Evaluation of Indoor Automated Stockpile Measurement Systems

Final Report

CLEAR ROADS

research for winter highway maintenance

CTC & Associates, LLC

Project 1030951/CR20-03
December 2022

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16. Abstract (Limit: 250 words) The goal of this project was to conduct a data-driven evaluation of currently available automated or semi-automated indoor salt stockpile measuring systems in order to improve agencies' day-to-day management of their salt stockpile inventories. Based on the types of automated and semi-automated indoor stockpile measuring systems available, project need, and vendor willingness to participate in the project, the following systems and state sites were selected for the project: Stockpile Reports photogrammetry system at two sites in Texas and one site in Washington state, Carlson FiX1 lidar system at a site in Delaware, and Skydio drone analyzed by DroneDeploy software at the same site in Delaware. Comparable measurements were taken at these sites using Total Station optical surveying, FARO 3-D scanner surveying, and tape-and-wheel measurements and compared in controlled tests. Both the Stockpile Reports and Carlson FiX1 equipment appeared to work as presented by vendors and regularly produced stable and precise measurements with little or no effort required of state DOT staff after the equipment was set up. The Skydio equipment worked well but is not close to being an automated or semi-automated solution at this time.			
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Evaluation of Indoor Automated Stockpile Measurement Systems

FINAL REPORT

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- Delaware, Texas and Washington State Departments of Transportation for providing staff time and financial support for equipment site demonstrations.
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CHAPTER 1: PURPOSE AND OVERVIEW

Accurately measuring indoor salt stockpiles presents a challenge for transportation agencies. The Clear Roads Transportation Pooled Fund Project (#TPF-5(479), https://clearroads.org/)—a consortium of 37 state departments of transportations (DOTs) focused on winter maintenance research solutions—was interested in examining a range of existing and emerging approaches to indoor stockpile measurement, including systems using lidar, photogrammetry, surveying, acoustic sensing, and drone technology.

In particular, Clear Roads was interested in investigating automated or semi-automated systems that have the capability to measure a stockpile, and transmit the data to a central location. By automating this process, states can improve their inventory management and minimize costly rush orders of salt.

Clear Roads previously examined the methods agencies employ to monitor their stockpiles of solid winter maintenance materials. Clear Roads project 16-S2 (http://clearroads.org/project/16-S2/) produced a synthesis report that included discussions of indoor stockpile monitoring, including robotic track systems and various 3-D laser-scanning methods. While agencies have explored a range of indoor measuring technologies from such suppliers as Stockpile Reports, GeoSLAM, BinMaster, and Carlson Software, a comparative investigation of a range of systems would provide beneficial information to all Clear Roads member states.

The goal of this project was to conduct a data-driven evaluation of currently available automated or semi-automated indoor salt stockpile measuring systems in order to improve agencies' day-to-day management of their salt stockpile inventories.

1.1 PERSONNEL AND OVERSIGHT

This project was being was guided by a technical advisory panel (TAP) consisting of the following Clear Roads staff:

- James Morin, Washington State DOT (TAP Chair)
- James Stevenson, Texas DOT (TAP Vice Chair)
- Tom Peters, Minnesota DOT (Clear Roads Lead State)
- Jim Andersen, Washington State DOT
- Rhett Arnell, Utah DOT
- Emil Juni, Wisconsin DOT
- Scott Lucas, Ohio DOT
- Jeremy McGuffey, Indiana DOT
- Todd Miller, Missouri DOT
- Alastair Probert, Delaware DOT
- Daryl Starkes, Texas DOT

The TAP met regularly throughout the course of this project to provide project guidance and oversight and make key decisions about the project scope and direction.

MnDOT contracted with Madison, Wisconsin-based technical consulting firm CTC & Associates to perform the work detailed in this report.

1.2 PROJECT TASKS AND ORGANIZATION OF REPORT

Beyond project management and reporting tasks spanning the life of the project, this research effort was scoped in distinct tasks. These are associated with the chapters of this report:

- Chapter 2. Literature Search and Industry Review
- Chapter 3. Surveys and Interviews
- Chapter 4. Selection of Systems and States for Evaluation
- Chapter 5: Methodology for System Evaluation
- Chapter 6: Data Collection and Considerations
- Chapter 7: Data Analysis, System Performance, Conclusions and Recommendations

CHAPTER 2: LITERATURE SEARCH AND INDUSTRY REVIEW

A review of the industry aimed to determine the types of automated and semi-automated indoor stockpile measuring systems available from commercial vendors. This task included stockpile measuring systems already used in transportation maintenance as well as related industries, such as aggregate mining and agriculture.

A literature search, Appendix A to this report, helped identify recent research that describes the use and effectiveness of automated indoor stockpile measuring systems in use by DOT agencies and others, with a focus on citations from the past 10 years. Specific vendors and vendor solutions noted in the research citations are listed by name in this literature search and grouped into functional categories.

The citations and vendors are organized into the literature search as follows:

- Previous Clear Roads Research
- State Research in Progress
- State Research and Guidance
- Other Publications
- Vendor Technologies and Solutions
    - Acoustic-Based Technology
    - Drones
    - Laser Technology
    - Software
    - Stockpile Monitoring Systems

CHAPTER 3: SURVEYS AND INTERVIEWS

Based on findings from the literature search and industry review (see Chapter 2) and comments from members of the TAP, the investigators conducted two parallel online surveys in summer 2021 to gather information on agency use of automated or semi-automated indoor salt stockpile measuring systems, as well as the capability of other systems that Clear Roads members might not be aware of.

3.1 AGENCY SURVEY

A web-based survey, conducted with the aid of the SurveyMonkey tool, was distributed to all Clear Roads member states as well as members of AASHTO's Snow and Ice Listserv. While the AASHTO Listserv includes non-agency recipients, only agency representatives were asked to participate in the survey.

The survey questions follow.

Please provide your contact information (Name, Title, Agency, Email, Phone)

1. Please describe your agency's indoor salt storage facilities (number, type, capacity).
2. How does your agency measure and manage your indoor salt stockpile inventories?
3. Does your agency use an outside service or vendor to measure and/or calculate salt volumes?

   If "Yes," what is the cost of such services?
4. Has your agency used, or does it plan to use, a fully-automated or semi-automated indoor salt stockpile measuring system?
5. Which systems (manufacturers and models) has your agency used or is your agency using? What are your plans for these systems for the 2021-2022 winter season?
6. What has been your experience with these systems?
7. Would your agency be interested in participating as an evaluation site for this research project?
8. Please use this space to provide any additional comments you wish to share.

Twenty individuals responded to the agency survey representing 18 states, one county and one city.

3.1.1 Findings of Agency Survey

Complete responses to the agency survey may be found in Appendix B to this report. Highlighted findings follow:

- Six agencies reported using an automated or semi-automated system

- Three of those (North Dakota, Iowa and Michigan DOTs) are not already on the project panel. Full answers appear in Appendix B, but in brief:

  - **North Dakota DOT** (Jesse Kadrmas) — "NDDOT is actively looking at Pix4D and Stockpile Reports, but is not fully committed to going this route as of yet. Our plan would be to use these systems to make inventory measuring more consistent and more accurate throughout the state. If one of these programs are implemented, initially, we would use traditional survey methods (GPS, total station) to compare quantities with these programs to check the accuracy."

  - **Iowa DOT** (Craig Bargfrede) — "We use handheld Lidar devices to scan/measure salt sheds. This device gives us a 3-D image of the pile along with a volume measurement. We then convert the pile volume to a tonnage amount. We utilize this device to measure salt sheds when we have discrepancies in the tonnage shown in the RMS system. Once the scan is completed we compare the tonnage in RMS to the scan and then make adjustments in RMS as appropriate."

  - **Michigan DOT** (Matt Pratt) — "[We have used] Stockpile App with Skydio Drone. The main issues we have is with poor, broken, or missing lighting, not stacking material per our guidelines, not able to fly dome sheds YET."

    Stockpile Reports later commented in Fall 2022: "Stockpile Reports supports processing of Skydio data for any environment, including an indoor shed."

- North Dakota and Iowa indicated that they would be interested in participating in this study. Michigan was a maybe.

- All agencies indicated how they measure or manage their salt stockpile inventories.

  - Three agencies use an outside vendor to measure or calculate salt:

    - **Michigan DOT** and **Oregon DOT** use Stockpile Reports.

    - **North Dakota DOT** also noted: "Currently, we don't use such services, but are currently looking into these types of programs. Pix4d has a desktop version. Pix4d has two apps that you can use for calculating quantities. One that can be used with a phone and one that can be used with a drone."

3.2 VENDOR SURVEY

Investigators sent a second survey to 37 of the 38 commercial vendors identified in Task 2 and by the TAP. (A recipient could not be identified for one of the vendors.) The following message was distributed by email to recipients.

> The Clear Roads Winter Maintenance Pooled Fund (https://clearroads.org, a research consortium of state DOTs) is investigating automated and semi-automated systems for

measuring indoor salt stockpiles. The plan is to evaluate a selected number of systems this coming winter at Clear Roads members' field sites.

Your company was identified in an initial literature search on this topic. I hope you can assist Clear Roads with this effort by letting me know:

(a) If your product can be used for automated or semi-automated indoor salt stockpile measurement, and
(b) Which highway agencies are using your product.

Please reply to this email with your response, and let me know if you have any questions. Thank you very much.

3.2.1 Findings of Vendor Survey

A total of 22 vendors responded to this survey. Highlighted findings follow:

- A number of vendors spoke to the potential of using their equipment, software or solution for this work. Positive responses were provided by the following vendors:
    - **BinMaster**
    - **Henry M. Wood Company**
    - **FARO**
    - **Laser Technology Inc.**
    - **Maptek**
    - **TruePoint**
    - **Applied Imagery**
    - **Esri**
    - **Virtual Surveyor**
    - **GeoSLAM**
    - **Stockpile Reports**
- Automated or semi-automated use of drones was of particular interest to the TAP. Survey responses from drone vendors follow.
    - **Flyability** (Elios 2) wrote: “As of today, the flights are not automated, and require an operator to pilot.”
    - **GeoCue** wrote: “Our systems use GNSS for positioning and hence cannot be used for indoor operations. If the goal is to use (consider) drone technology, you will want to look toward SLAM [simultaneous localization and mapping] solutions such as HoverMap.”
    - **Skyward** wrote: “We can ingest drone images and create stockpile measurements, but most drones require GPS to be able to fly the automated routes. If these indoor spaces

have enough room to fly drones and have indoor GPS coverage, this should be completely doable." Their customers include West Virginia and Ohio DOTs.

- **UAV Imaging** wrote: "I wouldn't call it a product, more of a service. We manually fly a drone and take pictures at set intervals as we fly a grid pattern of the enclosure."

Not included in the survey was drone vendor **Skydio**, which Clear Roads members were already familiar with.

CHAPTER 4: SELECTION OF SYSTEMS AND STATES FOR EVALUATION

Based on project need, currently available technology, vendor willingness to participate in the project, and state availability to participate in the project, the following systems and states were selected for the project. Vendor equipment is detailed in Chapter 6: Data Collection and Considerations.

4.1 SYSTEMS AND SITES

1.
Stockpile Reports photogrammetry system
https://www.stockpilereports.com/
Texas DOT
Decatur, Texas (Dallas-Ft. Worth area) (see Figure 4.1)
Configuration: One pair of cameras mounted at the loading side of the salt shed.

and

2.
Stockpile Reports photogrammetry system
Texas DOT
Happy, Texas (see Figure 4.1)
Configuration: Two pair of cameras, one mounted at each end of the salt shed (salt is loaded on both sides)

TxDOT had an existing agreement with Stockpile Reports to install the Stockpile Reports fixed camera system at two locations in Texas: one with staff onsite and internet infrastructure (Dallas-Ft. Worth), and one in a rural location that required a cellular solution for data collection (Happy, Texas). The costs were already accounted for in TxDOT's budget.

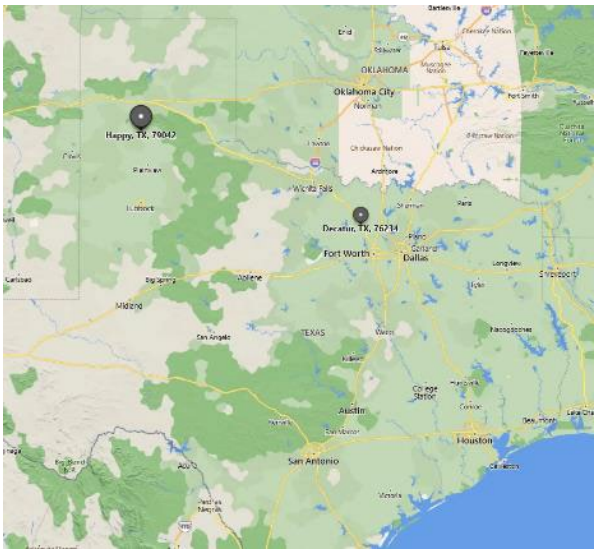


Figure 4.1. Location of Happy and Decatur sites in Texas. (Source: Google Maps)

3.

Stockpile Reports photogrammetry system
Washington State DOT
Bullfrog facility (see Figure 4.2)
Cle Elum, Washington
Configuration: Three pairs of cameras mounted at the loading each end of the salt shed: one pair in the center and a pair on either side.

WSDOT worked with Stockpile Reports to install the Stockpile Reports fixed camera system at the Bullfrog maintenance facility in Washington state. WSDOT was able to cover the cost of this equipment and installation.

