the moderate snow experienced in the Cleveland area for the month of December. Another change in the volumes is observed in the month of January as the winter season gets underway, and the salt levels diminish over the course of the month before a large delivery on January 20th. This delivery is followed by substantial usage during the last couple of weeks in January.

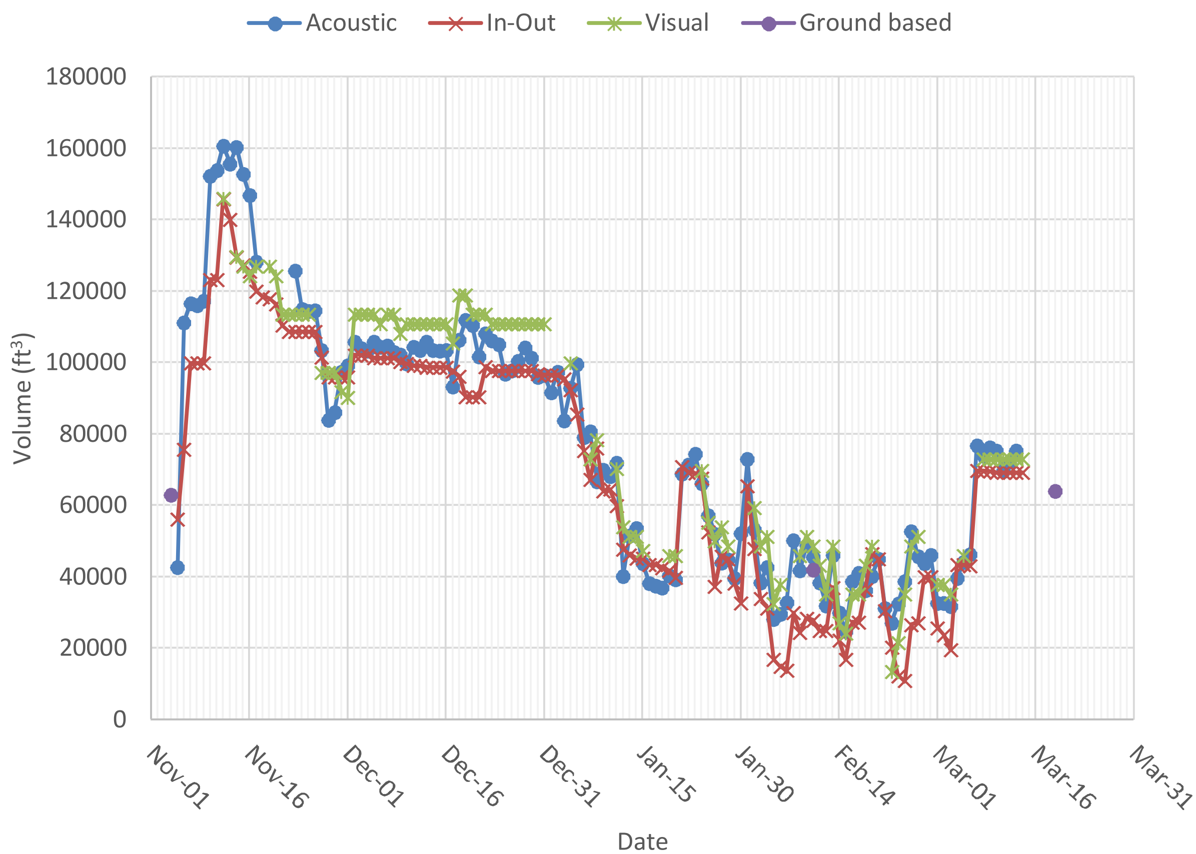


Figure 27. Total volume versus time for acoustic scanners, salt delivered/dispensed, and visual estimates.

At the start of February, the salt volumes reported by the scanners and those based on the salt delivered/dispensed diverge, with the salt delivered/dispensed falling below the salt volumes reported by the scanners. The research team believes that the discrepancy in the data is likely due to an error in the records for salt dispensed (i.e. missing data, incorrectly reported data, etc.) rather than an error in the acoustic scanner readings. This conclusion was based on the consistency with which the scanners were tracking the salt delivered/dispensed prior to, and the similarities in the volume fluctuations reported by both methods following, February 1st. This assertion is further supported by the following: (1) the volumes determined from the acoustic scanner system during this time reflect the same increase in salt reported by the visual estimates and (2) the acoustic scanner volume is in agreement with the volume determined by the ground-based laser scan on February 10th.

Comparison of the acoustic scanner volume data with the salt delivered/dispensed and the visual estimates in Figure 27 reveals some important features of the acoustic scanner system. First, the scanner data contains fluctuations that are not due to actual changes in the volume of salt in the dome. Some of these fluctuations are due to the volume error corrections discussed in Section 4.2.2. However, other fluctuations are too large to be attributed to the same. Also, there are volumes reported by the acoustic scanner system that are not consistent with the overall volume change determined from the salt delivered/dispensed and visual estimates. Upon closer examination of some of the larger differences in volumes around November 14th, December 1st, December 18th, and March 4th, they appear to coincide with the larger changes in the salt volume, which typically occurred over several days as salt was either delivered to the dome or removed due to a winter storm. The acoustic scanner system appears to overshoot, or overestimate, the change in salt volume for these large changes. The overshoot may be attributed to using empty and fill rates in the scanner software that are not consistent with the actual rates at the dome.

In order to look closer at the differences in the volumes reported by the acoustic scanners and that determined by salt delivered/dispensed and the visual estimates, the percent differences in the acoustic scanner readings were calculated and plotted over time. The percent differences were calculated as follows:

$$\%\Delta = \frac{V - V_{acoustic}}{V} \times 100\ \%, \tag{14}$$

where V represents the volume calculated from the salt delivered/dispensed or the visual estimate, and $V_{acoustic}$ represent the volumes reported by the acoustic scanners. Figure 28 shows the percent differences between the acoustic scanner and the salt delivered/dispensed versus time. Also presented in the figure is the volume of salt in the dome calculated as a percentage of the dome capacity, or 'percent full', based on the record of salt delivered and dispensed. Figure 28 shows that the two volumes compare well up until the beginning of February, with the few previously noted exceptions. After February 1st the percent differences between the two volumes are larger, but then decrease again after March 3rd. Figure 28 also shows that when the salt levels remain relatively steady from December 2nd – December 18th and December 23rd – January 3rd, the percent differences between the two sets of volumes are generally smaller. The exception to this occurs from January 12th – January 19th, where the salt levels remain steady at around 30 %, but some percent differences between the volumes reach almost 20 %. On the contrary, Figure 28 shows that when there are sharp changes in the volume such as early and late November, December 19th, and early January, the percent differences between the volumes are generally larger. A comparison of the percent differences in February and early March has been intentionally omitted as these percent differences are already large due to the disagreement in the volume data.

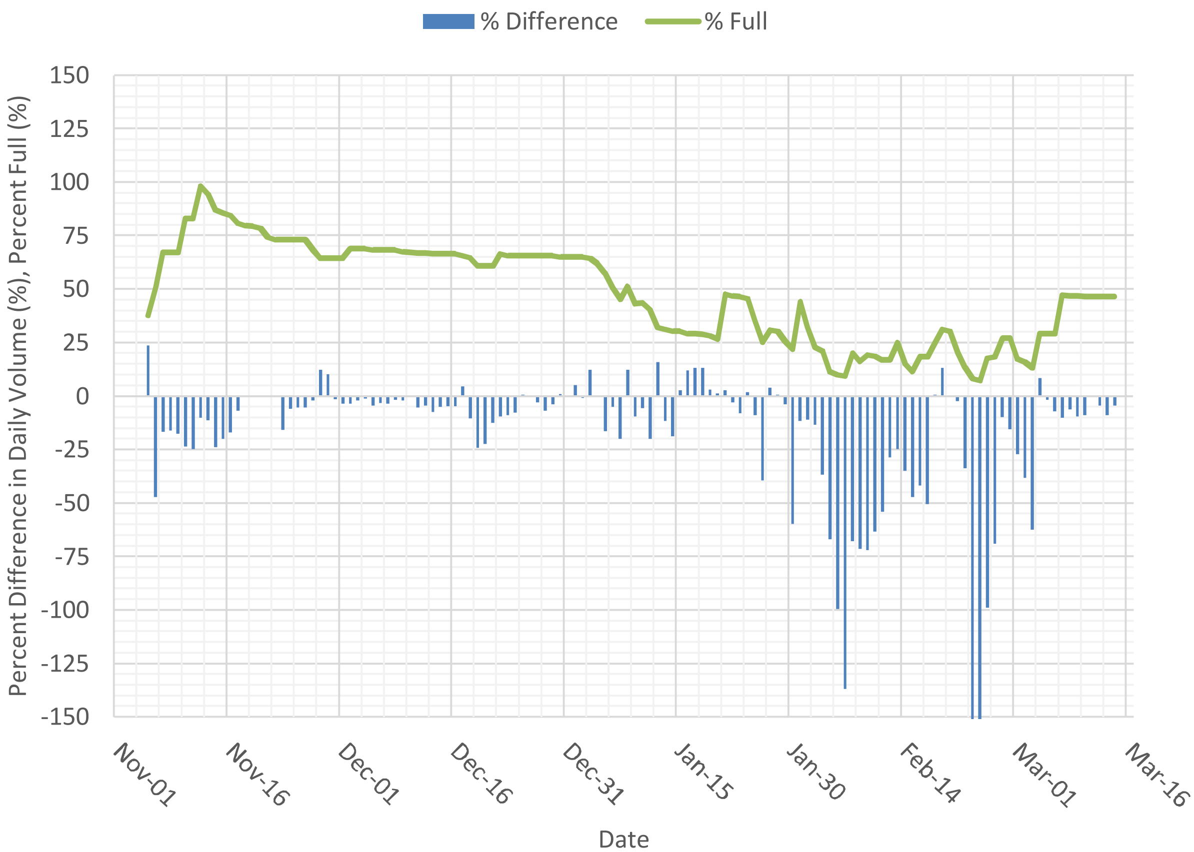


Figure 28. Percent difference in volume between acoustic scanner system and salt delivered/dispensed, and percent full, versus time.

In addition to comparing the acoustic scanner volumes with the volumes based on salt delivered/dispensed, they were also compared with the volumes based on the visual estimates. Figure 29 shows the percent differences between the acoustic scanner volumes and the visual estimate volumes versus time. Also presented in the figure is the 'percent full', which is again based on the record of salt delivered and dispensed. It should be pointed out that visual estimate volumes are missing for some days during the data collection period, and in general these days can be identified by values of zero percent difference on the y-axis. Figure 29 shows that the two volumes are comparable over the data collection period, with notable exceptions occurring mid-November, January 12th, and on February 22nd and 23rd. Once again, it is observed that the percent differences between the two sets of volumes are smaller when the volume in the dome is not changing, or changing gradually. Meanwhile, the percent differences are larger for sharper, more frequent volume changes.

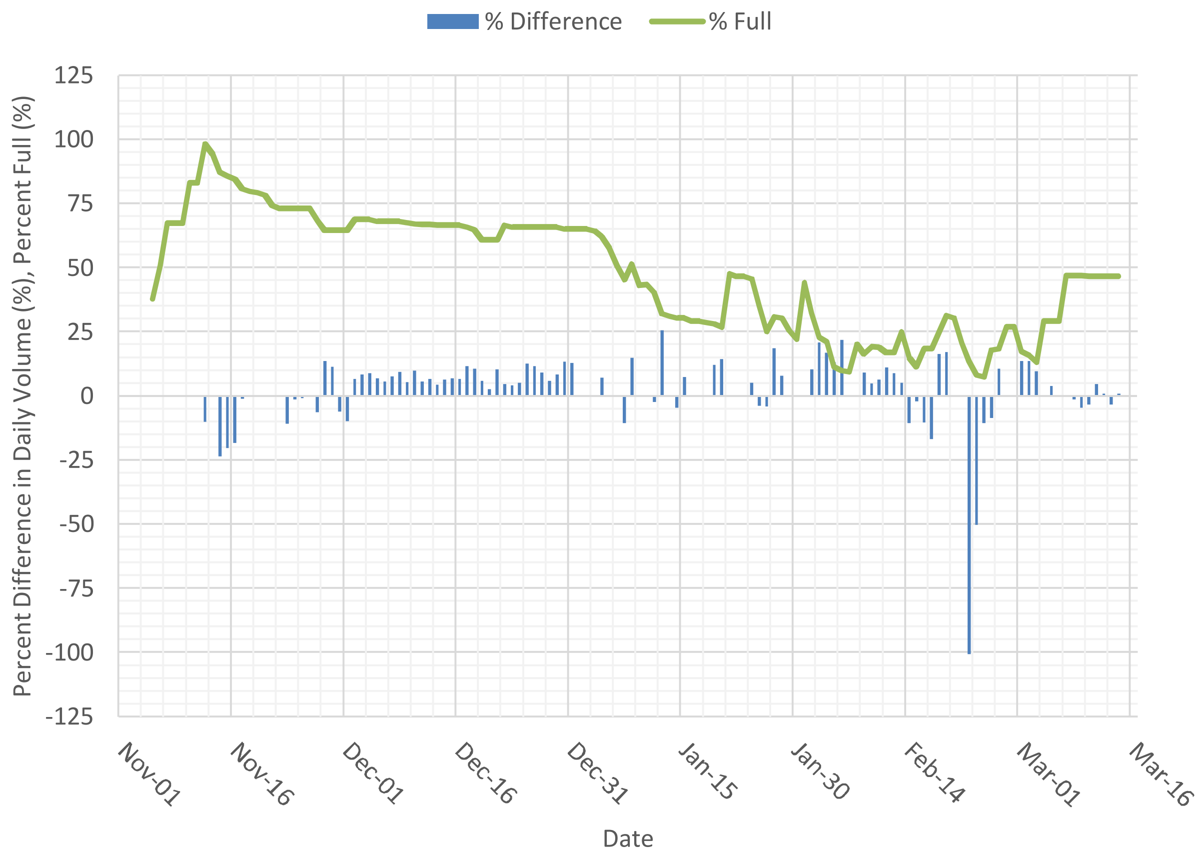


Figure 29. Percent difference in volume between acoustic scanner system and visual estimates, and percent full, versus time.