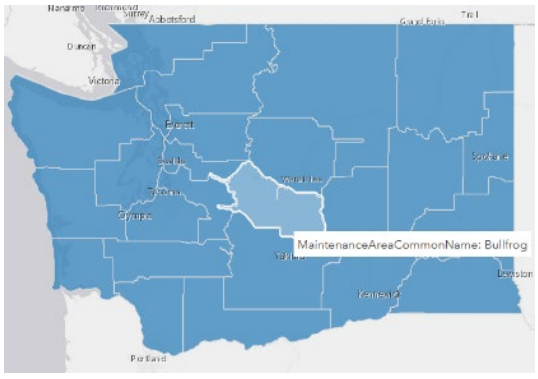


Figure 4.2. Location of Bullfrog facility in Washington state. (Source: Washington State DOT)

4.

FiX1 lidar system from Carlson

https://www.carlsonsurveysupply.com/product/carlson-fix1-scanner/
Delaware DOT
Gravel Hill, Delaware (see Figure 4.3)
Configuration: Equipment mounted near the ceiling.

Carlson covered the cost of a demo of the lidar-based FiX1 in Delaware, with the understanding that this is a national project in follow-up to its demonstration in Maine.

Figure 4.3. Location of Gravel Hill facility in Delaware. (Source: Google Maps)

5.
Skydio drone + DroneDeploy Software
https://www.skydio.com/
https://www.dronedeploy.com/
Delaware DOT
Gravel Hill, Delaware (see Figure 4.3 above)

Delaware was already working with drone vendor Skydio; Skydio agreed to allow Delaware to use its drone with advanced AI for this trial. Though the drone won't be automated, it won't require a Part 107 pilot's license, since a fully enclosed indoor space is not governed by the FAA.

After exploring alternatives for photogrammetry analysis software (including Carlson and Pix4D), ultimately Drone Deploy software was selected.

4.2 VENDOR CONTACTS

Stockpile Reports
Galen Kovak-Lewis
Director of Strategic Solutions
541-601-7912
galen.kovak-lewis@stockpilereports.com

Carlson Software
Jim Carlson
Mid-Atlantic Regional Sales Director
703-627-3055
jcarlson@carlsonsw.com

CHAPTER 5: METHODOLOGY FOR SYSTEM EVALUATION

Working closely with the TAP, investigators developed the following methodology for system evaluation.

5.1 APPROACH

The goal of this study is to examine a range of technologies to automate/semi-automate the measurement of indoor salt stockpiles. Three Clear Roads member states have agreed to install test equipment in their salt storage facilities to measure stockpiles during the 2021-2022 salt spreading season.

5.2 EQUIPMENT AND LOCATIONS

- Stockpile Reports:
  - Texas Department of Transportation — Decatur, Texas
  - Texas Department of Transportation — Happy, Texas
  - Washington State Department of Transportation — Bullfrog maintenance facility, Cle Elum, Washington
- Carlson Fix1 scanner:
  - Delaware Department of Transportation — Gravel Hill, Delaware
- Skydio Drone with DroneDeploy software:
  - Delaware Department of Transportation — Gravel Hill, Delaware

5.3 DATA COLLECTION

Each piece of test equipment will utilize a software package to generate a report summarizing the results of each measurement event. At a preset interval—not more than once monthly—a separate control measurement will take place at the same time using one or more traditional measuring tools (Total Station optical surveying, FARO 3-D scanner surveying, or tape-and-wheel measurements) to check the accuracy of the automated/semi-automated measurement.

It is suggested that the equipment be tested at least twice when initially installed, with no changes to the stockpile, to ensure the equipment is compiling consistently accurate information. Each stockpile should be measured once a week after each state begins its salt spreading season.

There will be multiple sources of data gathered during testing:

1. Measurement reports generated by the software used for each piece of test equipment.
2. Measurement results from using the Total Station, FARO or tape-and-wheel control method used to compare with the test equipment measurement results.
3. Material deliveries.

5.4 DATA COLLECTION SPREADSHEET

An online data collection spreadsheet has been created to log each measurement event. The operator for each measurement will enter information into the spreadsheet.

While the reports generated by the software associated with each piece of testing equipment will provide images and quantities, the data collection spreadsheet will summarize the results from both the test equipment and, when used, the control equipment. The spreadsheet will also allow the operator to comment on any mechanical or operational issues that occurred during the measurement. Information in the data collection spreadsheet will assist in the final evaluation of each piece of test equipment.

The data collection spreadsheet will be used to collect the following information:

- State
- Location
- Activity (Stockpile Reports, Carlson, Skydio, Total Station, Tape/Wheel, FARO, Delivery)
- Date
- Time
- Stockpile volume
- Stockpile tons
- Operator
- Data entered by
- Notes, comments, issues (if any)

5.5 ADDITIONAL CONSIDERATIONS

Accuracy is a critical element when measuring stockpiles, but there are other important criteria to consider. These include but are not limited to:

- General ease of use
- Durability
- Staff time required (training and use)
- Mounting and maintenance requirements
- Costs
- Vendor responsiveness
- Compatibility with inventory and management systems

These are addressed in the next part of this methodology, Analysis Approach.

5.6 ANALYSIS APPROACH

- Data (volumes and tonnage) from the test equipment software reports and the control measurements will be compared to ascertain, as much as possible, the accuracy and precision of each piece of test equipment.

- Information from the data collection spreadsheets will be reviewed and summarized, with particular attention being paid to any comments on any mechanical/operational issues that occurred during testing events and differences between test and control measures.
- In addition to data collection from the field, the investigators will have frequent discussions with Texas DOT, Washington State DOT, and Delaware DOT staff to obtain information to add context to the data. As noted in "Additional Considerations" above, topics will include best practices, challenges, and lessons learned regarding using these systems for salt stockpile inventory management. These discussions will include the practitioner and the Clear Roads TAP representative, if they are not the same person.
- The accuracy of the various technologies will then be compared and considered with the other criteria assessed during the equipment testing period.
- Technology recommendations will not be made; this is beyond the scope of this project.

CHAPTER 6: DATA COLLECTION AND CONSIDERATIONS

6.1 COLLECTED DATA

Data collection began at the four test sites on the following dates:

- Texas Department of Transportation — Decatur, Texas: 4/6/2022
- Texas Department of Transportation — Happy, Texas: 10/21/2021
- Washington State Department of Transportation — Bullfrog maintenance facility, Cle Elum, Washington: 11/5/2021
- Delaware Department of Transportation — Gravel Hill, Delaware: 9/14/2021

At all four sites, the last recorded day of data collection was 5/16/2022.

A complete record of the data can be found in Appendix C. Data, a Microsoft Excel worksheet with four tabs (one for each site).

6.2 SETUP AND VENDOR COMMENTS

6.2.1 Stockpile Reports

Vendor Stockpile Reports described the imagery-measuring hardware and the installations for this project in a March 2022 presentation to Clear Roads members. Per Stockpile Reports, common issues faced by salt shed owners and operators include the following:

1. *Don't know when or what to order.*
2. *Run out of salt during storm events.*
3. *Receiving errors, overpayment for salt.*

The benefits from automated measurement include:

1. *Labor savings: no manual tracking.*
2. *Ease stress levels and emotional toll during storm events.*
3. *Safeguards taxpayer assets.*

Stockpile Reports provided the following overview of the camera system:

- *Automated measurements*
- *Interior or exterior mounting*
- *Cell or WiFi enabled*
- *Wired power*
- *Compact housing: 10" x 6" x 4"*

Figure 6.1 shows an external view of the Decatur facility.

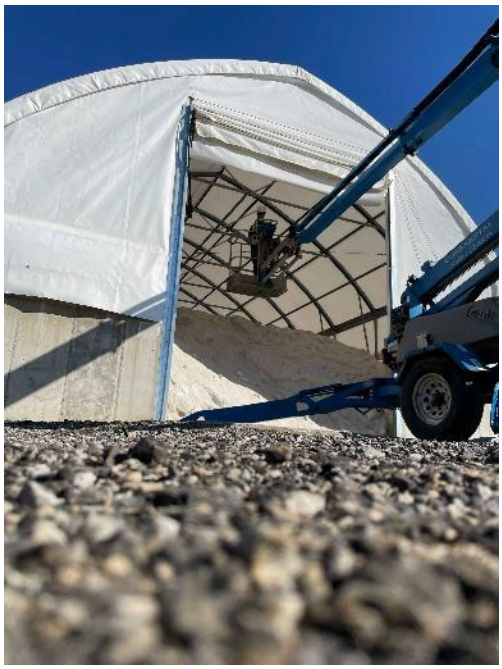


Figure 6.1. Decatur facility.

The Happy facility (Figure 6.2) shows two sets of cameras, one at either end.

Figure 6.2. Happy facility and sample report.

The Bullfrog facility (Figure 6.3) has three pairs of cameras, all at the open end of the shed.

Figure 6.3. Bullfrog facility with three camera pairs at the loading end of the shed.

Stockpile Reports provided these insights:

- *Installation was easy.*
    - *Sheds and piles were as expected.*
- *Access to power requires planning.*
- *Each salt shed is unique (lighting, volume, structure).*
    - *Large sheds benefit from more camera placement choices.*
- *Automated measurements reduce fire drills.*
    - *Saves time and reduces stress.*
    - *Improves confidence in salt on hand.*

A sample Stockpile Reports report is show in Figure 6.4.

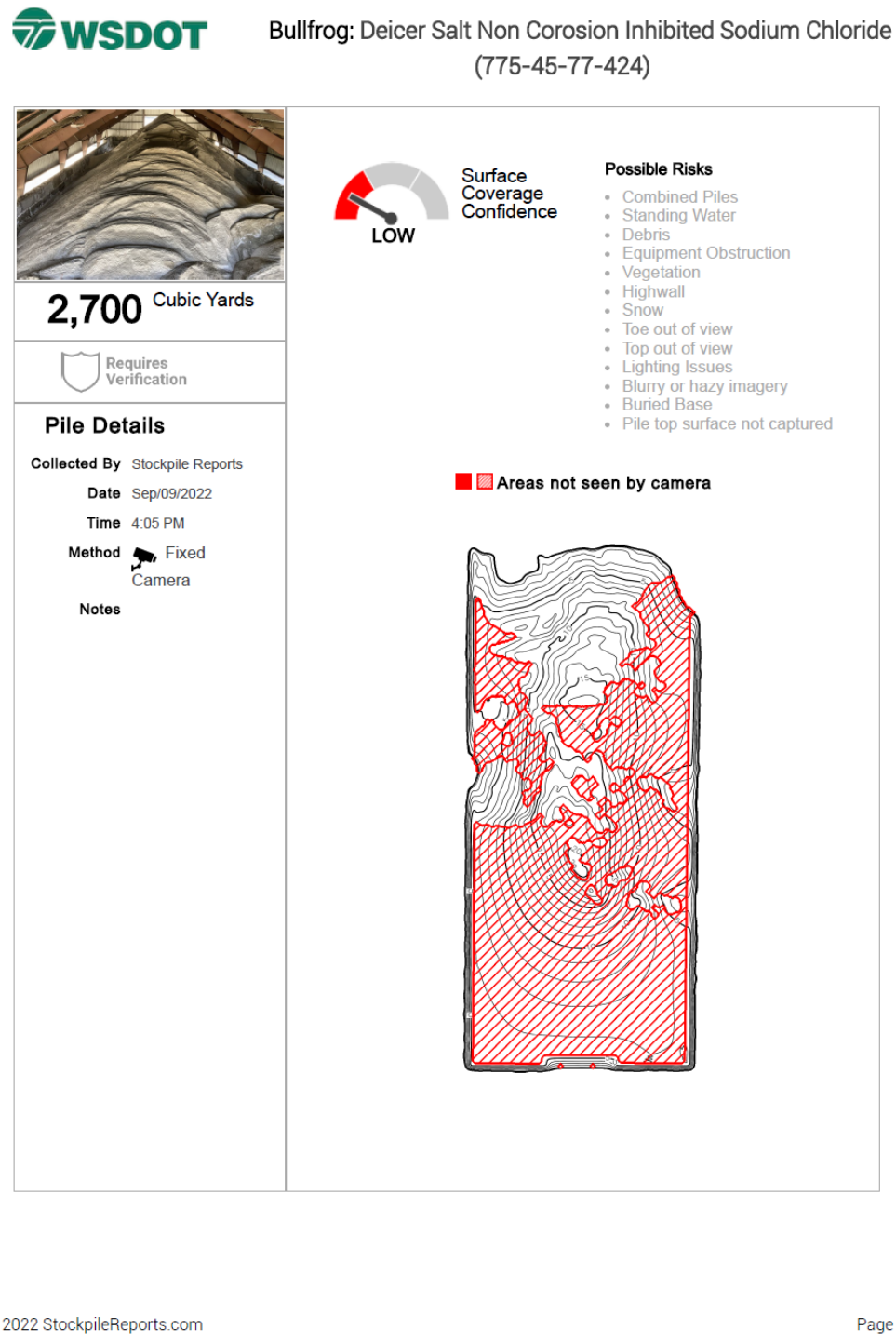


Figure 6.4. Stockpile Reports report.

6.2.2 Carlson Fix1

Vendor Carlson discussed its hardware and the installation for this project in a March 2022 presentation to Clear Roads members.

Carlson further provided the following summary of the installation:

> *[As depictured in Figure 6.5, the] shed is a steel tube structure with a stretched canvas cover on a concrete foundation. Exterior dimensions are approximately 120' x 80' with an interior ceiling height of 48' above the average floor elevation. The scanner is mounted to a custom-made mount very close to the center of the structure for the best "view" of the material.*
>
> *To calculate a Volume the Fix1 Stock Pile Scanner needs an Existing Surface model to compare the Scan to. If the Bin were empty we could scan it and create the Existing Surface in a Point Cloud software such as Carlson Point Cloud. In this situation the Bin already contained material covering 80%+ of the space so we had to measure the exposed structure to create the Existing Surface.*

Figure 6.5. Measuring the Salt Shed with the Carlson BRx7 GPS receiver and RT4 Data collector.

> *The Carlson BRx7 GNSS receiver was able to fix positions inside the salt shed because canvas roof allowed enough signal to get through. This is not possible with wood or metal roof structures.*
>
> *Jim Carlson created the Bin Existing Surface 3D model in Carlson Civil software and loaded into the scanner. With the Existing Surface in place and roughly aligned a new scan was run to qualify the data.*
>
> *The 3D image [*Figure 6.6*] ... is generated by the scanner when requested. It is used to qualify data. High resolution scans can take as much as 45 minutes to run. If people or equipment are in the area at that time parts of them may appear in the data even though the Fix1 uses powerful*

algorithms to avoid them. It also shows areas (in grey) of the surface that the Laser beam cannot reach due to the field of view.

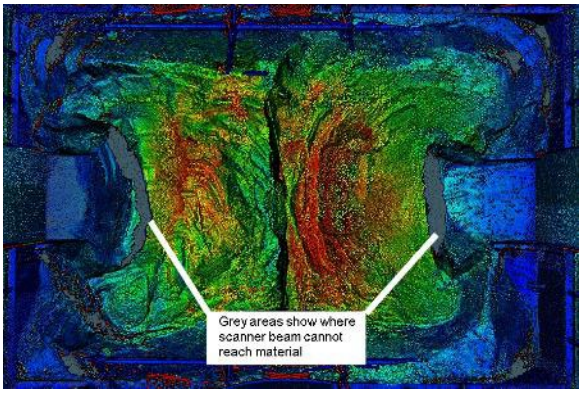


Figure 6.6. 3-D image created by Carlson software.

The automatic generation of Volume Reports is now possible and will be Emailed to a list of recipients after every scan.

A sample Carlson FiX1 report is show in Figure 6.7.

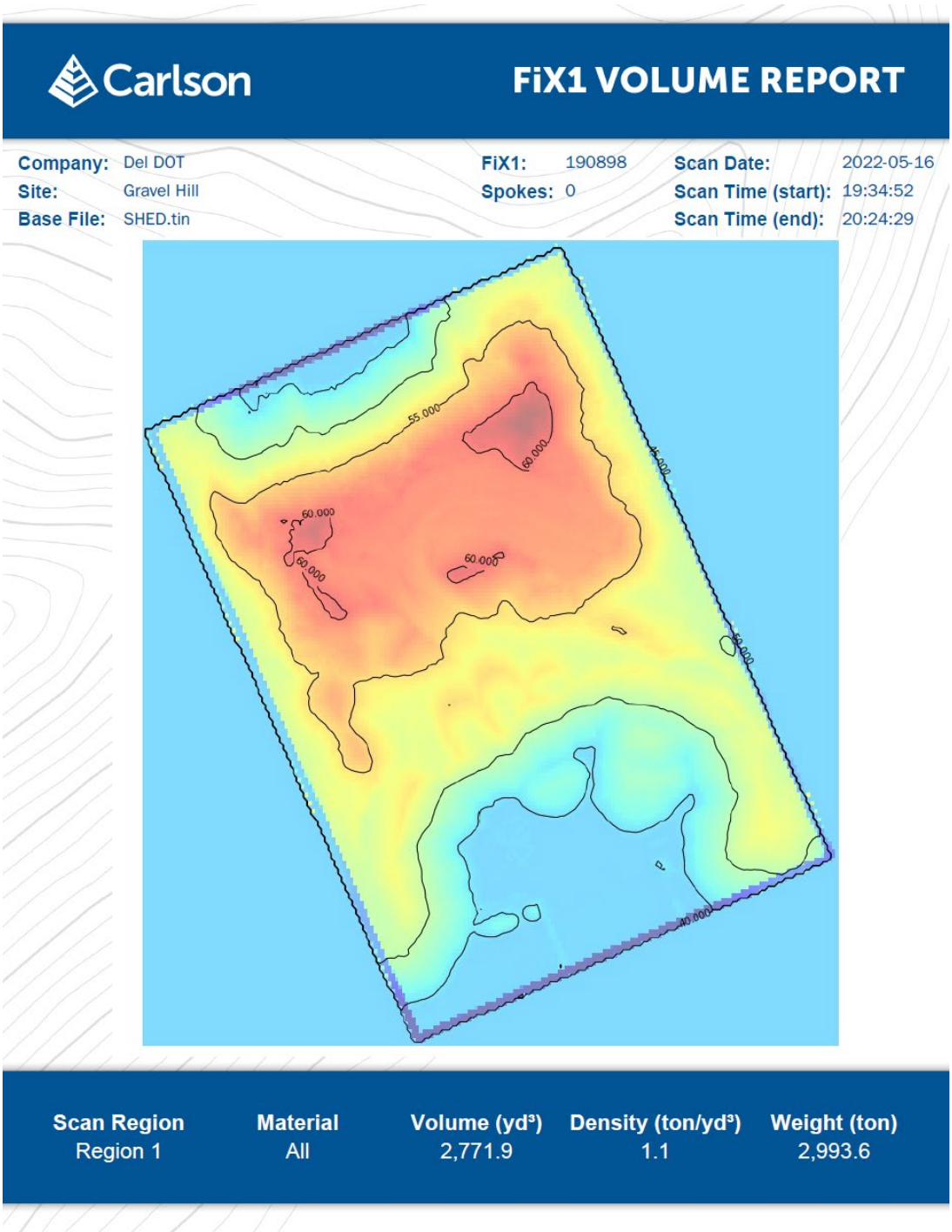


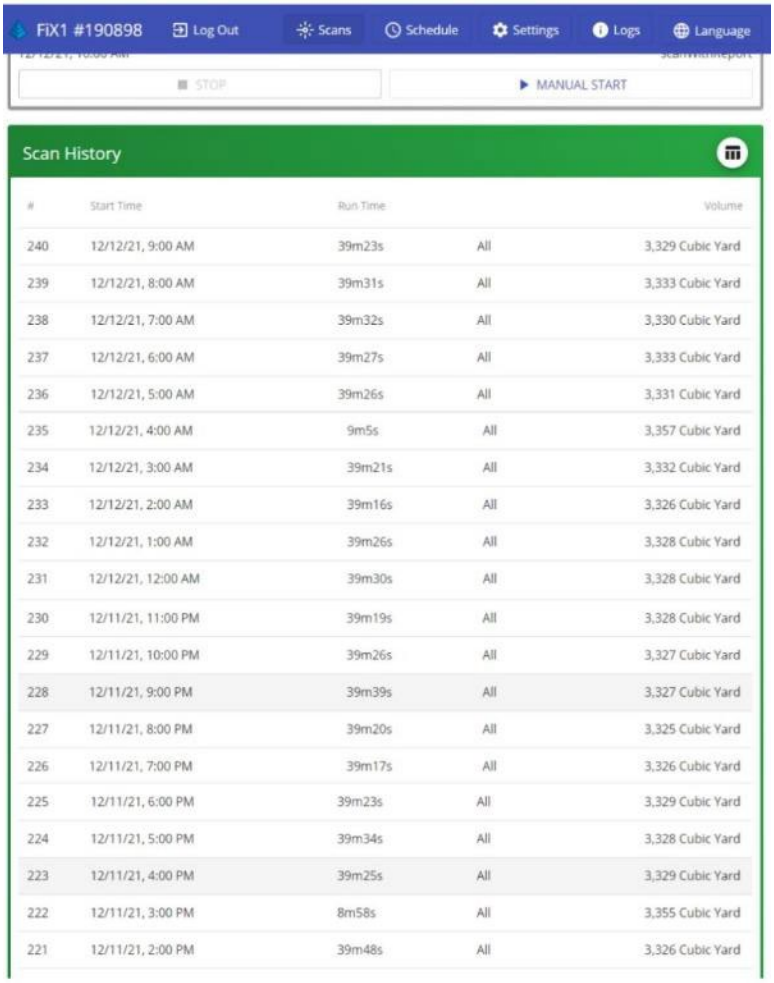
Figure 6.7. Sample Carlson FiX1 report.

Beyond a PDF report, additional data types that may be downloaded for a given run are binary (.bin); LASer (.las); elevation, base and top grid (.grd); full report (.json); and scan log (.txt).

Further, per Carlson:

Scanning can be triggered Manually by authorized users or scheduled to happen automatically. Schedule can be viewed Daly / Weekly / Monthly, and scans can be setup to run at specific times of the day and "repeated" periodically as seen in the following image. A typical user would not schedule so many scans as each one Emails the Volume Report to a list of users.

*The Fix1 keeps a list of all scans and point cloud data [*Figure 6.8*] so users can review the history, re-run volume reports and review 3D images for qualifying data.*



#	Start Time	Run Time		Volume
240	12/12/21, 9:00 AM	39m23s	All	3,329 Cubic Yard
239	12/12/21, 8:00 AM	39m31s	All	3,333 Cubic Yard
238	12/12/21, 7:00 AM	39m32s	All	3,330 Cubic Yard
237	12/12/21, 6:00 AM	39m27s	All	3,333 Cubic Yard
236	12/12/21, 5:00 AM	39m26s	All	3,331 Cubic Yard
235	12/12/21, 4:00 AM	9m5s	All	3,357 Cubic Yard
234	12/12/21, 3:00 AM	39m21s	All	3,332 Cubic Yard
233	12/12/21, 2:00 AM	39m16s	All	3,326 Cubic Yard
232	12/12/21, 1:00 AM	39m26s	All	3,328 Cubic Yard
231	12/12/21, 12:00 AM	39m30s	All	3,328 Cubic Yard
230	12/11/21, 11:00 PM	39m19s	All	3,328 Cubic Yard
229	12/11/21, 10:00 PM	39m26s	All	3,327 Cubic Yard
228	12/11/21, 9:00 PM	39m39s	All	3,327 Cubic Yard
227	12/11/21, 8:00 PM	39m20s	All	3,325 Cubic Yard
226	12/11/21, 7:00 PM	39m17s	All	3,326 Cubic Yard
225	12/11/21, 6:00 PM	39m23s	All	3,329 Cubic Yard
224	12/11/21, 5:00 PM	39m34s	All	3,328 Cubic Yard
223	12/11/21, 4:00 PM	39m25s	All	3,329 Cubic Yard
222	12/11/21, 3:00 PM	8m58s	All	3,355 Cubic Yard
221	12/11/21, 2:00 PM	39m48s	All	3,326 Cubic Yard

Figure 6.8. List of Carlson FiX1 data runs.

With a quick look at the 20 scans listed above we can make an assessment of the consistency of the scanner during a period of no material movement. Outliers can be scrutinized by viewing the 3D image and looking for anomalies.

6.2.3 Skydio

The investigators did not work directly with Skydio on its drone system (Figure 6.9) or with DroneDeploy on its analysis software. Skydio was not a fixed system like Stockpile Reports or Carlson Fix1, so installation issues are not addressed.

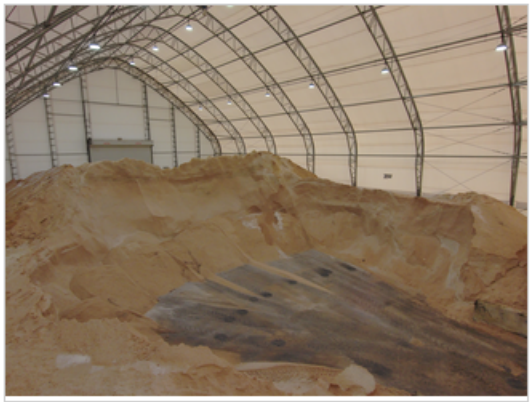
Figure 6.9. Skydio drone in flight (left), photo taken by Skydio drone in flight (right).

A sample Skydio 3D capture report is shown in Figure 6.10.

Skydio

3D Capture

Scan generated at 06:31 AM on January 06, 2022



Summary

Description	No description
Scan ID	4ef2f4cfe3644175a5e9be0f75eb6cc9
Started	05:45 AM on January 06, 2022
GPS Location	(38.71087559, -75.31998299)

Settings

Scan Mode	3D Capture
Stop Vehicle at Photo	Disabled
Take HDR Photos	Enabled
Distance to Surface	20 ft
Overlap	80%
Sidelap	70%

Visual Geofence

Strict Ceiling	Strict Floor	Strict Lateral
Enabled	Enabled	Enabled

Scan Passes

Z	Y	X
Enabled	Enabled	Enabled

Stats

Scan Area	13258.3 sq ft
Pillars	5
Flights	3
Batteries	3
Flight Time	35 minutes
GSD	0.099 in

Images

Total	Autonomous	Manual
575	543	32

Flights

Flight	Flight ID	Takeoff Time	Images	Vehicle Name	Vehicle ID
1	3A1311693A1A43A18E70EE7CAD120602	2022-01-06 05:45 AM	35	Skydio2-9n89	240098274912417
2	F57921C44EB94660A0D595EFA48C16DA	2022-01-06 05:57 AM	418	Skydio2-9n89	156456238790101
3	E45F3260E494424F8E915B2C7B87CBB6	2022-01-06 06:22 AM	122	Skydio2-9n89	139499180005503

Figure 6.10. Skydio 3-D capture report.

CHAPTER 7: DATA ANALYSIS, SYSTEM PERFORMANCE, CONCLUSIONS AND RECOMMENDATIONS

7.1 DATA ANALYSIS

Tests with controls on par with a lab test environment could not be performed in active salt sheds that were primarily serving winter maintenance needs. However, during periods when salt was not being added or removed, controlled measurements and field tests provided insights on system performance.

These tests included:

- Comparisons of different measurement methods on unchanged volume
- Before-and-after measurements of reconfigured, but otherwise unchanged, salt piles
- Before-and-after measurements of salt piles with a fixed volume removed
- Changes in analysis outcomes using a different number of cameras (Stockpile Reports equipment)
- Changes in readings by changing lidar scanning settings (Carlson FiX1 equipment)

One additional testing condition—measurements before and after delivery—had been considered. However, since material *removal* was not generally tracked, it was impossible to include this test.

Refer to Appendix C. Automated Stockpile Evaluation Data for data sources.