4.2.5 Issues Encountered

The primary issues with the acoustic scanner system occurred during installation. Due to high vehicle activity between the dome and garage, it was not possible to hard-wire the scanners to the controller by running cable underground or overhead. Therefore, it was necessary to transfer the data via a wireless signal. As described above, the slow rate of data transfer between the scanners on the dome and the controller on the garage resulted in errors in the processed data. This issue was corrected by reconfiguring the setup so that the controller was hard-wired to the scanners on the dome side, and the processed signal was then transferred wirelessly to the garage.

5. Conclusions and Recommendations

ODOT has identified two issues with salt storage at garage facilities within Ohio: 1) an inability to maximize salt storage in dome structures and 2) an inability to maintain accurate salt inventory using visual estimates. To realize greater efficiency at salt dome facilities, research was performed to identify the state of the practice in salt storage, and evaluate modifications to ODOTs existing salt storage practices to improve salt storage in the State of Ohio. Specifically, research was performed to evaluate salt domes, identify the state of the practice for salt loading and inventory, identify available options and useful equipment, perform a cost-benefit analysis, provide recommendations based on the identified options, and perform field evaluations of approved recommendations. Based on the results of the research, ODOT will benefit by having tangible solutions that once implemented, can increase efficiency and safety at salt dome facilities, ultimately saving ODOT time and money.

5.1 Salt Loading

After identifying the best practices in salt loading both in and outside the state of Ohio, a portable diesel conveyor with 6-ton hopper was identified as the best option for improving salt loading in dome structures in Ohio. As a result, the conveyor was selected for field studies to take place at the Wood County Garage over the course of a four month period (November-February). The performance of the conveyor was evaluated through comparison with a PTO conveyor configured in different loading setups. The setups included the PTO conveyor with a dump truck and loader, PTO conveyor with a 6-ton hopper and loader, and the PTO conveyor with direct-dump trough conveyor. The PTO conveyor was selected for comparison as it was the previous loading method at the Wood County Garage, and provided a benchmark from which to evaluate a potential improvement in the loading method.

For each loading setup, data was collected on the loading rate, number of staff and equipment required for operation, and operational costs. The operational cost was calculated both including and excluding the cost of ODOT standard equipment such as loaders, dump trucks, and tractors. The cost and loading rate data was used to calculate a rating index for comparing the cost-effectiveness of the loading setups. Based on the data collected, the following conclusions can be made about the loading setups studied:

1. When considering the cost, loading rate, and garage resources (i.e. staff, equipment), the diesel conveyor is the best option for loading salt in domes.
2. When only considering loading rate, the diesel conveyor is the best option for loading salt in domes.
3. When loading rate is not a priority and only cost is considered (i.e. garages with low salt demand), and garage resources are available, the PTO conveyor with dump truck is the best option for loading salt in domes.
4. Where loading rate is not a priority and only cost is considered, and garage resources are limited, the PTO with trough conveyor is the best option for loading salt in domes.

It is important to note that the decision to select a particular loading setup will be based on a balance between the needs of a garage and its available resources, and should be made on a garage-by-garage basis. However, the data collected during the course of this research can be used to select between the four loading setups studied. Furthermore, the methodology presented for analyzing the loading setups can be extended to other loading alternatives if sufficient information is available.

5.2 Salt Inventory

In order to address ODOTs need to improve their salt inventory, two fast, accurate, and autonomous methods for salt inventory were identified; acoustic and laser scanning systems. Of these, the acoustic scanner system was selected for field studies and installed in a 5500 ton salt dome at the Riveredge Garage in Cleveland, OH. The acoustic scanner system was selected based on its faster scanning times, low maintenance requirement (i.e. self-cleaning feature), ease of performing maintenance, and relatively low cost. Data on the volume of salt reported by the scanner system was collected over a four month period (November-March). In order to evaluate the acoustic scanner system, ground-based laser scanning was performed and the resulting volumes were compared. In addition, the daily salt balance at the garage determined from incoming and outgoing salt, as well as visual estimates, were compared with the scanner volumes over the duration of the data collection period.

It was found that the acoustic scanner volumes and the volumes determined from the 3rd party ground-based laser scanning were in agreement. Furthermore, comparison of the acoustic scanner volumes with the volumes determined from salt delivered/dispensed and visual estimates demonstrated that the acoustic scanner system was capable of tracking the changes in salt volume in the dome for most of the of the data collection period. In general, the volumes reported by the scanners are closer to those determined from the salt delivered/dispensed and visual estimates when the salt volume in the dome remains steady, or changes gradually. However, the scanner system has more difficulty tracking the salt volume when it fluctuates due to salt being added and removed on a frequent basis. Fluctuations in the scanner volumes that are not consistent with the overall volume change were observed, and these fluctuations should be considered when using the system as an inventory tool for reporting daily volumes. Based on the results of the scanner evaluation, it is recommended that the system be used in combination with another inventory method (i.e. visual estimates) for salt inventory. In doing so, garage managers will have a frame of reference for interpreting the volumes reported by the scanner system. Due to the novelty of such a system for salt inventory in large dome structures, additional monitoring of the system performance is warranted before considering widespread implementation.

One of the observations made during the evaluation of the acoustic scanner system was that the volumes determined by salt delivered/dispensed were not consistent with the volumes determined by ground-based laser scanning and visual estimates at the beginning of February. This was attributed to human error in the reporting of outgoing salt during this time. Improvement of daily salt balances based on salt delivered/dispensed could be achieved by using electronic methods for measuring and recording the salt dispensed, thereby minimizing human error. The observations made during the present study suggest that future research into such methods is warranted.

6. Recommendations for Implementation of Research Findings

6.1 Salt Loading Implementation

The results of the research conducted herein suggest that the diesel power conveyor with 6-ton hopper is the most effective method for loading salt into dome structures in Ohio. This is due to the high loading rate and low staff requirement associated with this method. However, equipment and operational costs, salt output, and the availability of county garage resources will influence the selection of the best loading option for a particular garage. Based on the results of the research conducted herein, the following is recommended for loading salt into domes in Ohio:

- For high salt output garages where loading speed, cost, and available garage resources are all considered, the diesel conveyor with 6-ton hopper should be utilized.
- For high salt output garages where loading speed is the highest priority, the diesel conveyor should be utilized.
- For low output garages where loading speed is not a priority, and garage resources are available, the PTO conveyor with dump truck should be utilized.
- For low output garages where loading speed is not a priority, and garage resources are limited, the PTO conveyor with trough conveyor should be utilized.

By implementing one of the recommendations above, county garages will benefit by having a salt loading method that fits their specific needs and available resources. This will lead to a potential increase in loading efficiency and cost savings by ensuring that each garage has the loading equipment appropriate for its winter snow and ice operation.

Prior to implementing one of the recommendations listed above at a garage in Ohio, the salt output, financial resources, and available equipment and staff should be considered. Once a decision has been reached as to which loading option best fits the garage, a company specializing in conveyance equipment should be contacted. In the state of Ohio, a state contract with Kimco conveyors is already in place, and pricing for the conveyance equipment required for each loading setup is available (see Table 9, Section 4.1.3). It is suggested that the recommendations detailed above be implemented for the 2015-2106 winter season.

6.2 Salt Inventory Implementation

The results of the acoustic scanner evaluation suggest that the system has potential as a tool for salt inventory management. In general, the system was shown to track the salt use at the Riveredge garage over the course of the data collection period. However, the natural fluctuations in the daily volume readings, combined with the measurement errors observed during frequent salt usage, should be considered when using the acoustic scanner system for daily inventory purposes where a high level of accuracy is desired for the purpose of predicting salt levels, and placing timely salt orders. As a result, it is recommended that the system be used in combination with some other inventory method, such as visual estimates. This would provide the garage manager a frame of reference for interpreting the volumes reported by the scanner. Another use of the system could be to track salt usage on a seasonal basis in order to determine the end-of-season balance. This information can be used for determining the amount of salt required for the next season's fill-up. Furthermore, the system can be used to identify trends in salt usage that would help ODOT predict their monthly salt needs in future seasons. In summary, the recommendations for potential future implementation of the acoustic scanner system are:

- Use the system in combination with another inventory method (i.e. visual estimates) as a salt inventory tool for reporting daily salt volumes.
- Use the system as a tool to determine the end-of-season balance and the amount of salt necessary for the pre-season fill-up.
- Use the system as a tool for assisting ODOT in identifying salt usage trends and predicting salt needs for future seasons.

By implementing the acoustic scanners for the uses recommended above, ODOT will benefit by having a quick, convenient method for salt inventory.

In order to implement the acoustic scanner technology, a company specializing in the installation and operation of the equipment should be contacted. The cost for the 4-scanner system used in the present study was $47,500, and included a raising/lowering system for maintenance. However, domes of different sizes will require different numbers of scanners, and the cost will vary accordingly. In the first year of operation, it is recommended that the volumes reported by the system be checked with the garage records for salt/delivered dispensed, as was done in the present study. A monthly comparison will reveal any significant discrepancies between the two records. It is also recommended that this information be shared with the company technical representative so that any fine tuning of the system may be performed. It is suggested that implementation take place prior to the pre-season fill-up for the 2015-2016 winter season, as the post-fill-up volume serves as the first useful benchmark from which to compare the scanner readings.

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Appendix A1. Preliminary Survey of DOTs

Topic: Salt Storage Practices for Winter Snow and Ice Management

Audience: State Maintenance and Operations Administrator, District Deputy Directors, District Highway Management Administrator, County Transportation Administrators (County Managers), County Garage Managers.

Deadline: 10/18/2013

Contact Information:

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Survey Context: Salt domes are widely used in the State of Ohio for storing salt for winter snow and ice removal. Difficulties accessing storage space in salt domes due to dome geometry and loading equipment (loaders) has resulted in a salt storage process that is inefficient and potentially unsafe to maintenance staff. Furthermore, inadequate protection of salt stored in dome structures from rain and snow may result in conditions that are unsafe to the environment. For these reasons, ODOT is investigating alternatives for loading and storing salt that maximize salt dome storage capacity while simultaneously providing for the safety of the maintenance staff and the environment. The purpose of this survey is to determine what other salt loading equipment, salt loading procedures, and salt storage facilities are being used by state DOTs throughout the country. The information from this survey will be used to evaluate alternatives to ODOT's current process with respect to cost, efficiency, and safety.

Preliminary Survey Questions:

1. What type(s) of storage facilities do you use to store salt for winter snow and ice removal?
2. What type(s) of equipment do you use to load salt into the storage facilities?
3. How is the volume of salt in the storage facilities determined for salt inventory?
4. What measure(s) do you use to protect the environment at the storage site from salt contamination?
5. Can you provide technical expert contact information in order to discuss your state DOT's salt loading and storing practices in more detail?

Appendix A2. Responses to Preliminary Survey of DOTs

Table A2.1. Summary of response from preliminary survey of DOTs.

DOT (1)	**Q1** (2)	**Q2** (3)	**Q3** (4)	**Q4** (5)
Arkansas	Domes, wooden framed structures, fabric covered structures w/ metal frame	Loader, indoor delivery	Estimated w/ pile dimensions	concrete pads/walls, runoff containment areas
British Columbia	salt sheds; salt piles	truck and loader	needs clarification	primarily bib and liner design; explored/experimented with paved surfaces and containment ponds
California	permanent salt sheds	front end loaders	amount received during season should be close to operator daily salt logs	grades slope away from salt shed; concrete floors (mostly 6 ft walls)
Idaho	arched or trussed buildings with openings at both ends - no domes	belt loaders/conveyors when available; sometimes front end loader	inventory is based on tonnage received from scale tickets	asphalt floor sloped to the center
Illinois	salt domes (90%); 1 fabric structure; few lean-to or building bay style storage	conveyors (safer and more efficient); end loaders	estimate the percentage full and reconcile with our inventory records.	All domes and salt storage are on impermeable surfaces
Indiana	several dome structures, several poured concrete with canvas covered type facilities	front end loader; schedule our salt vendor to use a conveyor to load the salt into the facilities at ~$4.00/ton more.	3 year average usage	new facilities designed to prevent runoff or leaching; older facilities have added doors, pads, pits and wash bays
Iowa	wooden framed buildings; fabric-roofed hoop buildings; domes	stainless steel augers and loaders	estimated from facility capacity and type of loader used	paved floors; aprons around building; salt piles are to be under roof; all salt structures have doors to keep out weather

Kansas	salt domes, salt cones, three sided bunkers with steel frame, fabric covered, stacked bridge beams with a wood truss roof	loaders and conveyors	tons delivered and loader buckets used	salt stored under roof; salt sand stored under bunker; salt dumped on asphalt pad and cleaned up with loader
Kentucky	Domes, wooden sheds, fabric covered structures, a few multi-bay open sheds	loaders, stainless steel elevator (similar to grain elevators for silos)	estimated based on dimensions of the salt pile, inventory reporting system?	salt stored under roof, stored on asphalt pads, open facilities are covered until needed, retention ponds to catch runoff
Maryland	salt stored in domes and barns (began to transition from domes to barns in the mid 90's and that is all that is built now).	wheeled loader of varying size	salt delivery tickets determine initial inventory; used salt tonnage captured by loader scoops; new deliveries added	spilled salt returned to structure; temporary berm at the entrance keeps salt in buildings between winter events
Michigan	concrete walled storage facility; few older salt domes.	sheds use loader; domes use conveyor	sheds - line on the wall indicating the maximum height of our salt pile (keep the pile flat).	floor slope to back wall of shed; trucks loaded inside shed; drive and pad outside sheds are paved with runoff contained
Minnesota	older lean-to style buildings; wood framed w/ wood trusses; steel columns w/ steel joists; steel frames w/ fabric roof	front end loaders; conveyors for larger sheds due to ability to stack higher without risk to equipment operators.	track usage as it goes out and use standard survey equipment to validate; Lidar has been proposed but not evaluated	impervious floor; sloped floors to contain drainage; max fill height; entrance setback; covered loading area; good house keeping
Missouri	fabric storage buildings, some salt domes, fewer wooden bays	loaders and conveyors	estimated based on dimensions of the salt pile	all salt covered; prevent runoff from leaving property
Montana	steel arched w/doors, metal sided building, open-ended fabric buildings	loader, conveyor, auger	subtract amount used from amount delivered; questionable stockpiles (compared to inventory) are measured	cover the stockpile when possible; build containment pads with evaporation ponds
New Jersey	Domes, fabric covered structures, wooden structures	loaders & conveyors	Guessing based on building capacity	Salt covered at all times

N. Carolina	domes, bay storage, bulk storage, and sheds for salt storage	domes - conveyor or 2cy front end loader (typical); bay, bulk, and shed storage - front end loader	domes-measure "cone" and figure the volume; bulk/bay storage-measurements on wall to determine volume visually	all facilities covered; hay bales at bay doors; county yards use check dams and silt basins; outfalls inspected bi-annually
New York	domes, high gambrel barns, "CoverAll" type fabric covered structures	two facilities are equipped with conveyor systems; the remainder use front-end loaders	inventory tracked by accounting of delivery tickets and salt usage; visual estimates are made from time to time	curtains at entrances, impervious floors, clean up of spilled salt, all salt covered, pavement graded away from salt
Quebec	Domes, fabric buildings	loaders	software developed in-house to determine inventory	salt stored on asphalt/concrete pad, investigation of environmental impacts and solutions
Rhode Island	wood structures, fabric roof structures, open pavement areas with fabric covers	loaders	visual inspection and estimation; track salt orders and per storm usage	fabric covers, sand/earth berm, drainage system
S. Carolina	fabric tension membrane storage facility with galvanized steel trusses	loader	initial inventory from delivery tickets; salt use estimated by loader operator; corrections made by visual estimates	salt inventories are completely contained in the storage facility and protected from the environment
S. Dakota	Domes, covered sheds	loaders	piles are surveyed	salt kept under roof, stored on concrete slabs
Utah	metal 3 sided sheds; fabric covered storage areas; metal 4 sided buildings; fiberglass salt domes; open storage	wheeled front-end loaders exclusively (2 or 3 cy capacity)	delivery tickets and number of loads loaded into trucks minus returns to the salt piles	half of storage covered; all storage on dense-graded zero-voids asphalt pads; no surface runoff allowed
Virginia	Domes, pole-barn structures (wooden siding), metal sided buildings	Elevators, conveyors, loaders	Estimated based on amount delivered & amount used, measurement of pile	Asphalt pads, detention ponds for runoff, salt delivery indoors

Washington	metal roofed pole structures; canvas topped facilities	front end loaders; conveyors	quantity from delivery; salt use by truck/scoop volume; some loader scales; pile measured; salt applied vs inventory	catchment devices to prevent salt or liquid deicers to enter the surrounding environment
Wisconsin	Domes, wood sheds, cloth covered sheds, stockpiles, cribs, bunkers	Conveyors, loaders, dozers, snow blowers	based on usage	all salt covered year round; sand piles with less than 5% salt are covered from April 1 through October 1; annual inspections
Wyoming	1 dome, canvas arch buildings w/ conc. block base, metal sided/roofed pole barns, steel sided/roofed w/ 10ft concrete walls	Salt dumped outside structure and moved inside w/ loaders	load counts, and Force America instrumentation	Cancrete pads built to EPA standards

Appendix A3. Responses to Follow-Up Survey of DOTs

British Columbia
Limited information was collected from British Columbia. They have about 100 fabric covered open-ended structures, with a capacity of about 590 short tons each. The estimated service life of the fabric is 13-15 years, and about 30 years for the structure. The benefits of the fabric buildings are that they are relatively inexpensive and are a pragmatic solution, but they note that it is not a perfect design and can lead to environmental contamination. To combat this, they have evapotranspiration liners constructed in front of some of the sheds to capture dissolved road salt, and prevent migration of salt water off site. They also note that inappropriate use and maintenance can shorten the building lifespan.

All loading is contracted out. They are constantly stressing improved salt handling practices and use of best management practices.

California
Limited information was collected from California. Canvas/fabric covered buildings are used on most of the buildings, which have concrete walls, PCC floors and wood superstructures, some have metal roofs. Estimated building storage capacity was 400 tons.

Idaho
Idaho has two types of salt storage buildings, fabric covered steel truss facilities (about 45%) and open-end steel sheds (about 55%). Until recently, Idaho was exclusively building fabric covered structures due to cost, about $12-13 /sq. ft but the last bid they got was $18 /sq. ft; the same cost as the steel open-end building. At this time, they do not measure salt loss from the buildings, but estimate it at about two percent. Idaho uses survey equipment to measure salt piles at the end of each winter season. They measure the pile volume and then convert it to tons. Idaho is implementing mobile data collection from their spreaders to get more accurate data on salt usage. When asked the importance of inventorying salt on a scale of 1 to 5, with 5 being the highest, Idaho rated it a 4, and rated their salt inventory efforts a 4.

Idaho uses loaders and belt conveyors to load and stack salt into their facilities. They now require the lower portion of the belt conveyor frame to be constructed of stainless steel. The only issues they have had with using loaders is that stacking the salt with loaders can crush the salt crystals creating a smaller gradation, but they have not noticed this affecting salt performance.

Illinois
Illinois has almost all domes structures, a few open-ended sheds, and covered storage piles on AC pads, and one fabric covered building. Illinois prefers domes, even though they require a temporary salt ramp for loaders to fill the domes. They conduct special training for their loader operators when salt ramps are used. Conveyors are used and shared within an 80 mile radius and are used in the big domes, with more than 5000 tons capacity. Illinois has one building elevator/conveyor, and occasionally contracts out loading services.

To inventory salt, Illinois uses delivery tickets minus scoops used, and only survey salt piles occasionally. When asked the importance of inventorying salt on a scale of 1 to 5, with 5 being the highest, Illinois rated it a 5, and rated their salt inventory efforts a 4.

Indiana
Indiana has mostly dome structures and fabric covered buildings, with a few wood framed buildings, high gambrel barns, and steel frame buildings. Indiana noted that they have had issues with roof repair of the domes and have used “foam” which has proved to have a 10 year service life, stating that it is hard to repair damage in the domes. Indiana is building some large rectangular metal and tension fabric structures with one very large door at one end and a door on the opposite side at a right angle to the building axis so that trucks can pass through without backing up. The buildings also contain wash bays with a recovery sump to reduce salt loss. The spacing between buildings is kept to at least 80 ft so that trucks can turn around.

Indiana uses loaders to load salt, and employs a third party service to use a conveyor to load salt 15 to 20% of the time. Indiana inventories salt using delivery tickets minus the amount withdrawn and applied. When asked to rate the importance of inventorying salt on a scale of 1 to 5, with 5 being the highest, Indiana rated it a 5 with their efforts at inventorying salt a 5.

Safety concerns noted by Indiana include workers on foot in the presence of loaders, which is now prohibited. Indiana noted that a management issue of salt storage facilities is corrosion, but that it can be managed by proper choice of construction materials. Indiana feels their fabric buildings are an example of a new technology that has improved their storage capabilities.

Iowa
Iowa has fabric covered buildings, wood framed buildings, and domes. The fabric covered buildings are the preferred building type for Iowa and allow for a semi dump trailer to dump a load in them, but they are not building them anymore. The wood framed buildings can have the salt pushed into them or bottom dumped.

Almost all loading is done in part with loaders. All conveyors used by Iowa are portable, about 25% of the garages have conveyors. Iowa inventories salt based on delivery tickets minus loader buckets out, and uses AVL/GPS reports on amount distributed. Three garages have loaders with load cells. Overall, Iowa does weekly or monthly salt surveys. Workers have memorized the approximate amount in a building by the lay of the pile. When asked to rate the importance of inventorying salt on scale of 1 to 5, 5 being the highest, Iowa rated it a 5 and rated themselves a 5 on their efforts to inventory salt.

Iowa has runoff containment at their brine facility for loss of up to one tank. They provide lighting on structures for night work. Iowa noted some safety precautions: avoid backing in to some structures like drive-through washing rooms or when loading brine. Challenges in managing salt storage facilities noted by Iowa were getting timely and correct reports. Iowa obtains cost adjustments for salt with contamination, by water, sand, etc. A new technology Iowa is using to better manage salt is the installation of AVL/GPS on all of its vehicles and they have found it to be very accurate. They are pairing the AVL/GPS with distributor rates and load cells weights and comparing this to application rates, and using this to calibrate units.

Kentucky
Kentucky currently has canvas/fabric covered buildings, domes, wood-framed buildings, open-ended structures, and a few arch/truss buildings. The canvas/fabric buildings were cited as being

easy to build and load, but that the fabric requires some maintenance at the seams and ends. The dome structures were cited as being easy to fill and load out, and provide good weather resistance, but that the shingled roofs require maintenance and they have had problems with ventilation fans. The wood-framed buildings were cited at being easy to construct, requiring minimal space, but do not provide the storage capacity needed. Some of the open-ended sheds used by Kentucky are canvas covered, and generally have too small of capacity for their needs. Kentucky uses concrete and asphalt as impervious liners between salt and soils. Kentucky also uses concrete aprons on all of their facilities to increase the lifespan of the structure and to reduce runoff.

Kentucky uses loaders and elevators to load salt. The elevators were cited as being able to properly load salt into the larger domes, but that availability of them is limited. Kentucky has a few permanently installed conveyors but some are mobile. They stated that stainless steel elevators are equipment modifications best suited to increase safety, capacity or environmental stewardship.

When asked to rate the importance of inventorying stored salt on a scale of 1 to 5, 5 being the highest, Kentucky rated it a 5 and rated their efforts at inventorying salt a 5. Kentucky uses a material management program that tracks salt use and deliveries.

When asked about examples of new technology or methods being used to improve salt storage at facilities, Kentucky stated that they are currently replacing their liquid storage tanks on a schedule and they are building some larger capacity facilities.

Maryland

Maryland contracts out about 70% of their snow and ice operations. Maryland has mostly domes, and wood framed buildings with one end open, and few storage piles that are covered. Barns are considered a safe salt storage building, and Maryland feels their newer barns are an example of new technology they are using that has improved salt storage in their state. Maryland also collects data from spreader controllers on dispensed salt. Maryland uses loaders almost exclusively and has one conveyor. Some of the salt loading is contracted out.