7.1.1 Comparisons of different measurement methods on unchanged volume

7.1.1.1 Stockpile Reports

Stockpile Reports calculates measurements to the nearest 25 cubic yards.

At the Decatur, Happy and Bullfrog sites, Stockpile Reports measurements were **internally consistent** from measurement-to-measurement when stockpiles were unchanged.

At the Bullfrog facility, staff periodically measured the pile using tape-and-wheel measurement (Table 7.1) and Total Station handheld laser scanning (Table 7.2) on the same days that Stockpile Reports measurements were taken. In all instances, these **traditional methods produced higher readings than Stockpile Reports**. However, the measurements were not consistently higher, ranging from 4 to 50 percent for the tape-and-wheel, and from 5 to 25 percent for Total Station.

As noted, material removal was not tracked, and not all deliveries were tracked. In some cases, small gaps in time on the same day between measurements could have accounted for these differences. However, the trend of both tape-and-wheel and Total Station being greater than Stockpile Reports suggest that both methods do measure a higher volume as calibrated.

Table 7.1. Stockpile Reports measurements compared with tape-and-wheel measurements.

Date of Measurement	**Stockpile Reports** (cubic yards)	**Tape-and-wheel** (cubic yards)	**Percent Difference** Tape-and-wheel compared with Stockpile Reports
11/8/2021	2,525	2,985	18%
11/15/2021	2,850	2,962	4%
11/21/2021	2,575	2,916	13%
11/28/2021	2,350	2,847	21%
12/5/2021	2,050	2,561	25%
12/12/2021	1,900	2,069	9%
12/19/2021	1,300	1,725	33%
12/27/2021	1,325	1,610	22%
1/2/2022	1,000	1,495	50%
1/10/2022	1,200	1,380	15%
1/16/2022	1,050	1,839	75%
1/23/2022	1,475	1,724	17%
1/30/2022	1,300	1,566	20%
2/6/2022	1,200	1,566	31%
2/13/2022	1,475	1,750	19%
2/20/2022	1,425	1,540	8%
2/28/2022	1,325	1,483	12%

Table 7.2. Stockpile Reports measurements compared with Total Station measurements.

Date of Measurement	**Stockpile Reports** (cubic yards)	**Total Station** (cubic yards)	**Percent Difference** Total Station compared with Stockpile Reports
12/8/2021	2,250	2,582	15%
1/13/2022	1,250	1,564	25%
2/24/2022	1,425	1,491	5%

7.1.1.2 Carlson FiX1 and Skydio

Carlson calculates measurements to the nearest 0.1 cubic yard. For clarity, the decimal fraction is rounded off in all data tables in this report. DroneDeploy calculates measurements to the nearest 10 cubic yards.

At the Decatur, Happy and Bullfrog sites, day-to-day Carlson FiX1 measurements were **internally consistent** from measurement-to-measurement when stockpiles were unchanged, typically differing by no more than 10 cubic yards on an unchanged pile.

Comparison measurements were taken on five days for Carlson FiX1 compared with Skydio (Table 7.3) and on one day for Carlson compared with a FARO 3-D scanner (Table 7.4). These did not produce

predictably similar results, ranging from Carlson FiX1 showing slightly less than Skydio and FARO (7 to 8 percent) to Skydio measuring nearly 50 percent more than the Carlson FiX1.

Table 7.3. Carlson FiX1 measurements compared with Skydio measurements.

Date of Measurement	**Carlson** (cubic yards)	**Skydio calculated by DroneDeploy** (cubic yards)	**Percent Difference** Skydio compared with Carlson
12/28/2021	3,332	3,520	6%
1/6/2022	2,143	2,910	36%
1/9/2022	2,374	2,470	4%
1/14/2022	2,775	2,570	-7%
1/25/2022	1,919	2,940	53%

Table 7.4. Carlson FiX1 measurement compared with FARO measurement.

Date of Measurement	**Carlson** (cubic yards)	**FARO** (cubic yards)	**Percent Difference** FARO compared with Carlson
1/24/2022	1,916	1,760	-8%

7.1.2 Before-and-after measurements of reconfigured, but otherwise unchanged, salt piles

For both Stockpile Reports and Carlson FiX1, tests were conducted to reconfigure salt piles to determine if readings would correctly remain unchanged.

7.1.2.1 Stockpile Reports

On March 30, WSDOT staff conducted controlled tests with cooperation from Stockpile Reports and investigators offsite. Measurements included three conditions, pictured in Figure 7.1:

Condition W1. Starting condition (pile "as is")

- Tape-and-wheel: 1,350 cubic yards
- Stockpile Reports: 1,375 cubic yards

Condition W2. Using a loader, staff moved significant volume into two small piles at the foot of the main pile. This is the same volume as **W1**, but a new geometry.

- Tape-and-wheel: 1,368 (35 cubic yards measured in two smaller piles is included in this total)
- Stockpile Reports: 1,375 cubic yards

Condition W3. Using a loader, staff moved significant volume into a single pile separate from the main pile. This is the same volume as **W1** and **W2**, but another new geometry.

- Tape-and-wheel: 1,325 cubic yards (45 cubic yards measured in a smaller pile is included in this total)

- Stockpile Reports: 1,375 cubic yards

Figure 7.1. Measuring the Washington State DOT pile in three configurations (left to right: Conditions W1, W2 and W3).

Stockpile Reports measurements were identical in all three conditions. Within the Stockpile Reports' increment of measurement (25 feet), the tape and wheel performed identically as well. Side-by-side reports from Stockpile Reports are shown in Figure 7.2.

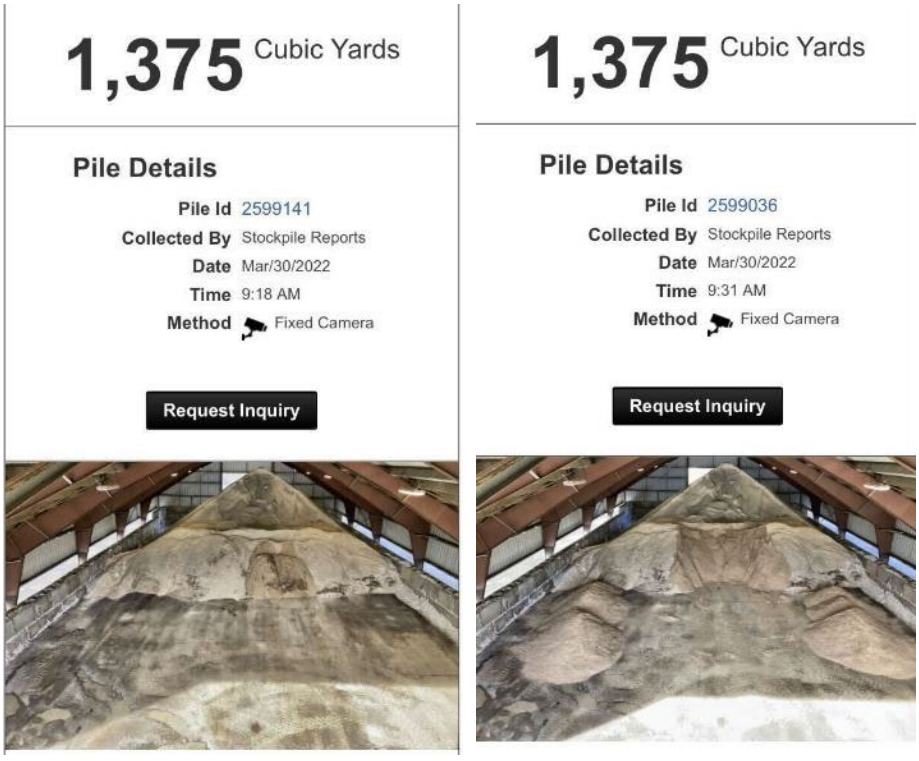


Figure 7.2. Reports on the Washington State DOT pile in two configurations (Conditions W1, left, and W2, right).

7.1.2.2 Carlson FiX1

On March 15 and 16, DelDOT staff conducted a controlled before-and-after test, rendered in Figure 7.3 using Carlson FiX1 quality-control software accessed remotely by the investigator.

Condition D1. Starting condition (pile "as is")

- Carlson FiX1: 2,333 cubic yards

Condition D2. Using a loader, staff moved significant volume into two small piles at the foot of the main pile. This is the same volume as **D1**, but a new geometry.

- Carlson FiX1: 2,323 cubic yards

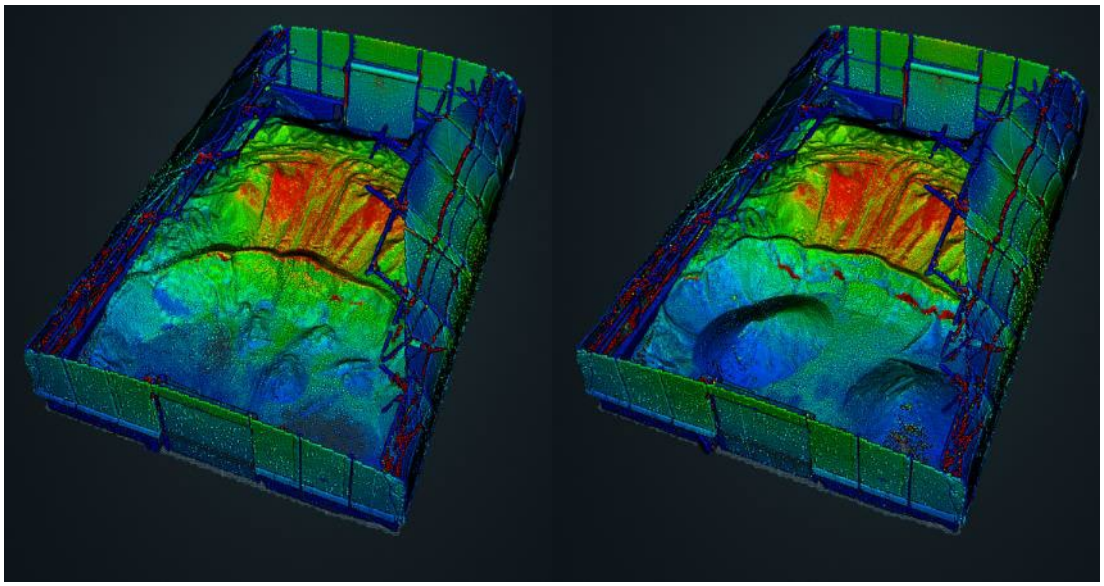


Figure 7.3. Point cloud renderings of the Delaware DOT pile in two configurations (Conditions D1, left, and D2, right).

The difference in measured volume before and after was only 10 cubic yards. This difference is negligible, representing only about half a percent of the entire pile.

7.1.3 Before-and-after measurements of salt piles with a fixed volume removed

For both Stockpile Reports and Carlson FiX1, tests were conducted to remove a known quantity of stock to determine if readings would correctly reflect the removal.

7.1.3.1 Stockpile Reports

On March 30, WSDOT staff further conducted controlled tests with cooperation from Stockpile Reports and investigators offsite. Measurements included two conditions (Figure 7.4), taken with both the tape-and-wheel method and with Stockpile Reports equipment.

Condition W3. Starting condition (pile "as is"); same as Stockpile Reports **Condition W3** above

- Tape-and-wheel: 1,325 cubic yards (45 cubic yards measured in a smaller pile is included in this total)
- Stockpile Reports: 1,375 cubic yards

Condition W4. Starting condition (pile "as is"); same as above

- Tape-and-wheel: 1,324 cubic yards
    - This reflects a removal of 1 cubic yard.
- Stockpile Reports: 1,350 cubic yards
    - This reflects a removal of 25 cubic yards.

Figure 7.4. Measuring the Washington State DOT pile before and after a small volume is removed.

The amount of salt actually removed – a pile approximated at 20 cubic yards, is likely smaller than the tolerance of tape-and-wheel and is smaller than the measurement increment for Stockpile Reports.

- This is reflected in the negligible difference in the tape-and-wheel measurement
- The Stockpile Reports measurement does drop by a single increment of 25 cubic yards, which is not unexpected given an actual drop of around 20 cubic yards.

7.1.4 Changes in analysis outcomes using a different number of cameras (Stockpile Reports)

For the Bullfrog facility in Washington state, the TAP was interested to learn relative value of having three camera pairs trained on the pile and feeding Stockpile Reports' analysis compared with just one centrally placed camera pair.

Stockpile Reports was asked to conduct this analysis and reported:

> *Removing two of the front camera pairs only impacted the results when the shed was at capacity as it created a coverage gap on the front 10% of the pile where cameras could not see material. For the remainder of the cases where the pile was 80% full or less, there were no significant differences that could be attributed to removing camera pairs from the solution. When this particular pile was below capacity, even a single camera pair was sufficient for coverage.*

Our findings reinforced the idea that the number of camera pairs needed will depend both on the size and layout of the shed, as well as the business need of the customer.

7.1.5 Changes in readings by changing lidar scanning settings (Carlson FiX1)

Carlson staff suggested that changing some setting might reduce the total time needed for the lidar scanning process while having little impact on the results. The baseline settings for a scan that Carlson proposed changing include the following:

- Scan line interval: 21 steps/change; this can be raised or lowered
- Head rotation speed: 450 degrees/second; Carlson's suggested setting was the maximum
- Laser pulse rate: 5 kHz; Carlson's suggested setting was the minimum

The settings screen is shown in Figure 7.5.

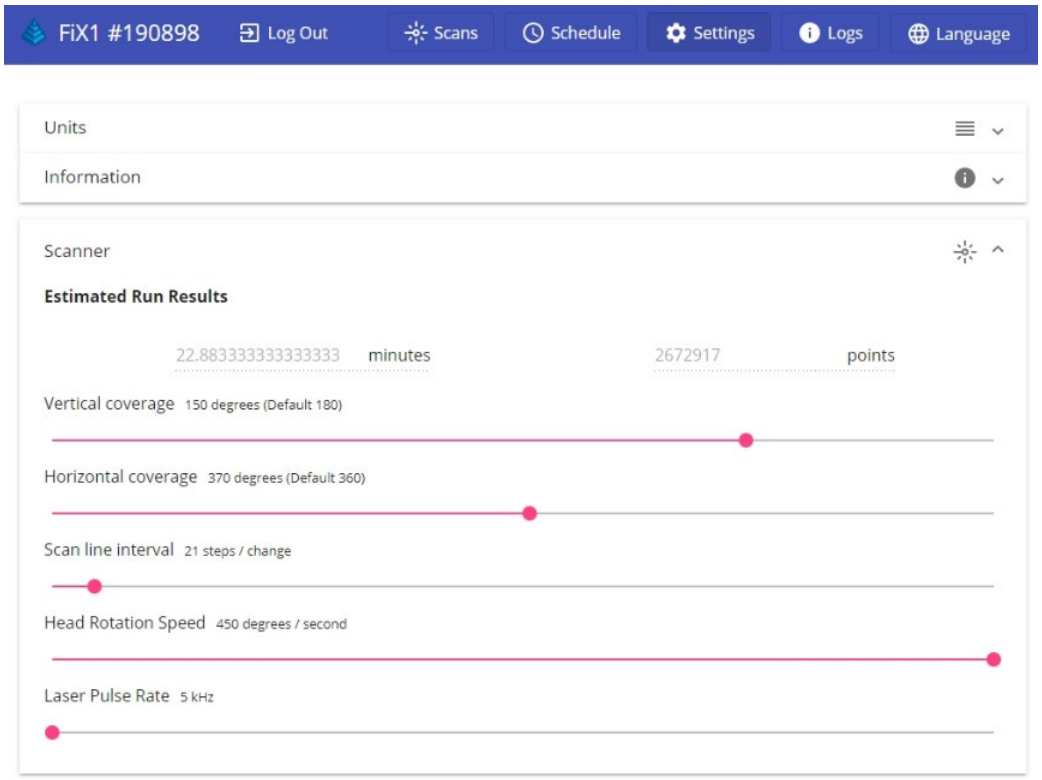


Figure 7.5. Carlson FiX1 scan settings screen.

Table 7.5 shows the settings and outputs (scan time, points, and calculated pile volume) for a baseline control run and six subsequent test runs.

- In runs 2 through 5, the scan line interval is moved to both finer and coarser settings compared with run 1.
- In run 6, the head rotation is decreased compared with run 1.
- In run 7, the laser pulse rate is increased compared with run 1.

Table 7.5. Control and test runs changing Carlson FiX1 scan settings on an unchanged pile.

Run	Setting: Scan line interval (steps/change)	Setting: Head rotation speed (degrees/s)	Setting: Laser pulse rate (kHz)	Output: Scan time (minutes)	Output: Points	Output: Pile volume (cubic yards)
1. Baseline	21	450	5	22.9	2,672,917	2,783
2. Finest interval	10	450	5	46..4	5,612,500	2,772
3. Coarser interval 1	40	450	5	12.7	1,404,167	2,794
4. Coarser interval 2	80	450	5	7.0	702,083	2,804
5. Coarsest interval	160	450	5	4.3	350,000	2,816
6. Slower head rotation	21	300	5	35.6	4,008,333	2,784
7. Faster pulse rate	21	450	10	22.9	5,345,833	2,769

The following conclusions are drawn:

- Finer intervals are associated with significantly slower scan times and with slightly lower calculated volumes. This trend holds across the range of all runs, but at the extremes:
    - 10 steps per change took about 11 times longer to run than 160 steps per change.
    - The calculated volume was about 1.5 percent lower
- Head rotation and pulse rate had a negligible effect (less than 1 percent) on calculated volume.

For a shed and pile similarly configured to the one tested, if time is critical for measuring pile volume, coarser settings appear not to have a significant impact on results.

For further comparison, the differences in scan intervals are illustrated in the data renderings (Figure 7.6) of Run 1 (21 steps/change) compared with Run 6 (160 steps/change). The lower resolution of the latter is clearly visible in the renderings.

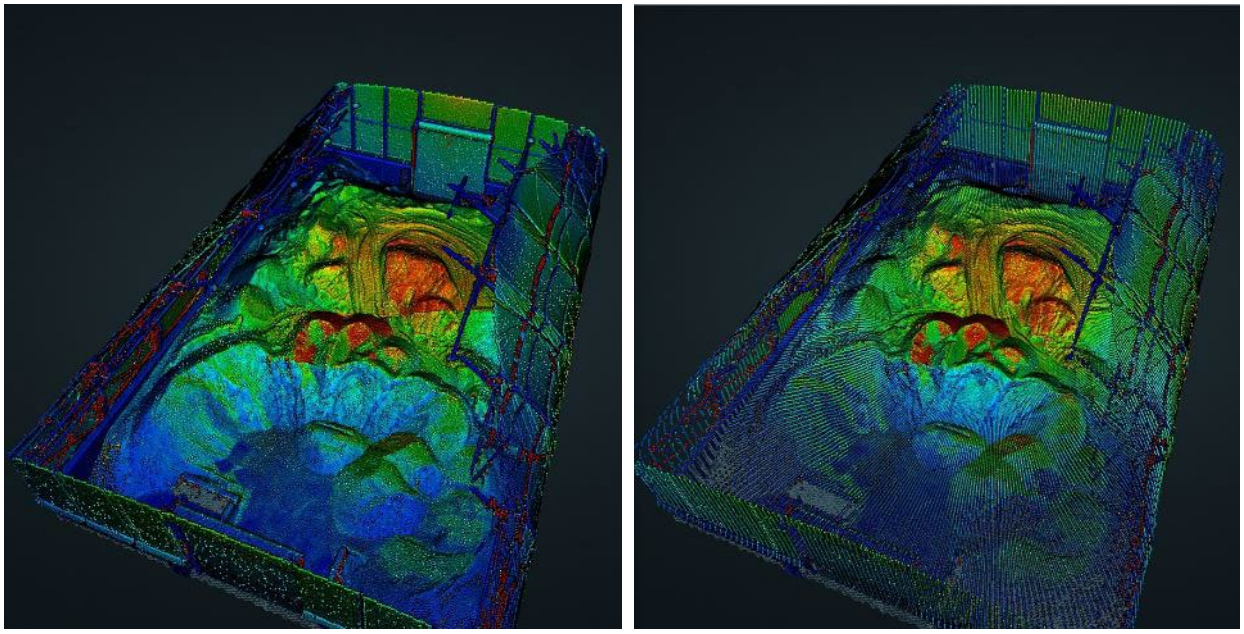


Figure 7.6. Renderings of Run 1 (21 steps/change), left, and Run 6 (160 steps/change), right.

7.2 SYSTEM PERFORMANCE

7.2.1 Stockpile Reports

- Texas and Washington State reported that installation and operation of the Stockpile Reports equipment went smoothly.
    - A one-time technical issue in Washington state involved condensation or fog on the lens; this was resolved.
    - Texas had internal issues related to providing power that delayed the start of using Stockpile Reports at its Decatur facility. This was unrelated to problems with the equipment or vendor.
- The investigators found the vendor to be communicative, helpful and proactive at all stages of this demonstration.

7.2.2 Carlson FiX1

- Delaware reported that installation and operation of the FiX1 scanner went smoothly.
    - The Carlson FiX1 system occasionally stopped working, and power would have to be cycled onsite to restore functionality and remote access to data (stored onboard the hardware in the shed).
        - Carlson representatives suggested this may be due to a “confused” modem SIM card and cellular connection used in the Delaware setup to transmit and receive data. A local wireless or wired network might solve this issue.

    - A one-time technical issue involved a haze in the room that caused an outlier volume reading. The issue was identified and diagnosed by analyzing the remotely accessed point cloud rendering in the FiX1 quality control software. This issue was not repeated.
- The investigators found the vendor to be communicative, helpful and proactive at all stages of this demonstration.

7.2.3 Stockpile Reports versus Carlson FiX1

- Operational similarities
    - Both systems allow access to source data for all readings: photo pairs for Stockpile Reports, and point clouds readable in multiple formats and visualizations for Carlson FiX1.
    - One or multiple pieces of equipment—camera pairs for Stockpile Reports and lidar scanners for Carlson FiX1—may be required depending on the configuration of a salt shed and the accuracy desired.
    - Reports for both systems include pile volumes and measurements as well as 3-D renderings.
- Operational differences
    - Stockpile Reports photos are taken instantaneously and processed using proprietary algorithms; the measurement cadence can be set at whatever frequency is required up to every 15 minutes. Carlson scans can be conducted in as little as four minutes based on required user accuracy (see Table 7.5); Delaware found a 20-minute scan to provide sufficiently accurate and usable readings.
    - Stockpile Reports data are stored on a web server; Carlson FiX1 data are stored onboard the equipment in the shed and can be retrieved on site or remotely via online access.
    - Stockpile Reports calculates volumes to the nearest 25 cubic yard. Carlson FiX1 calculates volumes to the nearest 0.1 cubic yards. Note: Carlson's additional significant figures in its measurements do not necessarily imply a higher certainty of its measurements.

7.2.4 Skydio and DroneDeploy

- Delaware DOT, which operated the drone, reported it took almost as long to fly the drone as to conduct a traditional laser scan. Moreover, the process of uploading the data to DroneDeploy was not a difficult process, and analysis was nearly "plug and play."
- The investigators did not work directly with Skydio or DroneDeploy.

7.3 CONCLUSIONS

- While the goal of this project is not to recommend (or advise against) specific equipment, generally:
    - Both the Stockpile Reports and Carlson FiX1 equipment appeared to work as presented by vendors and regularly produced stable and precise measurements with little or no effort required of state DOT staff after the equipment was set up.
    - The Skydio equipment worked well but is not close to being an automated or semi-automated solution at this time.

  Staff at Texas DOT, Washington State DOT and Delaware DOT may be contacted if personal recommendations are needed.

- Trends in volume reporting for Stockpile Reports versus tape-and-wheel, Stockpile Reports versus Total Station, and Carlson FiX1 versus Skydio are discussed in Section 7.1.1 of this report. It is unknown whether Stockpile Reports is underreporting volume or if tape-and-wheel and Total Station are overreporting volume. It is similarly unknown if Carlson FiX1 is underreporting volume or Skydio is overreporting volume.

  For the purposes of managing a salt pile, data that are precise but not accurate (that is, predictably inaccurate, or always off by a consistent amount) may be sufficient. Those data can accurately show how much a pile has increased or decreased in volume, and those data can be used to set thresholds for triggers to schedule materials delivery, to order salt, or to coordinate with neighboring facilities for materials and services.

- Tests to measure the removal of small amounts of stockpile volumes are discussed in Section 7.1.3 of this report. The removal of a small amount of materials (20 cubic yards) and attempts to measure this change illustrate that the different measurement processes (Stockpile Reports, tape-and-wheel, Carlson FiX1) are not well-suited to measure such small changes. However, such small changes are likely not of interest when managing a small salt pile.

APPENDIX A. LITERATURE SEARCH

August 30, 2021
Project CR20-03

Indoor Stockpile Measurement

Literature Search in Support of Clear Roads Project 20-03:
Evaluation of Indoor Automated Stockpile Measurement Systems
(Project Task 2)

State DOTs' indoor salt stockpiles are often located at remote facilities. As salt inventories change frequently during the winter and in the fall and spring shoulder seasons, getting timely and accurate measurements of indoor salt stockpiles has traditionally presented a challenge to transportation agencies. Clear Roads is interested in examining a range of existing and emerging approaches to indoor stockpile measurement, including systems using LiDAR, photogrammetry, surveying, acoustic sensing and drone technology. In particular, Clear Roads is interested in automated or semiautomated systems that have the capability to measure a stockpile and transmit the data to a central location. By automating this process, states could improve their inventory management and minimize costly rush orders of salt.

This literature search compiles relevant guidance and research on this topic, with a focus on citations from the past 10 years, as well as information on measurement technology vendors. The citations on the following pages are organized into these categories:

- Previous Clear Roads Research
- State Research in Progress
- State Research and Guidance
- Other Publications
- Vendor Technologies and Solutions
    - Acoustic-Based Technology
    - Drones
    - Laser Technology
    - Software
    - Stockpile Monitoring Systems

This literature search is the Task 2 deliverable of the research project, Evaluation of Indoor Automated Stockpile Measurement Systems.

Citations

Previous Clear Roads Research

Monitoring Stockpiles of Solid Winter Maintenance Materials: Synthesis Report, Clear Roads Pooled Fund, January 2017.
http://clearroads.org/wp-content/uploads/dlm_uploads/FR_Synthesis_SaltStockpiles.pdf
From the abstract: Finding the right method to take frequent, accurate measurements of stockpiles of solid winter maintenance materials can be challenging for transportation agencies. Measurement practices can be time-consuming or fail to produce measurements that are accurate enough for the agency to rely on. Without accurate measurements of the materials on hand, an agency can face shortages of the solid winter maintenance materials needed to see it through a winter season.

This synthesis sought best management practices for the accurate measurement of solid winter maintenance materials using technology and other measurement methods that are not technology-based. A national survey of state department of transportation winter maintenance experts was used to gather information about their stockpile measurement practices. Results of a literature search supplemented survey findings and provided information about other technologies and practices used to measure stockpiles of solid materials.

State Research in Progress

Indiana

Salt Monitoring and Reporting Technology (SMART): Development of a Photogrammetric System for Salt Inventory Reporting, Purdue University/Indiana Department of Transportation, start date: February 2021; expected completion date: July 2022.
Project description at https://trid.trb.org/view/1783588
From the project description: Salt is an expensive commodity that is critical for successful winter operation. This project proposes the development of a stationary multi-camera photogrammetric system for salt inventory (volume estimation and reporting) in an indoor environment—specifically, dome-like and rectangular storage facilities.