Maryland measures the salt on-hand from delivery tickets minus scoops taken out, and orders salt frequently after every storm. A full salt inventory is done every 3 to 4 years following a load-in. When asked to rate the importance of inventorying stored salt on a scale of 1 to 5, 5 being the highest, Maryland rated it a 5 and rated their efforts at inventorying salt at a 5. Maryland mentioned that an accurate salt inventory is critical to having enough salt on hand during storms.

Minnesota

Minnesota has mostly galvanized steel frame arch/truss buildings (about 50%), some fabric covered buildings (about 30%), and fewer wood-framed open-ended and gable-ended and small open-end lean-to sheds (about 10% each). The Arch/Truss buildings have had corrosion issues, and no cathodic protection has been used. The fabric covered buildings store higher salt volumes and have reduced truck and load hits. There have been some durability issues; salt can escape from the big opening, and these structures are difficult to modify. They have added covers over the fronts of these structures to reduce these issues. Overall, they estimate a 20 year service life, and have had luck with these structures. The pads are impenetrable and slope to the center for containment with a low point at the front of the pile. Minnesota also uses good housekeeping practices. They have lines on the walls to limit fill height. They use hard hats in all of these structures now after a building collapse. All new structures have a roof extension over the loading area to limit salt loss from runoff. The standard opening height is 18.5 ft.

Minnesota has portable loading equipment, and do all loading in-house. They mostly use multipurpose loaders. They do not allow driving on salt ramps. They have some conveyors that they share and have added spray bars to add liquid $MgCl_2$ to the salt. They have one auger unit and have found the auger screw, or flight, wears out quickly.

Minnesota inventories salt using delivery tickets minus scoops, and they use marks on the walls to aid in salt surveys. Minnesota tried LIDAR measurement for salt pile shape and volume but found it was too slow. When asked to rate the importance of inventorying stored salt on a scale of 1 to 5, 5 being the highest, Minnesota rated it a 5 and rated their efforts at inventorying salt at a 4. A major safety issue mentioned was driving on the pile, which is discouraged, and overfilling and truck washing were mentioned as environmental concerns.

To better manage their salt facilities, they have controllers on the trucks to measure the amount of salt used which is integrated with a maintenance decision supports system (MDSS). They are also using AVL and weather radar data on most trucks. Minnesota gets a refund for contaminated salt if the volume of contaminant is greater than or equal to 1.7% of the total volume.

Missouri

Missouri has a mix of fabric-covered buildings (about 55%) and domes (about 40%), with a few open-ended sheds they call bins, high gambrel barns, and wood-framed buildings. While Missouri prefers the dome structures for salt storage, they are higher in cost. For this reason, most of their salt is stored in fabric covered buildings because they cost less. For the dome structures, they use a rayon roof coating applied each year, and feel the buildings have an indefinite service life as long as the roof is replaced as needed. Only some of their domes have roof ports for loading. For the fabric covered structures, the fabric has a service life of about 10 years and the structure 10 to 15 years. The service life for the high Gambrel barns is listed as 30+ years.

For all building types, salt is kept 10 ft inside the building to prevent salt loss to the environment. All wash water is contained in lagoons or the sewer system with very strict control. Some washing is done off-site at an extra cost.

All of Missouri's loaders are shared and portable. Most loading is done with loaders, and they have four conveyors per 20 counties. For a small percentage of sites, tailgate dumps can be done inside of the structures. Missouri inventories their salt piles using survey equipment, delivery tickets minus scoops out, a few loaders have load cells and they have tried LIDAR for pile volume measurements. Missouri has found their spreader controllers do not keep an accurate count of applied salt. When asked to rate the importance of keeping a salt inventory on a scale of 1 to 5, with 5 being the highest, Missouri rated it a 5 and rated themselves a 3-4.

Montana

Montana has over 300 stockpile sites with about 25 to 30% of these covered by Quonset huts, stick wall with concrete footers, and fabric with metal trusses. The bulk of salt stored by Montana is at its five brine facilities, other locations store a salt (10-15% by weight)-sand blend. Montana has experienced major corrosion issues at its brine facilities with fabric structures, including fabric separating (maybe due to the elements – hot and cold), corrosion of cables, trusses, and electrical components. The fabric appears to hold in condensation from the brine making process and this seems to compound the corrosion problem. Ventilation was added, but this did not appear to fix the problem. The expected service life of the fabric structure was 10 to 15 years but they had one building condemned due to corrosion, after 7 years, which has now been replaced by a stick frame, metal sided structure.

Montana uses loaders to load material into storage and into trucks, as well as stacker belts or conveyors to load material into storage. Montana has found that the loader buckets can poke or rip unwanted "ventilation" holes into the fabric walls and damage trusses. Montana feels the stacker belt is the most efficient way to load salt into a building, because it better utilizes the size and height of the building, and makes a nice conical pile for size estimation. One lesson learned by MDT is that if the salt or sand on the stacker belt has a lot of minus 200 sieve material present and it is wet, the conveyor can get sticky and not work well. As a practice, Montana tries to hire personnel that already have machine experience, but will train personnel as needed on equipment.

Montana provided no comments on safety concerns other than corrosion issues to buildings and driving loaders in buildings and causing damage to the structures.

New York

New York has over 250 salt storage structures but does not keep statistics on them in a central database. These buildings include domes, fabric covered metal structures, wood framed buildings, open-ended sheds, gambrel barns, and a few arch/truss buildings. Domes are not favored due to high cost of re-roofing and loss of structures due to deterioration from lack of upkeep. They also noted that domes are vulnerable to damage from loaders and can be difficult to fully load. The door height of 20 ft is often not sufficient. A 40 ft code for overall building height makes it difficult to get the internal clearance. Based on these findings, New York no longer builds dome salt storage structures. New York's favored structure is a post and wood framed building, high gambrel barn, with a metal roof, 8 to 12 ft walls, with a 30 ft vertical door and internal clearance. New York has had issues with fabric buildings not lasting more than 15 years and corrosion issues of metal components. Internal liners were used to protect the structure, but ended up masking the corrosion. New York suggested using steel or cathodic protection on metal components. New York found that the fabric met wind speed codes but not snow weight codes. The building walls were built to resist damage by loaders. All salt storage structures are built with a complete site preparation guide, including environmental concerns. Brine runoff is impounded.

Safety issues of trucks backing up and into buildings and damaging structures and loaders being unsteady when driving on the salt piles were mentioned. Training is used to increase safety for loader operators.

New York does not keep track of loading equipment, but noted that they use loaders and have a few conveyors. Salt inventory is completed by keeping track of delivery slips minus material used. Some loaders track weight. When asked to rate the importance of keeping a salt inventory on a scale of 1 to 5, with 5 being the highest, New York rated it a 5 and rated themselves a 5.

North Carolina

North Carolina has domes, wood-framed buildings, open-end shed or bays, open storage piles, high Gambrel barns, and arch/truss buildings. North Carolina's preferred salt storage building is the bay storage referred to as the open-end shed; they can provide 1 to 4 per location with a capacity of 250 to 300 tons per bay. They have approved structural designs for the bay buildings and are all built the same either in-house or by contractors. They put hay bales at the entrances for storm water management. The domes, high Gambrel barns, and arch/truss buildings are all listed as having large storage capacity but issues with loading. The open storage piles are only used in an emergency and are covered by tarps.

All loading equipment is portable. Most loading is done with loaders but they also have conveyors.

North Carolina has annual maintenance yard and salt storage facility audits. They have safety signs up on structures and provide annual training. Noted safety concerns include loading distribution trucks at night in inclement weather, they have added lighting and operator training to reduce the risk under these conditions; vehicle flow through the loading areas for queued trucks is a hazard, and they have designed standard loading areas to avoid collisions in the yard. No one is allowed inside a storage facility outside of a vehicle. North Carolina also has storm water measures in place to prevent salt laden runoff from leaving the site, and noted that storm water management is a challenge.

When asked to rate the importance of keeping a salt inventory on a scale of 1 to 5, with 5 being the highest, North Carolina rated it a 4 and rated themselves a 4. The overall feeling is that their records are very accurate because of policies and annual audits. They use salt inventories to determine order times, and each department is responsible for its own salt inventory reconciliation.

Rhode Island

Rhode Island has wood framed salt domes, wood framed salt barns, and metal framed fabric structures, approximately 75% are wood, and 25% are fabric with this type increasing. Identified pros for each building type are: wood framed - rugged and durable; metal / fabric - rapid construction, low cost, salt does not seem to bother the structure. Identified cons for each building type are: wood framed - expensive, longer construction time, high maintenance, salt dry rots the wood; metal / fabric - susceptible to wind damage, life expectancy unknown at this point.

Wood structures were noted as being 3 times more expensive than fabric structures for the initial purchase and installation. No information was available on the maintenance cost of fabric structures because they are newly installed. Storage capacity for building types varies based on size, but for Rhode Island, domes hold the least, followed by barns, with the largest capacity building being the newly constructed fabric structure. Modifications made to increase security on seasonal facilities include overhead doors with the cost varying per location at $8,000 to $12,000, and fabric covers for the open salt piles at $30,000 per location per year.

Rhode Island uses wheel loaders to load salt into buildings. Rhode Island rents loading equipment. Salt is usually delivered in multiple haul trucks and one operator/loader loads the materials, roughly 8 to 16 hours to load. Operators usually require about 40 hours getting comfortable with the equipment.

Rhode Island did not state how they conduct their salt inventory, but on a scale of 1 to 5, they rate the importance of a proper salt inventory at a 5. They state that this has a greater impact on end of season inventory to control annual costs, that improper inventory will reduce operational capacity, and stress the importance of proper usage logs. Rhode Island rated itself a 3 out of 5 at salt inventory.

Safety issues raised by Rhode Island include vehicle and pedestrian traffic, and state that they restrict traffic in loading areas. Rhode Island listed environmental regulations and budget shortage as major challenges in management of salt facilities. New cost effective structures, in reference to the fabric structures just installed, were provided as an example of new technology to improve salt storage. The following is a success story shared by Rhode Island, "We have just completed construction of a new fabric building with 2 brine tanks inside and a covered loading area. This is the first of its kind in RI and we will begin construction on another similar structure in the spring of 2014 with plans for at least four more in future years."

South Carolina

As a state, South Carolina stores 40,000 tons of salt, which they purchase every two years or so based on need. They may go years without using it. South Carolina has one dome and 50 smaller structures scattered throughout the state, fabric covered and wood-framed buildings. All of these structures are younger than 10 years old, because of this annual maintenance is not well established, but often repairs are needed from equipment hits. The dome has concrete walls and is covered in fabric with a covered door, and they are building another one currently. The fabric covered buildings are similar; concrete walls and covered in fabric but are smaller. For the fabric salt storage structures modifications include PVC reinforced fabric, dip-galvanized steel for the support structure, fabric specified for hurricane winds (110 mph), and a wood wall inside the fabric to keep salt away from the steel structure. All loading is done with loaders and some third party loading is done. South Carolina is not concerned with salt inventory.

South Dakota

South Dakota has mainly fabric covered hoop structures, with some wood or steel sided buildings for salt storage. They have seen wind damage to the fabric structures when speeds exceed 60 mph. South Dakota prefers the wood or steel buildings for locations that do not need the headroom for loading and storing large salt quantities. They are currently bidding on concrete cast in place walled fabric covered structures for $29/sq.ft, and the wood and steel structures at $37/sq.ft. South Dakota is expecting a service life of 25 years for the fabric covered buildings and 40 years for the wood and steel buildings.

Loading is done with loaders, conveyors and hoppers and grizzlies. When they purchase new loaders, they require the vendor to provide up to 8 hours of training after delivery.

South Dakota uses survey equipment to measure the remaining salt at the end of the season. South Dakota reports minimal salt loss from buildings. When asked about the importance of inventorying stored salt on a scale of 1 to 5, with 5 being the highest, South Dakota rated it at a 4 and rated their salt inventory efforts at a 4, stating that they like to have an accurate accounting and this can minimize waste and prevent running out of salt during a storm. South Dakota is currently using MDSS and MDC's to increase their efficiency in salt usage, but maintaining an accurate salt inventory was listed as a management challenge.

Utah

Utah stores salt on open pads in the desert, four sided metal structures with roll-up doors, three walled south-facing doors, free standing arch/truss buildings, and three domes. Utah's favorite salt storage method is fabric covered galvanized or aluminum metal frame buildings with one end open on air-entrained PCC pads. They use a minimum door height of 16 ft protected with bollards. Utah uses "context-sensitive" design for their construction. Some examples of this include color choice of buildings and the direction the door faces. The latter is east in this case based on Navajo customs. Internal building lights are used in structures, some solar powered. Utah captures salt laden runoff in lined catchment ponds.

Utah uses loaders exclusively to load salt and only makes the piles as high as the loader can pile the salt. Utah stores up to 70% of annual salt usage, approximately 210 tons, and reorders mid-season based on needs. Salt is surveyed at the end of the year and is based on delivery tickets minus the amount used. Utah also has found that marking height on the building walls aids in surveying salt quantities. When asked about the importance of inventorying stored salt on a scale of 1 to 5, Utah rated it at a 5 and rated their salt inventory efforts at a 5.