Maine

"LiDAR Aids Maine DOT Winter Salt Situation," *Roads and Bridges*, August 12, 2020.
https://www.roadsbridges.com/lidar-aids-maine-dot-winter-salt-situation
From the article: The Maine DOT has begun using a tool often employed in the construction industry for inspections and data gathering in order to strengthen its winter maintenance regime as summer now begins to wane. The agency is now using LIDAR to determine how much salt is in the state's salt sheds. Using a fixed LIDAR scanner, which is programmed with the limits of a given shed's foundation, MDOT can perform scans of the pile to routinely update the amount inside to determine, based on weather patterns, if the stockpile is adequate or if more if needed to maintain the right levels of snow and ice control. DOT officials said part of the test is to see if this can be a cost-saving measure for the state. According to a local CBS affiliate, MDOT's Brian Burne said: "We'll be using this one scanner this winter. This is a test. The company has provided us this to try out. So, it's all about the cost benefit. It's not a cheap technology right now so we have to make sure the cost offsets the benefits we'll receive from this. So, we'll be tracking this in the winter."

State Research and Guidance

Iowa

"Iowa DOT Deploys GeoSLAM Survey Solutions to Monitor Salt Stockpiles and Improve Service Provision," *LiDAR News*, November 18, 2015.
https://lidarnews.com/articles/iowa-dot-deploys-geoslam-survey-solutions-to-monitor-salt-stockpiles-and-improve-service-provision/
From the article: Question: When 'Mother Nature' determines demand for road salt consumption in winter, how does a State Department of Transportation (DOT) strategically balance reserves? Answer: Iowa State DOT invested in Simultaneous Localisation & Mapping (SLAM) technology from GeoSLAM to accurately measure salt stockpiles in 109 maintenance areas in order to streamline salt distribution across 24,000 lane miles of state and federal roads.

Ohio

Optimization of Salt Storage for County Garage Facilities, Ken Walsh, Gayle Mitchell and Wallace Richardson, Ohio Department of Transportation, May 2015.
Publication available at https://cdm16007.contentdm.oclc.org/digital/collection/p267401ccp2/id/12503
From the 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.

Other Publications

"An Aerial Robotic System for Inventory of Stockpile Warehouses," Reynaldo M. Gago, Matheus Y. A. Pereira and Guilherme A. S. Pereira, *Engineering Reports*, March 11, 2021.
https://onlinelibrary.wiley.com/doi/full/10.1002/eng2.12396
From the abstract: This article describes the development and evaluation of an aerial robotic system for smart inventory of stockpile warehouses. The system was developed to automatically measure piles of different bulk materials, such as phosphorus and potassium compounds, which are stored in bays of different sizes inside a warehouse. This warehouse configuration is very common among fertilizer and animal food industries in Brazil. While an inventory can be executed by a human technician, the insalubrious environment, the imprecision of the manual volume estimation, and the time spent by the technician to access the information motivate the automation of the process. The proposed system uses a multirotor electrical drone that navigates autonomously inside the warehouse while it acquires light detection and ranging (LIDAR) point cloud data. This data is used to build a three-dimensional (3D) model of the environment, which is then processed to identify the stockpiles of

material and calculate their volumes. Since the environment is GPS-denied and its characteristics, including symmetry, illumination and texture, do not favor visual- or LIDAR-based localization, a drone navigation strategy that relies on relative positioning with respect to simple structures of the warehouse was developed. This article also presents our approach for autonomous stockpile volume estimation, which was numerically evaluated both in simulation and with real data, yielding in accuracy and precision of about 98%. The results presented in the article show that the aerial system is able to substitute the previously adopted manual procedure, highly increasing its accuracy, repeatably and safety, and drastically reducing its time of execution and cost.

"Figuring Out Aerial Surveying with a Drone Instead of Arguing About Photogrammetry vs LiDAR," Jeremiah Karpowicz, *Commercial UAV News*, August 23, 2016.
https://www.commercialuavnews.com/infrastructure/figuring-aerial-surveying-drone-instead-arguing-photogrammetry-vs-lidar
From the article: Surveying and mapping professionals have been using both photogrammetry and LiDAR for measurement and survey purposes for a long time now. As such, the question about which is more effective has come up in various ways. In fact, the contention that photogrammetry would make laser scanning obsolete is one that was making waves not too long ago. For anyone who takes the time to look at both technologies though, it's immediately evident that "better" and "obsolete" aren't words that really belong in this kind of conversation.

It's true that drones have made it easier than ever to create 3D models, and there are undoubtedly people who are convinced a cheap camera and drone will be all you need to gather the appropriate data for a given project. On the other side of that, there are people whose only experience has been with LiDAR, which compels them to ignore or disparage photogrammetry. Anyone making either claim is only looking at a specific application of the other technology, or his or her motivations are being driven by something besides what is going to be best for a given user.

There are simple as well as in-depth looks at the differences between the two technologies, and UAVs have given the conversation a whole new dimension. Professionals who work with these tools on a daily basis understand their strengths and limitations better than anyone though and can provide critical insights around how to best leverage the technology.

Vendor Technologies and Solutions

The vendor solutions described in the citations in this section are identified below and organized into five categories. Among the links and highlights for each vendor, selected related resources are also cited below.

Acoustic-Based Technology

- BinMaster
- Henry M. Wood Company

Drones

- DJI
- DroneDeploy
- DroneView
- Flyability
- GeoCue
- Kesprey
- Microdrones
- PrecisionHawk

- Propeller
- Skyward
- UAV Imaging

Laser Technology
- ABB
- Bosch
- EIP Enviro Controls
- Faro
- Laser Technology Inc.
- Maptek
- Neptec
- TruePoint

Software
- Applied Imagery
- Autodesk
- BinMaster
- Botlink
- ESRI
- Maps Made Easy
- PhotoModeler Technologies
- PIX4D
- Sitemark
- Virtual Survey

Stockpile Monitoring Systems
- Carlson
- GeoSLAM
- Merrett Mining Surveys
- SKYSSET
- SSP
- Stockpile Reports
- Wingfield Scale and Measure
- SSP
- Stockpile Reports
- Wingfield Scale and Measure

Acoustic-Based Technology

Acoustic Level Sensor: Model RL, BinMaster, 2021
https://www.binmaster.com/products/product/acoustic-level-sensor
From the web page: Highly reliable even in extreme dust, the BinMaster RL level sensor is a non-contact level sensor that works in powders and solid materials of all types—including very low dielectric materials. The BinMaster RL measures a single point in the bin using acoustics-based technology to provide continuous level measurement in a self-cleaning, low maintenance sensor.

Inventory Measurement/Control, Henry M. Wood Company, 2016.

https://www.henrymwood.com/dry-bulk-material-handling---emission-control.html
This company provided the acoustic scanner system for the Ohio DOT research project described on page 2 (see Completed State Research and Guidance).

Drones

Matrice 100, DJI, 2021.
https://www.dji.com/matrice100
This is the company web page for the DJI-Matrice 100, which was used in the research project described in "An Aerial Robotic System for Inventory of Stockpile Warehouses"; see page 3 in the Related Resources section.

Stockpile Inventory Management, DroneDeploy, undated.
https://www.dronedeploy.com/solutions/mining/
From the web page: Make planning and fulfillment decisions with more accurate, timely information to avoid waste and recognize revenue faster

- Measure stockpiles more often for a fraction of the cost of traditional methods
- One easy-to-use, audit-friendly hub for all stockpile volume measurements
- Report the total quantity and value of materials on site
- Export all drone data easily to your system of record

Aerial Mapping and Geospatial Services, DroneView Technologies, 2021.
https://www.droneviewtech.com/markets-served
From the web page: DroneView is a full-service aerial mapping and geospatial services company serving a broad array of end market customers - all who have a common interest in high accuracy mapping products. We utilize photogrammetry, LiDAR, and GIS to provide a wide range of products including aerial imagery, feature data collection, digital terrain modeling, contours, TIN surfaces, orthophotography, LiDAR, and Geographic Information Services (GIS).

Elios 2, Flyability, 2021.
https://www.flyability.com/casestudies/stockpile-3d-mapping
From the web page: In three different test flights, the Elios 2 collected raw aerial data of three indoor piles of industrial dust. This data was then processed using photogrammetry software Pix4Dmapper and turned into 3D models, which allows for the computation of the volume of each stockpile. Data collected by the Elios 2 was used successfully to map all three piles from each test. In three different test flights, the Elios 2 collected raw aerial data of three indoor piles of industrial dust. This data was then processed using photogrammetry software Pix4Dmapper and turned into 3D models, which allows for the computation of the volume of each stockpile. Data collected by the Elios 2 was used successfully to map all three piles from each test.

True View Fully-Integrated Drone LIDAR + Imagery Mapping Sensors, GeoCue, 2021.
https://geocue.com/products/3d-imaging-systems-true-view/
From the web page: The True View product series uses a common hardware and software foundation for a family of sensors. True View offers an innovative drone mapping solutions supporting LIDAR, photogrammetry, and direction geo-referencing solutions integrated in lightweight payloads. It allows for fast, easy automated generation of true 3D colorized point clouds, oblique imagery and orthophotos from a single drone flight.

Maximizing Mine and Quarry Profitability With Kespry's New Stockpile Measurement Solution Featuring DJI Drones, Kespry, October 2018.
https://kespry.com/stockpile-measurement-dji/

From the web page: Today, we're excited to announce a new partnership with DJI that will deliver a new solution to support our customers' needs to measure all of their stockpiles across mining and aggregate sites. This solution, available first quarter of 2019, delivers the unique Kespry autonomous flight and aerial intelligence experience for capturing data for stockpile measurement using a DJI Mavic 2 Pro drone. This new solution will enable our customers to greatly scale the number of sites and stockpiles they're able to manage using Kespry's inventory management capabilities. These capabilities are used to drive the profitability of sites by avoiding inventory write-downs, costly overproduction, and missed revenue due to insufficient material to meet customer orders.

mdLiDAR3000 aaS, Microdrones, 2021.
https://www.microdrones.com/en/integrated-systems/mdlidar/mdlidar3000-aas/?gclid=Cj0KCQjwnueFBhChARIsAPu3YkSwM4i7aQ0eJXQvUm4bpYZ-BafGpVUbTsc-FMgLT_GpdSbINFO4NhYaAtbPEALw_wcB
From the web page: Extreme LiDAR data collection, with convenient plans and data processing option. mdLiDAR3000 aaS is an end-to-end LiDAR solution combining a drone, a LiDAR payload, a fully integrated software workflow, and world class support to consistently provide quality deliverables.

AI-Driven Aerial Data Analytics, PrecisionHawk, 2021.
https://www.precisionhawk.com/precisionanalytics
From the web page: The complete aerial mapping, modeling, and inspection platform for the enterprise. Apply the latest generation of artificial intelligence to your aerial data and automate analysis, streamline reporting, and accelerate your work.

Propeller Platform, Propeller, 2021.
https://www.propelleraero.com/mining/
From the web page: Accurately calculate stockpile and pit volumes in seconds. Forget sending someone out to

Skyward's Drone Software and Training Services, Skyward, 2021.
https://skyward.io/
From the web page: Skyward provides a drone software platform, training, consulting and connectivity. We help companies and public agencies manage the entire drone workflow: planning missions, accessing controlled airspace, creating maps & models, and much more.

Related Resource:

> **"How a State DOT Cut Stockpile Survey Costs in Half Using Drones,"** Scott Duffin, Skyward, April 8, 2021.
> https://skyward.io/how-a-state-dot-cut-stockpile-survey-costs-in-half-using-drones/
> *From the web page*: A little while ago, Skyward hosted a webinar with the West Virginia Department of Transportation (WVDOT). We discussed WVDOT's drone program and the great ROI they quickly began to see. Now we want to take you inside one of their primary use cases. Here's how WVDOT used drones to transform what has always been expensive, accident-prone work — surveying aggregate stockpiles — for gains in accuracy, efficiency, safety, and cost savings.

Interior Barn Measurement Services, UAV Imaging Inc., 2021.
https://www.uavimaging.com/drone-stockpile-measurement/
From the web page: UAV Imaging provides stockpile storage enclosure measurements using drones. Our system performs safely and efficiently in almost all indoor environments and can provide the same accurate data as outdoor mapping and stockpile measurement methods. Our professional UAV pilots have logged hundreds of

hours conducting some of the most challenging flight missions in the industry. We emphasize safety and precision in every drone operation, so you can be confident that your project is in the right hands.

Laser Technology

VM3D Volumetric Laser Scanner, ABB, 2013.
http://vertassets.blob.core.windows.net/download/9b70fc6e/9b70fc6e-8f4b-4764-9ef0-1a702fe185da/datasheetenvm3d.pdf
From the data sheet: The 3D volumetric scanner system measures the volume of material stockpiles stored out in the open or in large structures like silos, bunkers, domes and sheds. By integrating accurate laser technology into a network of scanning instruments, complex surfaces can be mapped accurately. The system makes use of remote monitoring and data processing services to guarantee data integrity to the level needed for confident stock management and precise auditing.

Laser Measures, Bosch, 2021.
https://www.boschtools.com/us/en/boschtools-ocs/laser-measuring-23502-c/
This web page summarizes Bosch's laser measure product line.

3D Laser Scanner: Mounted on Poles or Warehouse, EIP Enviro Controls, undated.
https://eipenviroindia.com/3d-stockpile-inventory-pole-mounted-or-inside-warehouse/
From the web page: The Artemis 3D Laser takes multiple point measurements inside the shed (Plotting the X, Y and Z Co-ordinates of the material inside the silo) and generates a real time 3D Profile of material inside the silo along with Volume of the material and mass based on the density. ARTEMIS Scanner takes an average of 10,500 point measurements on a surface per individual scanning cycle and offers exceptional accuracies when utilised to quantify hard and soft bulk commodities.

The proprietary ART and AIMS software element of the ARTEMIS solution calculates volumes, publishes reports and provides a graphic interface. Scan results are immediately available on completion of a scan cycle and no additional calibrations or calculations are necessary.

Focus Laser Scanners, Faro, 2021.
https://www.faro.com/en/Products/Hardware/Focus-Laser-Scanners
From the web page: Capturing the measurements of a large object or building with conventional documentation methods can take days or weeks, and even then the data might contain errors or missing details. But FARO Focus Laser Scanners create accurate, complete and photorealistic 3D images of any environment or object in just a few minutes. With their intuitive touch screen and compact design, these FARO Focus 3D scanners are as easy to operate as a digital camera — with built-in protection from dirt, dust, fog, rain and heat/cold.

Stockpile Volumes, Laser Technology Inc., 2021.
https://www.lasertech.com/Stockpile-Volumes.aspx
From the web page: Measuring a stockpile volume using LTI's reflectorless laser technology is by far the quickest and safest method available. Whether it's aggregate, coal, wood chips, asphalt or anything else you inventory, our lasers have the ability to measure to almost any surface without the need of a reflector.
….

Take the TruPulse-360-R-Laser-Rangefinder, in conjunction with LTI's MapSmart on Android software, and you'll be able to accurately measure the volumes of any kind of material you own. Measuring indoor stockpiles is easy with LTI's MapSmart and TruPoint 300 compact total station. In a matter of minutes, you can measure volumes of material stored in bins or up against a wall. Collect the data you need from challenging areas quickly, accurately and cost-effectively.

Related Resources:

TruPulse Laser Rangefinder, Laser Technology Inc., 2021.
http://www.lasertech.com/TruPulse-Laser-Rangefinder.aspx
From the web page: You can instantly measure slope distance, inclination and azimuth* and calculate horizontal and vertical distance - all with a single push of a button. The TruPulse 200L and 200 models have just been revamped and now are better than ever with new enhancements and improvements. Offering higher accuracy, better target acquisition and higher range resolution these lasers are just another example of LTI's dedication to bringing the highest level of quality and innovation to the world.

MapStar TruAngle (Angle Encoder), Laser Technology Inc., 2021.
https://www.lasertech.com/MapStar-TruAngle-Angle-Encoder.aspx
From the web page: The MapStar TruAngle, like its predecessor - the MapStar Angle Encoder (MSAE), precisely calculates a turned horizontal angle that can be referenced to any desired point or direction. When integrated with an LTI laser, you can capture X, Y and Z coordinates for complete 3D mapping and surface modeling. With a smaller and lighter weight design, a more simplistic user interface and a price point that's nearly half of the MSAE, the TruAngle angle encoder is an attractive alternative mapping accessory.

Stockpile Volumes, Maptek, 2021.
https://www.maptek.com/products/mine_measurement/mine_survey.html
From the web page: Generate 3D models and accurate volumes to reconcile materials for indoor and outdoor stockpiles. Maptek laser scanning systems help you survey stockpiles safely, accurately and efficiently to meet reporting and contractor deadlines.

- Maptek XR3
- Maptek LR3
- PointStudio
- Maptek Drive

Related Resources:

Laser Scanning for Stockpiles, Maptek, 2021.
https://www.maptek.com/video/i-site-stockpile-measurement/
This video describes Maptek's use of laser scanning to measure stockpiles.

Stockpile Measurements Case Studies, Maptek, 2021.
https://www.maptek.com/products/mine_measurement/case_studies/stockpiles.html
This web page provides information on eight stockpile measurement case studies.

Opal 3D LiDAR Scanner and 3DRi Stockpile Monitoring Software, Neptec, 2021.
https://www.neptectechnologies.com/products/
From the web page: Introducing the completely redesigned OPAL 3D LiDAR scanner from Lumibird. Based on the latest innovations in laser optics and intelligent 3D processing, the OPAL delivers an unprecedented combination of range, data density, acquisition speed, and obscurant-penetration capability in a smaller, lighter package. The result is one of the most powerful and versatile 3D LiDAR scanners for real-time robotics and autonomous systems specifically designed for harsh environments.

Laser Scanning Equipment, TruePoint, 2021.
https://www.truepointscanning.com/laser-scanning-equipment
This web page lists the laser scanners used by TruePoint for 3D laser scanning.

Software

Quick Terrain Modeler, Applied Imagery, 2021.
https://appliedimagery.com/
From the web page: Quick Terrain Modeler is the world's premier 3D point cloud and terrain exploitation software package. Designed for use with LiDAR but flexible enough to accommodate any 3D data source, Quick Terrain Modeler provides an easy to use software experience that allows users to work with huge 3D data sets, quickly analyze that data, and export a wide variety of export products—all with a minimum of training and experience.

"Calculating Volumes for Salt Sheds," George Hatch, Autodesk, January 7, 2016.
https://knowledge.autodesk.com/support/civil-3d/learn-explore/caas/simplecontent/content/calculating-volumes-for-salt-sheds.html
From the web page: So you have a salt shed or stock pile that you would like to track volumes of? With the help of Autodesk Recap 360 and Civil 3D, the process is simple. The first thing you need to remember is that proper control is the key to repeatability and accuracy. Meaning, we need to ensure that we track the location of the object and ensure that every time we scan or photo capture it the data resides in the same x,y,z location (does not have to be a known coordinate system).

BinCloud Inventory Management Programs, BinMaster, 2021.
https://www.binmaster.com/products/category/inventory-management-programs
From the web page: Monitor your applications in real-time using BinCloud secure, user-friendly inventory management programs. Compatible with an array of sensors and capable of monitoring multiple vessels, these programs offer inventory visualization, automated alerts, and more — giving you access to the information you need to manage your operation efficiently.

Drone Software for Stockpile Measurement, Botlink, 2021.
https://botlink.com/automated-drone-software-for-aggregate
From the web page: Evolve the work site with Botlink's stockpile measurement tool. Increase frequency of data collection, lower costs, and discover the size of stockpiles within minutes. Botlink map stitching software is designed to be easy to use, and highly accurate. Map processing times are unrivaled, with a majority of maps being processed and returned to the customer within 30 minutes.

ArcGIS Drone2Map, ESRI, 2021.
https://www.esri.com/en-us/arcgis/products/arcgis-drone2map/overview
From the web page: ArcGIS Drone2Map streamlines the creation of professional imagery products from drone-captured imagery by implementing our professional photogrammetry suite, powered by Pix4D. Helping you to generate products quickly for visualization and analysis.
….

3D point clouds enable analysis of natural and built-up features including volumetric measurements, change detection, lines of sight, and obstructions.

Stockpile Volume Measurement, Maps Made Easy, 2021.
https://www.mapsmadeeasy.com/features

From the web page: Our web-based volume measurements make measuring and tracking stockpile volumes quick and easy. There is no expensive software to buy and the measurements can be made directly from your web-browser. Volumetric measurements are easily shared with others and are stored to track progress over time.

PhotoModeler Premium, PhotoModeler Technologies, 2021.
https://www.photomodeler.com/products/premium/
From the web page: The PhotoModeler Premium software has all the capabilities of the base PhotoModeler Standard product plus the capability to do Dense Surface Modeling (DSM), 3D scanning, SmartMatch, Geographic Systems, and Motion capture. Because Premium can handle all the functions of Standard (such as coded targets, manual projects, etc.), if you have a mix of project types, Premium may be the best choice for you. See the chart on the product overview page for a quick comparison of the products, and a detailed feature comparison.

PhotoModeler Premium is a sophisticated tool to build accurate Dense Surface Models and get measurements from your photos. Use PhotoModeler Premium to build:

- Dense Surface Models where a large number of 3D points are needed.
- Models that traditionally would require a 3D laser scanner
- Drone and UAV projects such as volume measurement, ortho-photos, contours, etc.
- Perform measurements over time with the Motion capability.

Photogrammetry and Geospatial Software PIX4D, 2021.
https://www.pix4d.com/
From the web page: The only drone mapping and photogrammetry software tools with a flight app, desktop, and cloud platforms.

Inventory Management and Reporting, Sitemark, 2021.
https://www.sitemark.com/industries/mining-aggregates/
From the web page: Reduce the need for staff to walk and measure stockpiles. The Sitemark platform includes tools for accurately measuring stockpile including comparisons with volume data from earlier surveys. The platform also supports export of volume, density, and mass measurements directly to other 3rd party applications.

Stockpile Inventory, Virtual Surveyor, 2021.
https://www.virtual-surveyor.com/stockpile-inventory-assess-the-value-of-your-stocks-frequently-with-drone-data
From the web page: Easily assess the value of your stocks. Create a materials library and calculate volumes, tonnages and monetary value. Export the numbers to .csv or create a PDF Report. A baseline is a terrain that represents an empty site. Convert your first drone dataset to a baseline by removing conveyors and piles. You can use this baseline for recurring stockpile inventories. Drone data often has conveyors hanging over the stockpiles. You do not want them included in your measurements. Learn about tools that allow to remove conveyors from your drone data. Sometimes you only need to quantify volume changes compared to the previous month for your accounting. Compare two drone datasets and extract the volume changes per area with a single click.

Stockpile Monitoring Systems

FiX1: Fixed Installation Scanner, Carlson, 2021.
https://www.carlsonsw.com/product/carlson-fix1
From the web page: The Fixed Installation Scanner (FiX1) from Carlson provides a simple, automated method for obtaining volumetric results of stockpiles in many different applications. The FiX1 system can be scheduled to scan, process and deliver a result without any user intervention. With remote connectivity through Cellular and Wi-Fi networks, the FiX1 can be permanently installed into inaccessible areas. It can be left to carry out volumetric scans that are triggered manually or by a user-defined schedule to automate a scan and provide continuous calculations.

- Hands-Free and Safe Stockpile Surveying - Monitor and measure remotely using the FiX1 Web UI all while improving safety in potentially hazardous environments
- Automate Volumetric Calculations - Schedule repeating scans and automate the delivery of volumetric results
- Base Scans off of Historical data - Pre-existing base data can be uploaded to provide a geo-referenced 'floor' from which to compute volumes

Stockpile Volumes Analysis, GeoSLAM, 2021.
https://geoslam.com/solutions/stock-pile-volumes/
From the web page: GeoSLAM's powerful mobile mapping technology enables you to build high-density 3D volumetric models within minutes. Our market-leading, handheld laser scanners can determine accurate stockpile volumes, silo reserves or mining tempos, without the need for GPS. Walk and scan, or attach the scanner to a trolley, drone, pole, UAV or vehicle for remote monitoring of hazardous environments. Our volumes software instantly turns data into actionable 3D information for rapid real-time decision making. So now you can confidently verify volumes at all stages of the supply chain as frequently as necessary. Train your staff in minutes, slash survey times and drive down costs.

Related Resource:

> **"Monitoring Salt Stockpiles for Improved Service Provision,"** *PositionIT*, August 15, 2016.
> https://www.ee.co.za/article/monitoring-salt-stockpiles-improved-service-provision.html
> *From the introduction*: To ensure accurate salt stockpile measurements, the Iowa State Department of Transportation acquired a hand-held laser scanning system. Accurate salt stockpile measurements help eliminate salt shortages at crucial times and avoid unnecessary and costly redistribution processes between storage facilities.

Stockpile Volumes, Merrett Mining Surveys, 2021.
https://miningsurveys.com/services/stockpile-volumes/
From the web page: Part of our Mining Survey services includes calculating stockpile volumes and providing stockpile surveys across mines, quarries, construction sites and any type of stock yard. Measuring stockpile volumes through the technologies available to us is clearly the safest and quickest options out there today.
….
Mobile mapping, laser scanning technology and UAV or drone methods provide rapid and cost-effective methods of computing stockpile volumes. Whether the stockpiles are situated outdoors, inside silos or warehouse storage sheds. High accuracy laser scanners combined with GNSS and IMU (inertial measurement unit) devices can be mounted on vehicles and driven through the mine site and around stockpile locations. This enables 3D modelling – or building information modelling – and hence accurate volume calculations of the mineral, waste or unprocessed ore stockpiles.

Volumetrics Specialists, SKYSSET, undated.
https://www.skysset.com/platform/
From the web page: This platform helps you measure bulk inventory levels and lets you segment all measurements by material or location.

- Information in the cloud
- Reduce on-site time
- Minimal time from data capture to a report
- Instant volume calculation on platform

Volume Measurement, SSP, 2018.
https://www.ssp-rotterdam.nl/services/volume-measurement/
From the web page: Where, in the past, measurements were taken by using tapes and where heights and curves were visually estimated in order to determine a volume of a stockpile, Ssp offers volume measurements by using survey equipment combined with GPS technology. The result of this technology is a 3D mapping of your stockpile and with an acceptable tolerance.

Working with high technical and advanced equipment we are able to calculate fast and accurate volumes using a higher density of points than traditional measuring methods and create volume reports directly in the field. To convert the volume measured into metric tons adequate sampling of your stockpile is required in order to determine the bulk density. The sampling and determination of the bulk density is performed in full accordance with ISO Standards.

Volume measurements can also be carried out in closed rooms such as warehousing. These measurements are carried out together with the company Coenradie by using laser scanners.

Calculate the Volume and Tonnage of Salt Stockpiles, Stockpile Reports, October 29, 2020.
https://www.stockpilereports.com/calculate-the-volume-tonnage-of-salt-stockpiles/
From the web page: If you have salt stockpiles that you would like to measure the volume and tonnage of, it's no problem with Stockpile Reports. We have three simple solutions available for you:

1. Fixed cameras for continuous monitoring and auto-replenishment
2. Indoor drone measurements for small and large salt stockpiles
3. iPhone measurements for piles that are indoors or in restricted spaces

Many traditional methods make estimations and aren't consistent from measurement to measurement. Our solutions provide you with consistent, reliable, and third-party compliant data. We go beyond volumetrics. We provide big data that allows you to plan ahead for future seasons and archived measurement tracking for dispute resolution. Our simple, easy to use service is being adopted by DOTs, like Idaho DOT and Texas DOT, and government organizations across the country.