Virginia

Virginia has 200 salt storage sites with about 20% of them domes, less than 10% of them fabric covered structures, and the remaining 70% wood-framed buildings (pole barns). They favor the wood barn structures because they are more permanent and have an almost infinite service life. Virginia does almost all of its loading with loaders, but some domes are retrofitted with fixed conveyors. They have found that the portable conveyors do not hold up well.

When asked about the importance of inventorying stored salt on a scale of 1 to 5, with 5 being the highest, Virginia rated it at a 3 and rated their salt inventory efforts at a 3. Management challenges with regard to salt storage facilities included environmental contamination and maintenance issues. Virginia does captures runoff from all mixing pads at salt storage facilities. A new technology being used to improve salt management is an underground runoff containment system, with a grit and water separator. It was very high in cost, and some feel was probably overdesigned.

Washington

Washington State's favored salt storage structure is the open-ended pole building, placed on an impermeable pad, with a 7 to 10 ft Portland Cement Concrete or "ecology block" wall, and a metal roof. They have found that they need to reinforce the corners with steel bracing to prevent shifting if hit by equipment, and they also added the bracing to some canvas structures. Washington has domes, canvas/fabric covered buildings, wood framed and open-ended sheds/old barns. They noted that it is hard to work inside of the domes and that they require a conveyor, and some have small entryways. Washington will not be building anymore domes. The canvas structures have failed from windstorms and have corrosion issues. The wood framed buildings were noted to be inexpensive, easy to repair and have a long life span. The open-ended sheds/old barns were noted to be inexpensive, but hard to work inside, and did not meet standards for door size.

Washington uses loaders to load salt and has one or two portable conveyors, but limited experience with them. Safety issues noted by Washington were backing control of the equipment. Major challenges in management of salt facilities included environmental contamination and maintenance issues. Washington conducts salt inventories monthly, and maintains a "net" from delivery trucks minus driver and AVL/GPS data. They found that the AVL/GPS data is not 100% accurate. When asked to rate the importance of salt inventories on a scale of 1 to 5, with 5 being the highest, Washington rated it at a 5 and rated themselves as a 4 for their efforts at inventorying their salt.

Wisconsin

Wisconsin does not own salt storage structures; the counties own them. The state buys the salt and pays the counties to store it and perform snow and ice operations. Wisconsin is not fond of the dome structures because it is difficult to accurately inventory the salt in them, they have found an error of up to 40%, and have had to empty out domes and put all the salt back in to get a more accurate inventory. Salt is loaded with a conveyor inside the dome, rarely through the roof. Wood frame structures and high gambrel barns with 10 to 12 ft concrete walls are favored, with a 5000 ton capacity and a grizzly bar-covered pit for vendor dumping/off-loading. The conveyors used start at the covered pit and dump material into the building. All of the conveyors are stainless steel belt conveyors, and are shared by three counties. For larger structures fixed-in place, 12,000 ton conveyors are used. Wisconsin's goal is to have empty salt storage structures at the end of winter, so they buy 125% of an average winter salt usage, with a 25% reserve contract with the distributor.

Appendix A4. Salt Storage Checklist

Date: 11/20/2013
Location: Wood County Garage
Inspector: Wally Richardson

Storage facility:

1.	Greater than 300 ft from water well? (y/n)	□Y
2.	Greater than 100 ft from ditches gutters? (y/n)	□N
3.	Greater than 300 ft from dry wells streams? (y/n)	□Y
4.	In a 100 yr floodplain? (y/n)	□NA

Impervious pad? (y/n)		□Y
1.	Asphalt or air entrained Portland Cement Concrete? (y/n)	□AC
2.	Is it strong enough to support equipment? (y/n)	□Y
3.	Does it have a 1-2% slope? (y/n)	□Y
4.	Is it curbed? (y/n)	□N

Sidewall:

1.	Is the salt contact height 1 ft below the wall height? (y/n)	□N
2.	If concrete block, is it coated to prevent seepage? (y/n)	□NA

Equipment Washing:

1.	Is equipment washed indoors? (y/n)	□Y
2.	Is equipment washed outdoors with controlled runoff? (y/n)	□N

Brine Equipment:

1.	Is brine equipment located on an impervious pad? (y/n)	□Y
2.	Is the containment capacity of impervious pad 110-125 % of tank capacity? (y/n)	□NA

Structure Condition:

1.	On a scale of 1-5, with 5 being the best, rate the wall condition. (1-5) (wall at entrance is in bad shape; interior wall is ok)	□2
2.	Are there leaks in the roof? (y/n)	□Y

Date: 11/21/2013
Location: Sandusky County Garage
Inspector: Wally Richardson

Storage facility:

1.	Greater than 300 ft from water well? (y/n)	□Y
2.	Greater than 100 ft from ditches gutters? (y/n)	□N
3.	Greater than 300 ft from dry wells streams? (y/n)	□NA
4.	In a 100 yr floodplain? (y/n)	□NA

Impervious pad? (y/n)		□Y
1.	Asphalt or air entrained Portland Cement Concrete? (y/n)	□Y
2.	Is it strong enough to support equipment? (y/n)	□NA
3.	Does it have a 1-2% slope? (y/n)	□Y
4.	Is it curbed? (y/n)	□N

Sidewall:

1.	Is the salt contact height 1 ft below the wall height? (y/n)	□N
2.	If concrete block, is it coated to prevent seepage? (y/n)	□NA

Equipment Washing:

1.	Is equipment washed indoors? (y/n)	□Y
2.	Is equipment washed outdoors with controlled runoff? (y/n)	□N

Brine Equipment:

1.	Is brine equipment located on an impervious pad? (y/n)	□Y
2.	Is the containment capacity of impervious pad 110-125 % of tank capacity? (y/n)	□N

Structure Condition:

1.	On a scale of 1-5, with 5 being the best, rate the wall condition. (1-5)	□5
2.	Are the leaks in the roof? (y/n)	□N

Date: 12/2/2013
Location: Independence Garage
Inspector: Wally Richardson

Storage facility:

1.	Greater than 300 ft from water well? (y/n)	□NA
2.	Greater than 100 ft from ditches gutters? (y/n)	□N
3.	Greater than 300 ft from dry wells streams? (y/n)	□NA
4.	In a 100 yr floodplain? (y/n)	□NA

Impervious pad? (y/n)		□Y
1.	Asphalt or air entrained Portland Cement Concrete? (y/n)	□Y
2.	Is it strong enough to support equipment? (y/n)	□Y
3.	Does it have a 1-2% slope? (y/n)	□N
4.	Is it curbed? (y/n)	□Y

Sidewall:

1.	Is the salt contact height 1 ft below the wall height? (y/n)	□Y
2.	If concrete block, is it coated to prevent seepage? (y/n)	□NA

Equipment Washing:

1.	Is equipment washed indoors? (y/n)	□N
2.	Is equipment washed outdoors with controlled runoff? (y/n)	□N

Brine Equipment:

1.	Is brine equipment located on an impervious pad? (y/n)	□Y
2.	Is the containment capacity of impervious pad 110-125 % of tank capacity? (y/n)	□N

Structure Condition:

1.	On a scale of 1-5, with 5 being the best, rate the wall condition. (1-5)	□4
2.	Are the leaks in the roof? (y/n)	□Y

Date: 12/2/2013
Location: Cleveland Garage
Inspector: Wally Richardson

Storage facility:

1.	Greater than 300 ft from water well? (y/n)	□NA
2.	Greater than 100 ft from ditches gutters? (y/n)	□N
3.	Greater than 300 ft from dry wells streams? (y/n)	□NA
4.	In a 100 yr floodplain? (y/n)	□NA

Impervious pad? (y/n)		□Y
1.	Asphalt or air entrained Portland Cement Concrete? (y/n)	□Y
2.	Is it strong enough to support equipment? (y/n)	□Y
3.	Does it have a 1-2% slope? (y/n)	□Y
4.	Is it curbed? (y/n)	□N

Sidewall:

1.	Is the salt contact height 1 ft below the wall height? (y/n)	□Y
2.	If concrete block, is it coated to prevent seepage? (y/n)	□NA

Equipment Washing:

1.	Is equipment washed indoors? (y/n)	□N
2.	Is equipment washed outdoors with controlled runoff? (y/n)	□N

Brine Equipment:

1.	Is brine equipment located on an impervious pad? (y/n)	□Y
2.	Is the containment capacity of impervious pad 110-125 % of tank capacity? (y/n)	□N

Structure Condition:

1.	On a scale of 1-5, with 5 being the best, rate the wall condition. (1-5)	□5
2.	Are the leaks in the roof? (y/n)	□N

Date: 12/3/2013
Location: Unionville Outpost
Inspector: Wally Richardson

Storage facility:

1.	Greater than 300 ft from water well? (y/n)	□Y
2.	Greater than 100 ft from ditches gutters? (y/n)	□N
3.	Greater than 300 ft from dry wells streams? (y/n)	□Y
4.	In a 100 yr floodplain? (y/n)	□N

Impervious pad? (y/n)		□Y
1.	Asphalt or air entrained Portland Cement Concrete? (y/n)	□Y
2.	Is it strong enough to support equipment? (y/n)	□Y
3.	Does it have a 1-2% slope? (y/n)	□N
4.	Is it curbed? (y/n)	□N

Sidewall:

1.	Is the salt contact height 1 ft below the wall height? (y/n)	□Y
2.	If concrete block, is it coated to prevent seepage? (y/n)	□NA

Equipment Washing:

1.	Is equipment washed indoors? (y/n)	□Y
2.	Is equipment washed outdoors with controlled runoff? (y/n)	□N

Brine Equipment:

1.	Is brine equipment located on an impervious pad? (y/n)	□Y
2.	Is the containment capacity of impervious pad 110-125 % of tank capacity? (y/n)	□N

Structure Condition:

1.	On a scale of 1-5, with 5 being the best, rate the wall condition. (1-5)	□5
2.	Are the leaks in the roof? (y/n)	□Y

Appendix A5. ODOT Salt Storage Practices

Wood County Garage

Salt Storage

The Wood County garage is located in District 2 in Bowling Green, OH. There are two salt domes located at the garage with only one dome currently used for storing salt. The dome dimensions were measured on site and are provided in Table A5.1. The dome has an outer diameter of approximately 62 ft, riser wall height of 5.5 ft, and a total height at the apex of around 30 ft. The storage capacity of the dome was reported to be 1,500 tons. A picture of the dome is shown in Figure A5.1. On average, approximately 4,500 tons of salt is stored in the dome per year. The salt is typically stored using either a portable conveyor or a loader, with the conveyor being used mostly during the initial pre-season fill-up and then the loader thereafter. When the conveyor is used for fill-up several piles are created by moving the conveyor around the interior of the dome (see Figure A5.1(b)). When the loader is used, the salt is pushed into the dome with the loader climbing the pile as the pile height increases.

The portable conveyor at the Wood County garage is driven using the PTO on a tractor. The salt is fed to the conveyor through the pigeon door on a dump truck, which in turn, is filled using a loader. In all, the process requires four pieces of equipment and two people. One drawback to this method is that the conveyor must be fed slowly to accommodate the limited power of the tractor PTO. The result is an approximate loading rate of only 57 tons/hr. Advantages of the conveyor are that it is capable of maximizing the storage space of the dome and may be operated with relative safety by ODOT maintenance staff.

The slow loading rate of the portable conveyor makes it inefficient for filling the dome during the active winter season. During this time, the dome must be filled quickly so that the salt can be loaded into the trucks for distribution on the roads. Therefore, in lieu of the conveyor, a loader is primarily used for filling the dome during the winter season. The loader is a more efficient method, as it requires only one piece of equipment and a single operator. Furthermore, the loader is faster with a reported loading rate of approximately 267 tons/hr. Drawbacks to the loader are that it cannot maximize the storage space of the dome (lose 300 tons dome capacity) and it is unsafe. The major safety issue with the loader is rolling while climbing the pile. A picture of a loader that has rolled during loading of a salt dome is shown in Figure A5.2. Accidents such as these can cause damage to the loader and/or the dome, as well as injury or death to the operator. One other drawback to using the loader is damage to the dome during routine operation. This typically occurs due to the lack of space inside the dome in which the loader can maneuver.

In order to make a direct comparison between loading methods at the Wood County garage, an ODOT staff member was asked to rate each method on a scale of 1 to 5, with 5 being the highest, in terms of loading speed, loading quantity, and safety. The results are shown in Figure A5.3. Included on the graph is the average rating (un-weighted) for each loading method, which yields a higher value for the conveyor. The result suggests that the conveyor may be an overall better loading method despite its slower loading speed.

Table A5.1. Dimensions for salt domes visited during site visits.