Related Resources:

> **Idaho Transportation Department Chooses Stockpile Reports**, Stockpile Reports, May 10, 2019.
> https://www.stockpilereports.com/idaho-transportation-department-chooses-stockpile-reports/
> *From the web page*: Stockpile Reports is proud to announce the Idaho Transportation Department (ITD) has selected Stockpile Reports for the improved management of their materials using our inventory tracking software and iPhone app. ITD is starting with a 600 stockpile subscription and anticipates approximately 120 users will be actively measuring their materials with Stockpile Reports in 2019.
> ….

After discussions and a successful trial of the Stockpile Reports software on a few of their six districts, ITD chose to roll out Stockpile Reports to the rest of the districts. Their primary focuses are:

- Ensuring deliveries are in alignment with orders
- Ensuring materials are available and properly allocated to designated projects
- Ensuring materials, such as salt, are available during weather events
- Improving data consistency through precise and reliable inventory counts
- Providing enhanced transparency from the ground up
- Becoming more efficient by digitizing previously manual processes
- Ultimately, saving taxpayers' dollars by leveraging new efficiencies

"Measure Piles Using Imagery with BinMaster's Stockpile Reports," BinMaster, August 17, 2018.
https://www.youtube.com/watch?v=c0hCSlfDj3Y
This YouTube video explains how Stockpile Reports functions. Although the video is of an outdoor stockpile, it does provide information on the product.

TxDOT Awards Stockpile Reports Statewide Contract, Stockpile Reports, February 12, 2015.
https://www.stockpilereports.com/txdot-contract/
From the web page: We're very proud to announce that the Texas Department of Transportation has awarded Stockpile Reports a contract for stockpile measurements, beginning in 2015.
The TxDOT will measure their materials using our service with the iPhone Stockpiles App.
….

The TxDOT estimates that there will be over 500 users taking measurements of stockpiles, half of which will be backup users. In addition, TxDOT estimates it will conduct almost 10,000 measurements per year and maintain data for 2,400 stockpiles. Maintenance sections will no longer depend on survey crews and special equipment to accurately calculate stockpile volumes, freeing surveyors up for more strategic work. A single person can video a stockpile in less than five minutes, without climbing on the stockpile, and obtain accurate measurement results within 24 hours.

Stockpile Volume Measurement: Shed and Barn Stockpile Inventories, Wingfield Scale and Measure, undated.
https://www.wingfieldscale.com/map-measure/surface-quarry-work/
From the web page: Repeatable and high accuracy data is required for scanning inside sheds and stockpiles. With normally less than ideal environments, we are experienced with capturing and rendering consistent results safely.

APPENDIX B. AGENCY SURVEY RESULTS

Respondent	1. Please describe your agency's indoor salt storage facilities (number, type, capacity).	2. How does your agency measure and manage your indoor salt stockpile inventories?	3. Does your agency use an outside service or vendor to measure and/or calculate salt volumes?	If "Yes," what is the cost of such services?	4. Has your agency used, or does it plan to use, a fully-automated or semi-automated indoor salt stockpile measuring system?	5. Which systems (manufacturers and models) has your agency used or is your agency using? What are your plans for these systems for the 2021-2022 winter season?	6. What has been your experience with these systems?	7. Please use this space to provide any additional comments you wish to share.
Arizona DOT Kevin Duby Statewide Road Weather Manager kduby@azdot.gov 602-712-7512	42 facilities with approx. storage capacity 70,000 tons	Manual process and measurements based off of usage and ordering	No		No			
Caltrans Mark Peters Winter Operations Manager mark.peters@dot.ca.gov 530-417-0310	65 cinder block and metal, 50-200 ton permanent structure.	Sq. footage of footprint X average height = volume	No		No			
Delaware DOT Alastair Probert District Engineer alastair.probert@delaware.gov 302-853-1300	Multiple buildings ranging from fabric covered structures to rectangular timber barns. Max capacity of the fabric covered structures are 6,000 tons. Max capacity of timber barns is 2,500. Approximately twenty storage buildings	Currently measured using visual means and estimating based on what the building would store when full	No		Yes	in house photogrammetry based system where camera system ran along a track. No longer in service due to amount of work needed to process the data	in house system. Data processing required a fair bit of work from a knowledgeable employee to generate usable info	We would be interested in implementing a solution if an automated and cost effective produce was created
Idaho Transportation Department Steve Spoor Maintenance Services Manager steve.spoor@itd.idaho.gov 208-334-8413	We have fabric covered structures as well as steel structures with steel roofing. Roughly a total of 100 locations. Total capacity is unknown	Once a year an inventory is required and conducted in May. We use AVL data from snowplows to update current inventories along with delivery receipts when material is replenished. Most areas are now using an App to measure inventory throughout the winter season to try and maintain an accurate on-hand inventory.	No	We use either the app to measure or measure the piles individually.	No			

Respondent	1. Please describe your agency's indoor salt storage facilities (number, type, capacity).	2. How does your agency measure and manage your indoor salt stockpile inventories?	3. Does your agency use an outside service or vendor to measure and/or calculate salt volumes?	If "Yes," what is the cost of such services?	4. Has your agency used, or does it plan to use, a fully-automated or semi-automated indoor salt stockpile measuring system?	5. Which systems (manufacturers and models) has your agency used or is your agency using? What are your plans for these systems for the 2021-2022 winter season?	6. What has been your experience with these systems?	7. Please use this space to provide any additional comments you wish to share.
Indiana DOT Jeremy Mcguffey Statewide Winter Ops Mgr jmcguffey@indot.in.gov 317-296-2504	Roughly 120 salt storage locations, building type are mainly wooden dome and fabric covered buildings, capacity ranges from 500 tons to 15000 tons.	Currently stockpiles are estimated visually. Inventories are managed online in Agile Assets WMS	No		Yes	We developed an in-house low cost LIDAR solution with Purdue University that we will be installing starting this Fall (2021)	No prior experience with automated stockpile measurements in Indiana	
Iowa DOT Craig Bargfrede Winter Operations Administrator craig.bargfrede@iowadot.us 515-290-2713	We have 101 garages across the state. Each garage has one or more salt storage sheds located either at the garage or at an off-site location. We have multiple types of sheds: Wooden sheds, Domes and Hoop buildings. The capacities will vary from a 300 ton wooden shed to a 3000 ton Hoop building. Each garage has a different storage capacity which is based on the garages salt usage. We are sizing our new sheds in a range of 125-150% of their 5 year average annual usage. The reason we are sizing the buildings that way is to cut down on the number of salt deliveries required during the winter season.	We track salt usage and on hand quantities through our Resource Management System (RMS). Garages enter usage on a daily basis into RMS and RMS uses this information along with information from Purchasing that records salt delivery tonnage to give us an on hand quantity by garage.	No		Yes	We use a hand held LiDar device to scan/measure salt sheds. This device gives us a 3-D image of the pile along with a volume measurement. We then convert the pile volume to a tonnage amount. We utilize this device to measure salt sheds when we have discrepancies in the tonnage shown in the RMS system. Once the scan is completed we compare the tonnage in RMS to the scan and then make adjustments in RMS as appropriate.	We use a Zeb scanner. The scanning device is very simple to use. A very small amount of training was needed to be able to use the system. We have found the scans to be pretty accurate so we have a high level of confidence in the data we are getting back from the unit. We own the unit so we do not have to depend on a vendor to do the scans.	

Respondent	1. Please describe your agency's indoor salt storage facilities (number, type, capacity).	2. How does your agency measure and manage your indoor salt stockpile inventories?	3. Does your agency use an outside service or vendor to measure and/or calculate salt volumes?	If "Yes," what is the cost of such services?	4. Has your agency used, or does it plan to use, a fully-automated or semi-automated indoor salt stockpile measuring system?	5. Which systems (manufacturers and models) has your agency used or is your agency using? What are your plans for these systems for the 2021-2022 winter season?	6. What has been your experience with these systems?	7. Please use this space to provide any additional comments you wish to share.
Kansas DOT Clay Adams Director of Field Operations clay.adams@ks.gov 785-296-3233	Numerous. Cones, Domes, concrete block bunkers, concrete wall shed, etc. Capacity from 500 to 1600 tons	Loader bucket counts, reconciles when facility is nearly empty	No		No			
Massachusetts DOT Mark Goldstein Lead Statewide Snow & Ice Engineer mark.a.goldstein@state.ma.us 857-368-9680	200+ (140 depots, some with multiple sheds). Fabric canopies on metal substructure (maybe 22-30 of these) with the rest wooden. Statewide capacity 334,000 tons	Multiple ways. We track inventories in proprietary Snow & Ice Management Software (SIMS). Usage from storms is entered and deducted in SIMS. Balances are verified in the field by counting bays and estimating.	No		No			
Michigan DOT Matt Pratt Maintenance Ambassador prattm@michigan.gov 517-322-5372	50+ Domes, Sheds	Salt Scales on loaders, Stock Pile App, Stock Pile Drone, Range Finders, Markings on walls, Guess, Lidar	Yes	Stock Pile App	Yes	Stock Pile App with Skydio Drone	The main issues we have is with poor, broken, or missing lighting, not stacking material per our guidelines, not able to fly dome sheds YET	
New Hampshire DOT David Gray Winter Maintenance Program Specialist David.Gray@dot.nh.gov 603-419-9017	112 salt piles, Gambrel and lean to sheds, anything from several hundred tons to 5500 tons	The field staff has marks on the walls and rafters that gives them the amount of salt in a shed	No		No			
New York State DOT Tina Crowley Snow and Ice Program Manager kristina.crowley@dot.ny.gov 518-457-6645	449 salt storage buildings Variety of domes, barns with coveralls, & Lean-tos 571,150 Tons capacity	Salt tonnage is measured (estimated) based on capacity of building and percentage filled.	No		No			

Respondent	1. Please describe your agency's indoor salt storage facilities (number, type, capacity).	2. How does your agency measure and manage your indoor salt stockpile inventories?	3. Does your agency use an outside service or vendor to measure and/or calculate salt volumes?	If "Yes," what is the cost of such services?	4. Has your agency used, or does it plan to use, a fully-automated or semi-automated indoor salt stockpile measuring system?	5. Which systems (manufacturers and models) has your agency used or is your agency using? What are your plans for these systems for the 2021-2022 winter season?	6. What has been your experience with these systems?	7. Please use this space to provide any additional comments you wish to share.
North Dakota DOT Jesse Kadrmas Grand Forks District Assistant District Engineer JLKADRMAS@nd.gov 701-787-6507	NDDOT currently has 61 salt piles state wide. Majority of the buildings are pole barn type buildings that have a capacity of around 600-700 CY.	NDDOT is actively looking at ways to measure salt piles consistently throughout the state. We are currently looking at using programs such as pix4d and/or stockpile reports.	No	Currently, we don't use such services, but are currently looking into these types of programs. Pix4d has a desktop version. Pix4d has two apps that you can use for calculating quantities. One that can be used with a phone and one that can be used with a drone. Stockpile Reports (SR) is considerably more expensive. SR offers a real time inventory solution for salt stockpiles using cameras mounted in the building. Depending on the size of the building, you may need two pairs. SR charges an annual fee to use their software for the real time inventory. SR does offer bulk discounts, so the cost/site/year can go down considerably if their are multiple piles that you would want to use the real time inventory one.	Yes	NDDOT is actively looking at Pix4D and Stockpile Reports, but is not fully committed of going this route as of yet. Our plan would be to use these systems to make inventory measuring more consistent and more accurate throughout the state. If one of these programs are implemented, initially, we would use traditional survey methods (GPS, total station) to compare quantities with these programs to check the accuracy.	NDDOT has tried trial versions of pix4d using the phone and drone apps. Pix4D is a great, easy to use program for calculation pile inventories in an outdoor setting, but in an indoor setting the phone app tends to pick up the interior ceiling, which then gets included in the 3d model when processing. This requires some extensive editing to remove those data points. NDDOT wants a user friendly program, that requires very little technical skill to obtain a stockpile quantity. More research or visiting with Pix4D is needed to see how this issue could be resolved. Stockpile Reports has multiple options for indoor pile inventory: real time inventory with cameras, iphone/ipad, and drones. My understanding is that Stockpile Reports is the leader in indoor stockpile inventory, but the downside is cost. SR charges an annual fee based on how many piles you would like to keep on inventory.	NDDOT's goal is to find something that is user friendly, consistent, and has an acceptable level of accuracy.

Respondent	1. Please describe your agency's indoor salt storage facilities (number, type, capacity).	2. How does your agency measure and manage your indoor salt stockpile inventories?	3. Does your agency use an outside service or vendor to measure and/or calculate salt volumes?	If "Yes," what is the cost of such services?	4. Has your agency used, or does it plan to use, a fully-automated or semi-automated indoor salt stockpile measuring system?	5. Which systems (manufacturers and models) has your agency used or is your agency using? What are your plans for these systems for the 2021-2022 winter season?	6. What has been your experience with these systems?	7. Please use this space to provide any additional comments you wish to share.
Oregon DOT Scott Rattay Winter Maintenance Program Coordinator scott.j.rattay@odot.state.or.us 971-701-1772	ODOT has about 20 salt sheds that range in capacity from 500 to 900 tons. There are two types; fabric/hoop covered built on a eco-block foundation, or steel beam with aluminum roof.	Stockpile reports phone app, visual estimates, estimates based on how much was applied during a storm/season.	Yes		No			

APPENDIX C. AUTOMATED STOCKPILE EVALUATION DATA

These data are presented in a multi-tab spreadsheet available for download.

research for winter highway maintenance

Lead state:

Minnesota Department of Transportation
Office of Research & Innovation
395 John Ireland Blvd.
St. Paul, MN 55155