		Dome		**Riser Wall**		**Entry**	
Garage	**Capacity (tons)**	**Height (ft)**	**Diameter (ft)**	**Height (ft)**	**Thickness (in)**	**Height (ft)**	**Width (ft)**
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Wood	1500	30.2	62.4	5.5	11.3	16.5	15.0
Sandusky	1000	34.6	62.0	9.8	12.0	16.5	15.2
Independence	5500	62.1	101.0	11.8	12.0	21.4	15.2
Cleveland	2300	43.0	67.5	12.0	11.8	19.8	15.1
Unionville	800	28.0	60.0	9.9	11.3	18.9	15.0

(a)

(b)

Figure A5.1. Picture of the (a) exterior and (b) interior of the salt dome at the Wood County garage.

Figure A5.2. Picture of a loader that overturned during loading of a salt dome (courtesy of Wood County garage).

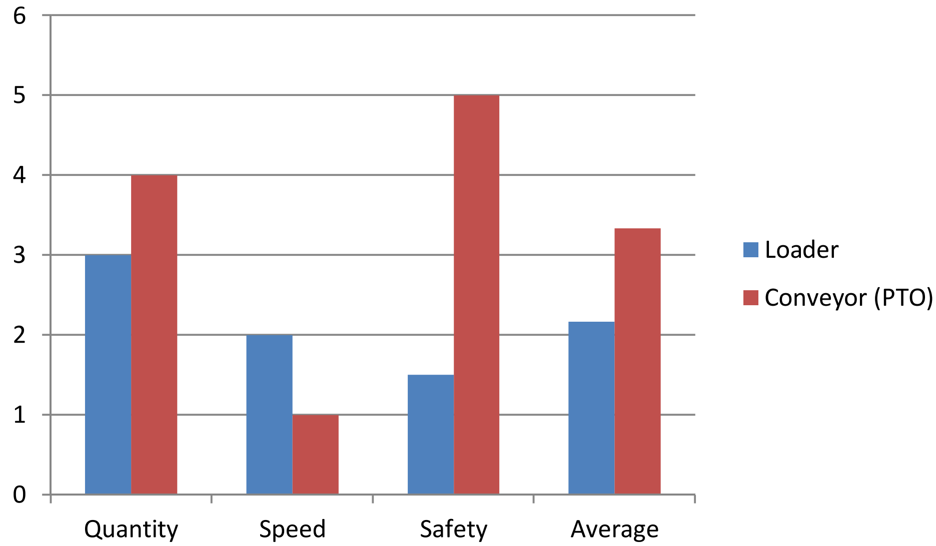


Figure A5.3. Rating of loading equipment based on data collected at the Wood County garage.

Salt Inventory

Salt inventory at the Wood County garage begins with tracking the incoming salt, measured in tons, using delivery tickets. Outgoing salt is accounted for by the drivers using the volume, measured in cubic yards, of the truck they are driving. The outgoing volume is converted to weight using a conversion based on the dry weight of salt. Both the incoming and outgoing weight of salt are recorded in an electronic management system (EMS) to determine salt inventory. After each winter event, an ODOT staff member visually estimates the quantity of salt and compares it with the value recorded in EMS. If the values do not match, an adjustment is made to the EMS amount. Some possible sources of error in the inventory method would be: (1) trucks are overloaded and carry more volume of salt than accounted for by volume of truck bed, (2) conversion of volume to weight is based on dry weight of salt which does not account for moisture content, and (3) visual estimates are subjective and rely on human judgment. The cumulative error will result in inaccurate salt accounting leading to improper salt inventory.

One impact of improper salt inventory is skewed estimations for annual salt orders. Each year, ODOT orders salt for the subsequent year using an estimate based on a five year running average. By contract, ODOT must pay for at least 80 % of the amount that they order and are only guaranteed up to 120 % of that amount. The implication of overestimating the required amount of salt for the upcoming year is that purchased salt may go unused and remain in storage until the following winter. Long-term storage of salt often leads to degradation in its quality and renders the salt less effective for snow and ice removal. If the amount of salt required for the upcoming year is underestimated, then the potential exist for the supplier to refuse delivery of additional salt or deliver at a new (likely higher) price/ton. Improper salt inventory also leads to a subjective decision regarding the appropriate time and quantity of salt to order after winter events, and leads to errors in balancing the ‘salt books’ which may reflect poorly on winter snow and ice operations management.

In order to gage the importance of proper salt inventory at the ODOT garages that were visited, an ODOT staff member was asked to rate the following on a scale of 1 to 5, with 5 being the highest:

Q1. Importance of accurate salt inventory on the management of winter snow/ice operations.

Q2. Importance of accurate salt volume measurement in the salt inventory process.

Q3. Accuracy of salt volume measurement for your salt storage facility.

The results of the survey for Wood County are provided in column 2 of Table A5.2. It can be seen that accurate salt inventory, and the impact of accurate salt volume measurement on inventory, was rated very high by Wood County maintenance staff. Meanwhile, the actual accuracy of salt volume measurement at the Wood County garage received a comparatively low rating. The result indicates that a more accurate method for measuring the volume would improve management of winter snow and ice operations at the Wood County garage.

Table A5.2. Results of salt inventory survey at ODOT County garages.

	Garage					
Question (1)	**Wood** (2)	**Sandusky** (3)	**Independence** (4)	**Cleveland** (5)	**Unionville** (6)	**Average** (7)
Q1	5	5	5	5	-	5
Q2	5	4	5	5	-	4.75
Q3	2	3	2	4	-	2.75

Sandusky County Garage

Salt Storage

The Sandusky County garage is located in District 2 in Fremont, OH. There is a single salt dome located at the garage. The dome dimensions were measured on site and are provided in Table A5.1. The dome has an outer diameter of roughly 62 ft, riser wall height of 10 ft, and a total height at the apex of around 34 ft. The storage capacity of the dome was reported to be 1,000 tons. A picture of the dome is shown in Figure A5.4. It was reported that on average approximately 4,000 tons of salt are stored in the dome per year. The salt is typically stored using either a portable conveyor or a loader, with usage similar to that of Wood County (conveyor used mostly during the initial pre-season fill-up and then the loader thereafter). The conveyor is the same one used by Wood County and is shared throughout the District. Fill-up using the conveyor is done using several piles throughout the dome (see Figure A5.4(b)). The loader pushes salt into the dome initially, then places it as the pile height increases. However, safety policy at the Sandusky County garage dictates that the loader wheels should not leave the ground.

As mentioned above, the conveyor used by the Sandusky County garage is the same one used by the Wood County garage. As such, details with respect to its advantages and disadvantages may be found in the salt storage description for the Wood County garage. The only reported difference in the conveyor between the two garages is the loading rate, which is estimated at 96 tons/hr by the Sandusky County garage. The other method of loading at the Sandusky County garage is through the use of the loader. Again, it is reported that the loader only requires one piece of equipment and a single operator. The loading rate is determined to be approximately 288 tons/hr, and is consistent with the rate of 267 tons/hr reported by the maintenance staff at the Wood County garage. Again, loader operators at the Sandusky County garage are required to keep the back wheels of the loader on the ground, thus prohibiting them from climbing the pile. This safety precaution is intended to protect the operator by preventing the loader from rolling. However, it also restricts the amount of salt that can be stored in the dome. A staff member at the Sandusky County garage was asked to rate each method of loading on a scale of 1 to 5, with 5 being the highest, in terms of loading speed, loading quantity, and safety. The results are provided in Figure A5.5. The average rating over all three categories yields a slightly higher value for the conveyor than the loader.

(a)

(b)

Figure A5.4. Picture of the (a) exterior and (b) interior of the salt dome at the Sandusky County garage.

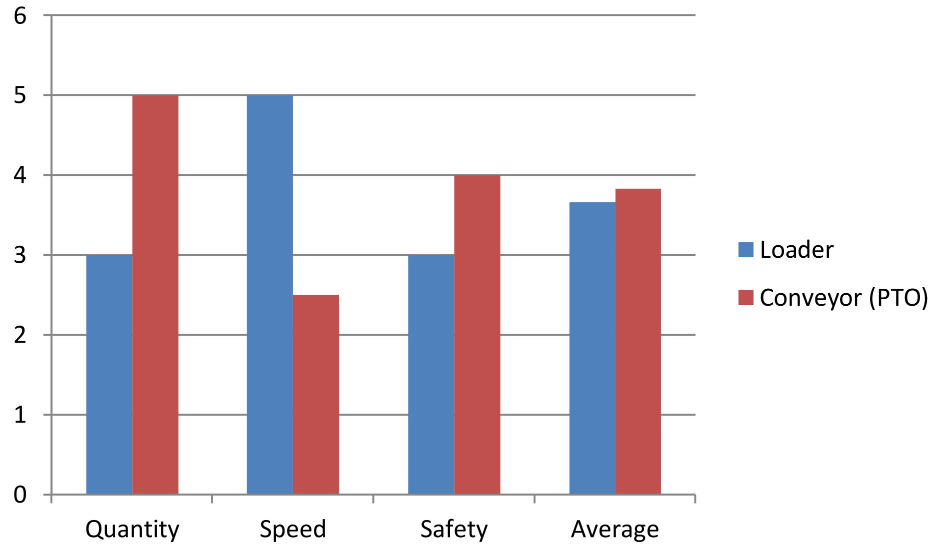


Figure A5.5. Rating of loading equipment based on data collected at the Sandusky County garage.

Salt Inventory

The salt inventory process at the Sandusky County garage is different than that at the Wood County garage. While incoming salt is still tracked using delivery tickets, the outgoing salt is accounted for by drivers based on the weight of salt spread during each shift. The weight of salt spread is recorded on-board each truck during a given shift. Both the incoming and outgoing weights are recorded in EMS to keep inventory. However, an adjustment is made to the outgoing weight prior to recording in EMS based on average of visual estimates by three individuals at the end of each winter event. Possible sources of error in the process may result from: (1) not accounting for moisture content and impurities in salt, (2) failure to zero the on-board system which determines the weight of salt spread, (3) using the volume of the truck bed when truck is overloaded and (4) subjectivity of visual estimates.

One of the major impacts of improper salt inventory as reported by ODOT maintenance staff at the Sandusky County garage is with ordering of salt during the winter season. By contract, salt distributors have a seven-day window to deliver an order once it is placed. During winter storms, when salt is being heavily used, not having an accurate real-time salt inventory makes projecting salt usage and anticipating salt needs over a short amount of time very difficult. This complicates the decision about when to order salt and how much to order.

The importance of different aspects of salt inventory according to ODOT maintenance staff at the Sandusky County garage was determined using a rating scale of 1 to 5, with 5 being the highest. The questions were the same as those asked at the Wood County garage and provided in the previous section. The results are provided in column 3 of Table A5.2. Similar to Wood County, it can be seen that accurate salt inventory, and the impact of accurate salt volume measurement on inventory, were rated very high by Sandusky County maintenance staff. Also, the actual accuracy of salt volume measurement once again received a comparatively low rating.

Independence Garage

Salt Storage

The Independence garage is located in District 12 in Independence, OH. There is a single salt dome located at the garage. The dome dimensions were measured on site and are provided in Table A5.1. The dome has an outer diameter of roughly 101 ft, riser wall height of 12 ft, and a total height at the apex of around 62 ft. The storage capacity of the dome was reported to be 5,500 tons. A picture of the dome is shown in Figure A5.6. The average annual amount of salt stored at this facility was reported to be 8,000 tons. The salt is typically stored using either a portable conveyor or a loader. Similar to Wood and Sandusky Counties, the salt is conveyed into several piles throughout the dome (see Figure A5.6(b)). When using the loader, salt is initially pushed into the dome. As the height of the pile increases, a salt ramp is constructed to place the salt higher in the pile.

Unlike the Wood and Sandusky County garages, conveyor loading at the Independence garage is performed by an outside contractor. Delivery trucks dump their salt near the entrance to the dome (only one truck at a time) where a loader is waiting. The loader fills a hopper with salt, which in turn feeds the conveyor. The conveyor is self-powered (no PTO) and can load salt at a reported rate of 120 tons/hr. This makes using the conveyor feasible even during the peak of the winter season. Some advantages of the conveyor identified by ODOT maintenance staff are speed, quantity stored, and safety. One drawback to contracting out the conveyor service is the additional cost, which has been reported to be around an additional $4/ton (in addition to the cost of the salt).

For the loader, it is again reported that only one piece of equipment and a single operator are required for loading salt. No loading rate information was provided for the loader at the Independence garage, rather it was suggested that the rate depended on the experience of the operator and the stage of the process. It is easy to see why this would be the case for the large dome at this location. As mentioned previously, salt is initially pushed into the dome at a normal loading rate. Once the ground level storage has been used, a salt ramp is constructed to access storage space higher in the dome. During this time, extra caution is required to prevent rolling of the loader, and the loading rate will decrease. While this method of loading the dome allows for more storage space to be utilized, it also creates safety issues for the loader operator. As with the Wood and Sandusky County garages, an ODOT staff member at the Independence garage was asked to rate each method of loading on a scale of 1 to 5, with 5 being the highest, in terms of loading speed, loading quantity, and safety. The results are provided in Figure A5.7 and show that the self-powered conveyor was rated higher than the loader in every category except speed, where the two methods received the same rating.

(a) (b)

Figure A5.6. Picture of the (a) exterior and (b) interior of the salt dome at the Independence garage.

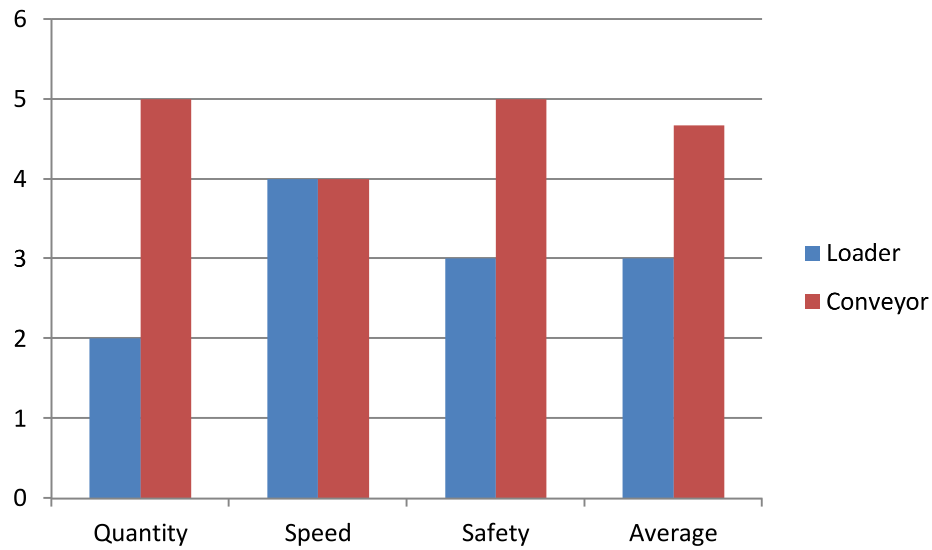


Figure A5.7. Rating of loading equipment based on data collected at the Independence garage.

Salt Inventory

The salt inventory process at the Independence garage differs slightly from that of both Wood and Sandusky County garages. The incoming salt is again tracked using delivery tickets, but the outgoing salt is accounted for by recording the number of loader buckets used to fill the salt trucks. The number of buckets, the volume of the bucket, and a volume to weight conversion is then used to calculate the total weight of outgoing salt. Any leftover salt at the end of a shift is placed back in the dome, but the quantity is not added back to the inventory. Each morning, a visual estimate of the salt is recorded. At some later time, the visual estimate is compared with the amount on record and an adjustment is made to the inventory. Some possible sources of error in the inventory process are: (1) neglecting moisture content of salt when converting from volume to weight, (2) overfilling loader buckets, (3) returning the leftover salt without adding it back to the inventory, and (4) subjectivity of visual estimates.

It was reported that poor accounting of salt makes maintaining an appropriate supply during the winter season difficult. This can lead to an insufficient quantity of salt at the dome or a surplus of salt. An insufficient quantity will limit the distribution of salt on the roadways and may lead to unsafe driving conditions. A surplus of salt could result in improper salt storage where salt is stored outside and exposed to the environment. The latter can compromise the quality of the salt and make it less effective for snow and ice removal. Once again, an ODOT maintenance staff member was asked to rate the different aspects of salt inventory (see section on Wood County) on a scale of 1 to 5, with 5 being the highest. The results are provided in column 4 of Table A5.2, and again show that accurate salt inventory, and the impact of accurate salt volume measurement on inventory, received very high ratings while the accuracy of salt volume measurement at the Independence site received a comparatively low rating.

Cleveland Garage

Salt Storage

The Cleveland garage is located in District 12 in Cleveland, OH, and has a single salt dome on site. The measured dome dimensions are provided in Table A5.1. The dome has an outer diameter of roughly 67.5 ft, riser wall height of 12 ft, and a total height at the apex of around 43 ft. The storage capacity of the dome was reported to be 2,300 tons. A picture of the dome is shown in Figure A5.8. The average annual amount of salt stored at this facility was reported to be 3,000 tons. The salt is typically stored using a portable conveyor (self-powered), a loader, or a blower. Loading with the self-powered conveyor and loader are similar to the processes used at the Independence garage, with the conveying out-sourced and the loader utilizing a salt ramp to access storage space higher in the dome (only one truck at a time permitted to dump salt). The conveyor speed was again reported to be around 120 tons/hr, while the loader speed was reported to be 33 tons/hr depending on the operator. The blower service is also performed by a contractor.

The blower consists of a high-powered fan that is fed salt using the pigeon door on a salt truck. The blower is placed at the entrance to the dome and blows salt toward a piece of plywood hanging near the apex (see Figure A5.8(b)). The salt hits the plywood and falls to the surface where it forms a pile. The blower only requires once piece of equipment and a single operator. The loading rate of the blower is reported to be 80 tons/hr. Some advantages of the blower are that a large quantity of salt can be stored in the dome and it is safe for the operator. However, the blower tends to pulverize the salt leaving a mix of salt and salt dust. This process compromises the quality of the salt and make is less effective for snow and ice removal. The dust also cakes on the wood of the dome leading to advanced deterioration. Finally, the blower operator tends to be covered in dust when loading is complete. An ODOT staff member at the Cleveland garage was asked to rate each method of loading on a scale of 1 to 5, with 5 being the highest, in terms of loading speed, loading quantity, and safety. The results are provided in Figure A5.9 and show that the self-powered conveyor and the blower both received the highest rating in each category. However, the conveyor results in a better quality of salt for effective snow and ice removal.


(a)


(b)

Figure A5.8. Picture of the (a) exterior and (b) interior of the salt dome at the Cleveland garage.

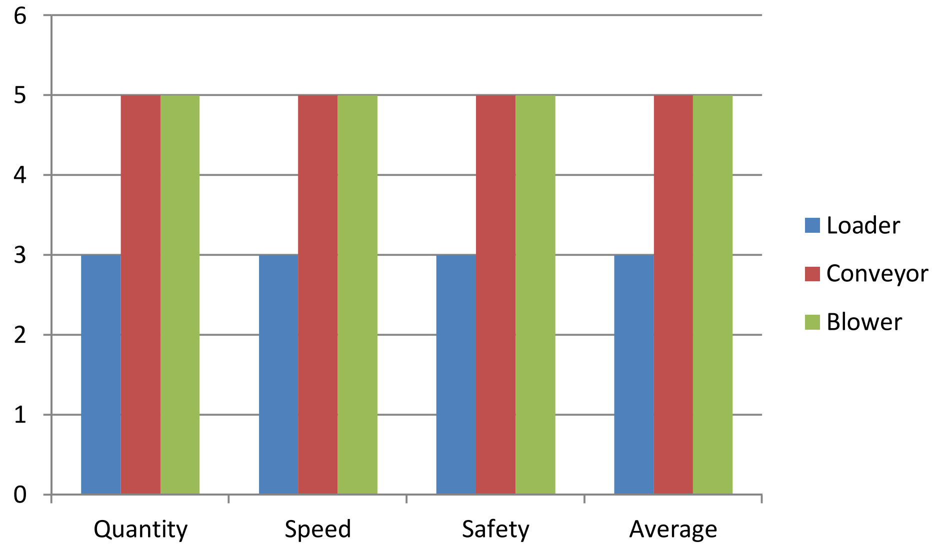


Figure A5.9. Rating of loading equipment based on data collected at the Cleveland garage.

Salt Inventory

The Cleveland garage uses the same process for salt inventory as detailed for the Independence garage and would be subject to the same error. It was reported that proper salt inventory is important for reordering of salt to ensure that a sufficient supply is maintained during the winter season. The results of the survey questions on salt inventory at the Cleveland garage are included in column 5 of Table A5.2. It is interesting to note that the accuracy of salt volume measurement at the Cleveland garage received a rating of 4 out of 5, which is high compared to the ratings provided by the Wood County, Sandusky County, and Independence garages. The rating was attributed to a high level of experience in visually estimating the volume of salt in the dome by ODOT maintenance staff at the garage.

Unionville Outpost

Salt Storage

The Unionville Outpost is located in District 12 in Madison Township, OH. There is a single salt dome at the location. The dome dimensions were measured on site and are provided in Table A5.1. The dome has an outer diameter of roughly 60 ft, riser wall height of 10 ft, and a total height at the apex of around 28 ft. The storage capacity of the dome was reported to be 800 tons. A picture of the dome is shown in Figure A5.10. The average annual amount of salt stored at this facility was reported to be 2,400 tons. The salt is typically stored using a portable conveyor (self-powered), a loader, or a flinger. Loading with the self-powered conveyor and loader are similar to the processes used at the Independence and Cleveland garages, with the exception that the conveyor is fed using the pigeon door on a salt truck rather than a hopper. The loading rate for the conveyor was reported to be only around 80 tons/hr, which is less than the 120 tons/hr rate reported for the conveyors used at the Independence and Cleveland garages. The decrease in loading rate may be attributed to the conveyor being fed through the pigeon door rather than a hopper. When salt is fed through the pigeon door, the flow is affected by the amount of salt in the truck, the door opening, and the angle of the truck bed. Achieving a constant uniform flow requires finding the right balance between these factors, and adjustments may need to be made to the door opening and the angle of the truck bed as the amount of salt in the truck decreases. As a result, salt will be loaded into the dome at a slower speed. The loading rate for the loader was reported to be 120 tons/hr once the salt ramp is established. No data was provided for the average loading rate from start to finish, which is expected to be less due to the time it takes to construct the ramp.

The salt flinger was described as a high-speed conveyor that ‘shoots’ salt into the dome. Similar to the conveyor, salt is fed to the flinger via the pigeon door on a truck. The flinger is similar to the blower in the following ways: (1) it requires only once piece of equipment and a single operator, (2) the loading rate is reported to be 60 tons/hr (80 tons/hr for the blower), (3) it can store a large quantity of salt in the dome, (4) salt is pulverized leaving a mix of salt and salt dust, and (5) the operator tends to be covered in dust when loading is complete. Due to the similarities between the flinger and blower, and the fact that this was the only reported use of a flinger for salt loading during this research project, the flinger is hereafter grouped in the same category as the blower. An ODOT staff member at the Unionville Outpost was asked to rate each method of loading on a scale of 1 to 5, with 5 being the highest, in terms of loading speed, loading quantity, and safety. The results are provided in Figure A5.11 and show that the self-powered conveyor received the highest rating in each category.

Figure A5.10. Picture of the (a) exterior and (b) interior of the dome at the Unionville Outpost.

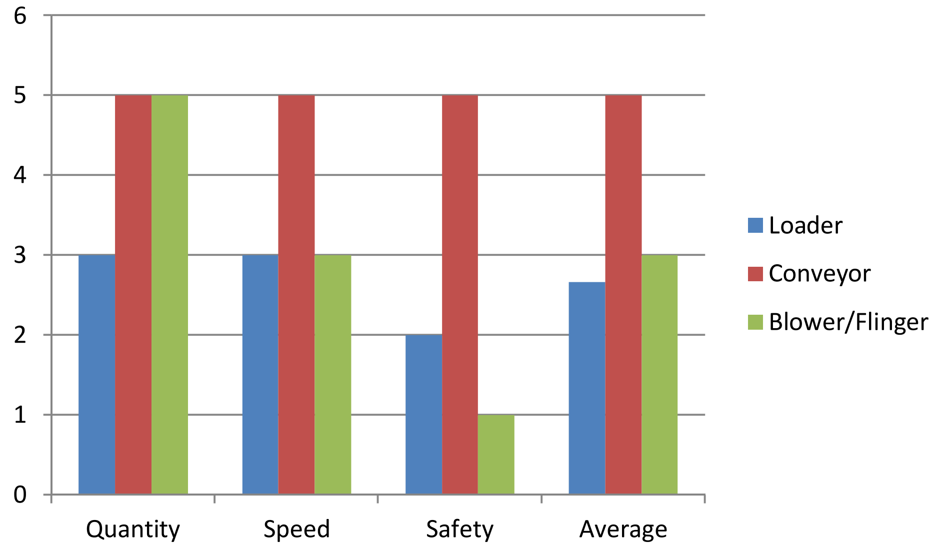
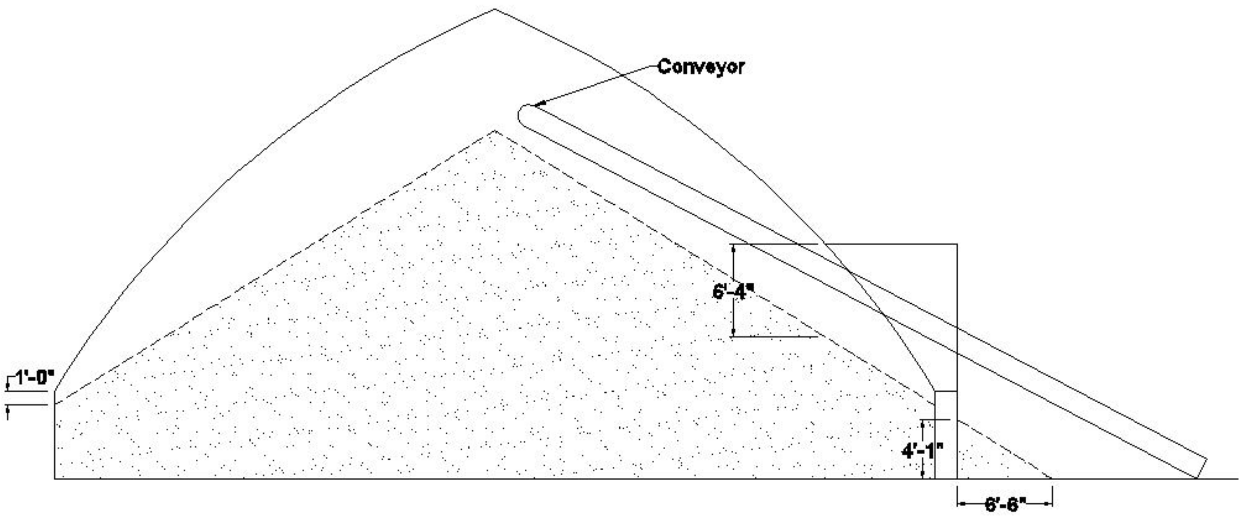


Figure A5.11. Rating of loading equipment based on data collected at the Unionville Outpost.

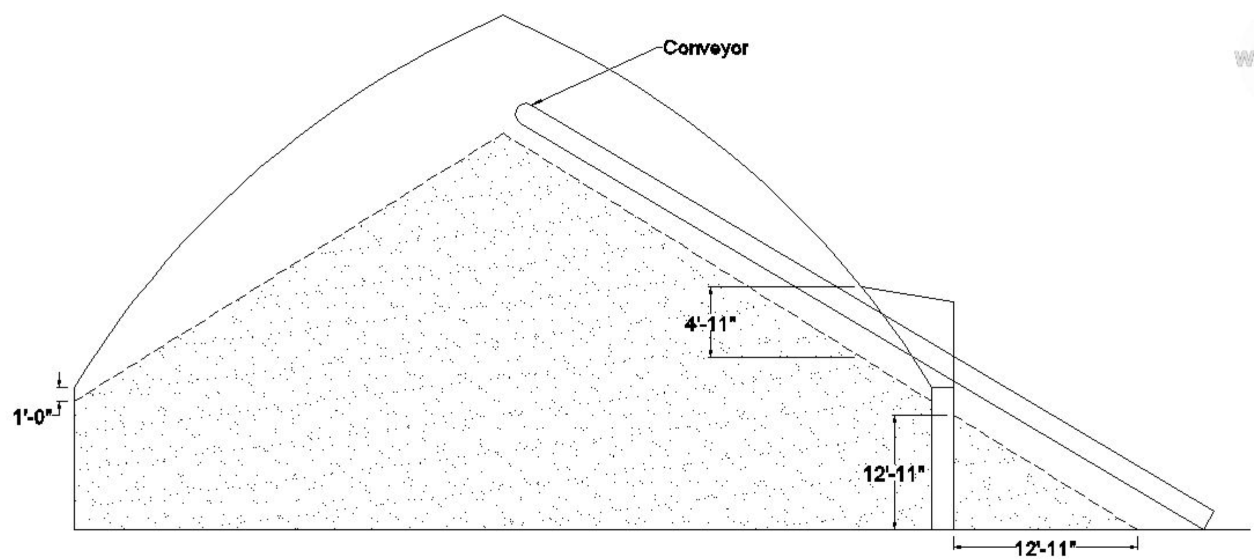
Salt Inventory

The ODOT staff member interviewed during the site visit did not have any personal knowledge of the inventory process used at the Unionville Outpost and reported that all salt was ordered by the District.

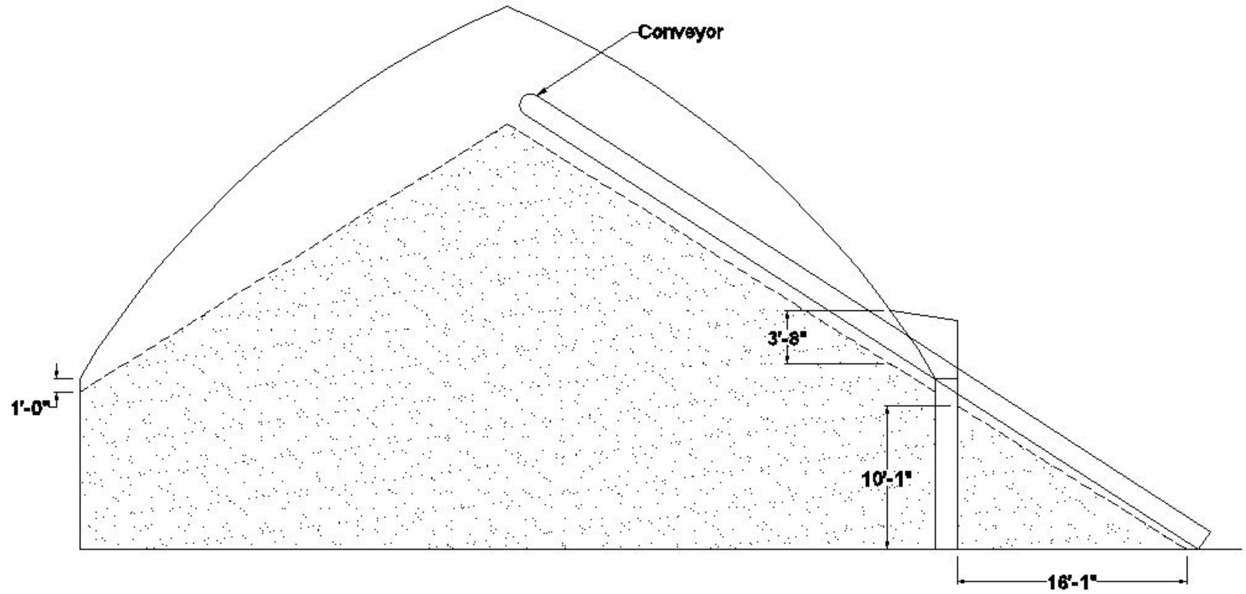
Appendix A6. CAD Representation of Domes with Conveyors



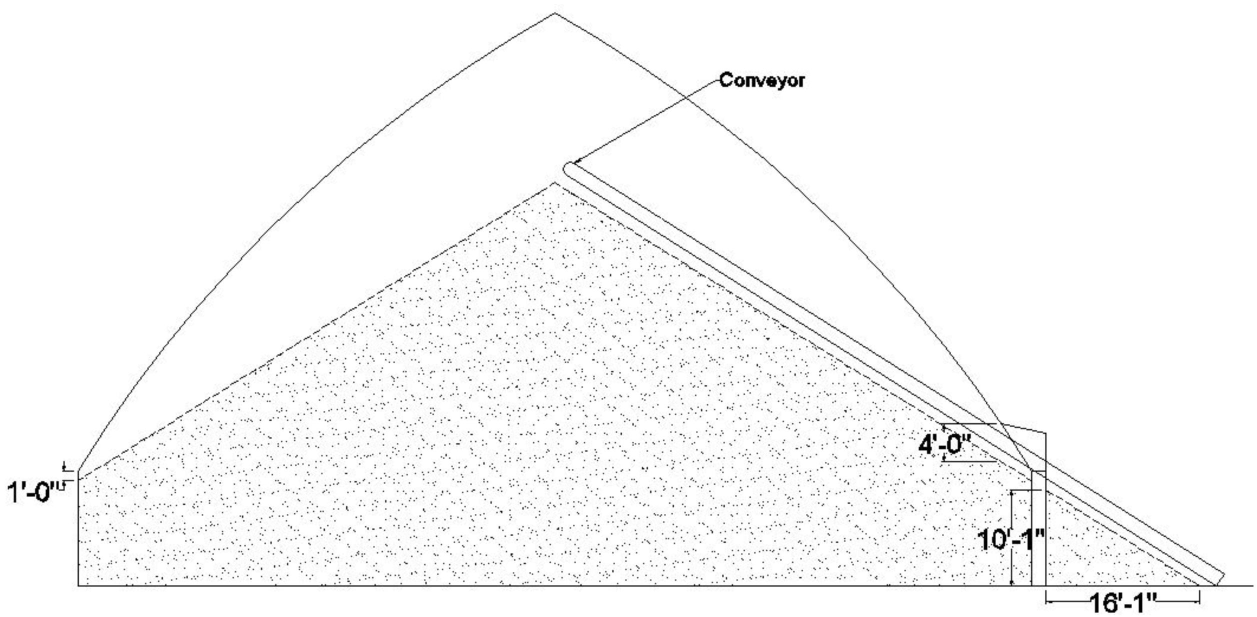
(a)



(b)



(c)



(d)

Figure A6.1. Salt domes at (a) Wood County (b) Sandusky County and Unionville Outpost (c) Cleveland and (d) Independence garages loaded to capacity using a conveyor.

Appendix A7. Itemized Costs of Conveyance Options

Table A7.1. Kimco using a portable conveyor in a fixed setup (option 1).

Item (1)	Description (2)	Cost ($) (3)	Quantity (4)	Total (5)
Conveyor	24 in, 70 ft, stainless steel, diesel motor	$62,427.18	1	$62,427.18
Hopper	6 ton, 8'x10'	$10,716.00	1	$10,716.00
Vibrator	vibrator & bracket for hopper	$1,685.38	1	$1,685.38
Delivery	delivery, installation, training	$1,580.00	1	$1,580.00
Dormer	opening for conveyor access	$5,000.00	1	$5,000.00
			Total	$81,408.56

Table A7.2. Kimco using a fixed conveyor without pit (option 2).

Item (1)	Description (2)	Cost ($) (3)	Quantity (4)	Total (5)
Conveyor	24 in, 75 ft, stainless steel, electric motor	$91,284.00	1	$91,284.00
Hopper	6 ton, 8'x10', vibrator	$10,716.00	1	$10,716.00
Vibrator	vibrator & bracket for hopper	$1,685.00	1	$1,685.00
Delivery	delivery, installation, training	$1,580.00	1	$1,580.00
Dormer	opening for conveyor access	$3,500.00	1	$3,500.00
			Total	$108,765.00

Table A7.3. Kimco using fixed conveyor with pit (option 3).

Item (1)	Description (2)	Cost ($) (3)	Quantity (4)	Total (5)
Conveyor	24 in, 75 ft, stainless steel, electric motor	$91,284.00	1	$91,284.00
Hopper	6 ton, 8'x10'	$10,716.00	1	$10,716.00
Vibrator	vibrator & bracket for hopper	$1,685.00	1	$1,685.00
Delivery	delivery, installation, training	$1,580.00	1	$1,580.00
Dormer	opening for conveyor access	$3,500.00	1	$3,500.00
Dump pit	shed cover, grate, rubber mat, sump pump	$34,000.00	1	$34,000.00
			Total	$142,765.00

Table A7.4. DCNA using portable conveyor with hopper in fixed setup (option 1).

Item (1)	Description (2)	Cost ($) (3)	Quantity (4)	Total (5)
Conveyor	24 in, 65 ft, stainless steel, electric motor	$55,000.00	1	$55,000.00
Hopper	hopper for feeding conveyor	$15,000.00	1	$15,000.00
Delivery	delivery, installation, training	$0.00	1	$0.00
Dormer	install dormer, add bracing, etc.	$15,000.00	1	$15,000.00
			Total	$85,000.00

Table A7.5. DCNA using fixed conveyor without pit (option 2).

Item (1)	Description (2)	Cost ($) (3)	Quantity (4)	Total (5)
Conveyor	24 in, 75 ft, galv. steel, electric motor	$115,000.00	1	$115,000.00
Hopper	hopper for feeding conveyor	$15,000.00	1	$15,000.00
Delivery	delivery, installation, training	$0.00	1	$0.00
Dome Retrofit	conveyor access, bracing, etc.	$30,000.00	1	$30,000.00
			Total	$160,000.00

Table A7.6. DCNA using fixed conveyor with pit (option 3).

Item (1)	Description (2)	Cost ($) (3)	Quantity (4)	Total (5)
Conveyor	24 in, 75 ft, galv. steel, electric motor	$115,000.00	1	$115,000.00
Hopper	hopper for feeding conveyor	$15,000.00	1	$15,000.00
Delivery	delivery, installation, training	$0.00	1	$0.00
Dome Retrofit	conveyor access, bracing, etc.	$30,000.00	1	$30,000.00
Dump Pit	shed cover, grate, rubber mat	$25,000.00	1	$25,000.00
			Total	$185,000.00

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