University of Nevada, Reno

Accurate Stockpile Material Inventory for Maintenance Activities

A thesis submitted in partial fulfillment of

the requirements for the degree of Master

of Science in Civil and Environmental

Engineering

by

Luis Alberto Rocher Neri

Dr. Adam J. T. Hand / Thesis Advisor

December 2022

THE GRADUATE SCHOOL

We recommend that the thesis
prepared under our supervision by

Luis Alberto Rocher Neri

entitled

Accurate Stockpile Material Inventory for Maintenance Activities

be accepted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE

Adam J.T. Hand, Ph.D.
Advisor

Elie Y. Hajj, Ph.D.
Committee Member

Peter E. Sebaaly, Ph.D.
Committee Member

Mihye Ahn, Ph.D.
Graduate School Representative

Markus Kemmelmeier, Ph.D., Dean
Graduate School

December, 2022

Abstract

This study focuses on the applicability of new technology to accurately quantify aggregate stockpiles. As part of the investigation, the study was divided into three phases. The first phase encompassed a literature review of different technologies currently employed by various departments of transportation (DOT) across the country to measure stockpiles. Furthermore, interviews with varying maintenance crews from the Nevada Department of Transportation (NDOT) and other states belonging to the Western Association of State Highway and Transportation Officials (WASHTO) provided insight into the regional methodology. It was found that both an accurate volume estimation and a realistic unit weight factor determination are crucial to quantify a stockpile. Thus, the second phase involved the laboratory testing of sampled aggregates to determine their physical properties and correlation with the unit weight. After the research and laboratory sections were completed, it was decided that implementing an iOS-based application named Stockpile Reports was suitable for NDOT's needs. Thus, the third phase aimed to compare the current NDOT methodology against this new alternative with a significant focus on measurement accuracy, data-collection time, and user adaption to the latest technology.

Dedication

To my wife. She has been the greatest support since I became a graduate student at the University of Nevada, Reno. All my accomplishments were possible thanks to her.

Acknowledgments

I would like to thank my advisor, Dr. Adam hand, for all the support throughout my master's degree at the University of Nevada, Reno. He guided me and was the cornerstone of this project. I want to express my gratitude to Dr. Elie Hajj and Dr. Peter Sebaaly for the knowledge and great advice I received from both as instructors. I would also like to thank Siththarththan Arunthavabalan for assisting me with the logistics and laboratory performance of the study. I would also like to acknowledge all those at the Nevada Department of Transportation, Maintenance and Asset Management Division. Specifically, Anita Bush, Nathan Morian, Ambere Angel, and Bill Walker for making this project possible and actively participating in my project development and monitoring. Lastly, I would like to thank Granite Construction for the support and knowledge they provided me with in the last phase of the project.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

1.1. Background

Road maintenance has become increasingly important in today's pavement management systems (PMS) as fewer new roads are built yearly, while the existing network condition constantly deteriorates. There are different types of pavement maintenance; preventive maintenance refers to activities performed to protect the pavement surface and slow the rate of deterioration; corrective maintenance is activities that will address specific pavement failures or distresses to correct them at an early stage before they generate severe problems; and seasonal maintenance involves particular activities linked to periodic climatic factors (e.g., snow removal and deicing agent placement on roads during wintertime) [1]. If the network size and weather conditions remain relatively constant through the years, agencies can estimate the necessary resources for each maintenance activity.

A crucial step in pavement maintenance is material inventory, as agencies must determine the existing material reserves to prevent shortages during maintenance periods. The current methodology employed by NDOT to quantify aggregate stockpiles relies on physical inspections of the stockpiled material and a comparison against inventory records [2]. To estimate it, the aggregate stockpile volume is approximated by regular shapes that are easily calculated (e.g., cones or rectangular prisms); then, a unit weight factor transforms the volume into mass (cubic yards to tons).

As has been discussed in different investigations [3], a visual estimation of a stockpile can lead to volume discrepancies over 30% of the actual volume due to simplifying an irregular shape. In addition, the variability among physical properties of materials poses a challenge in establishing a unique unit weight factor that could be applied statewide. A difference in gradation, specific gravity, and moisture content could also affect this number. When both elements (a difference in volume and unit weight) are combined, the probability of deviating from the actual quantity rises, leading to larger mismatches between the inventory records and the field measurements.

1.2. Research Objectives

To further evaluate the current procedure used by NDOT, this study’s objectives were: to review literature on different DOT’s stockpile inventory processes (including Nevada); interview NDOT and WASHTO employees regarding inventory tasks; investigate the impact of aggregate physical properties on the unit weight factor; compare the existing methodology and the Stockpile Report iOS application to determine if this could benefit NDOT with the stockpile field measurements; and, to describe the necessary procedures and documents to be implemented after the research is completed.

1.3. Scope of Work

To achieve the previously described objectives, a research approach was developed. The preliminary review of modern and traditional methods to measure a stockpile was performed to identify the most efficient and cost-effective alternative for NDOT. The second phase involved performing a sensitivity analysis of unit weight factor determinations. The third phase involved an experimental approach to validate the Stockpile Report application method. The plan of the study is shown in Figure 1.

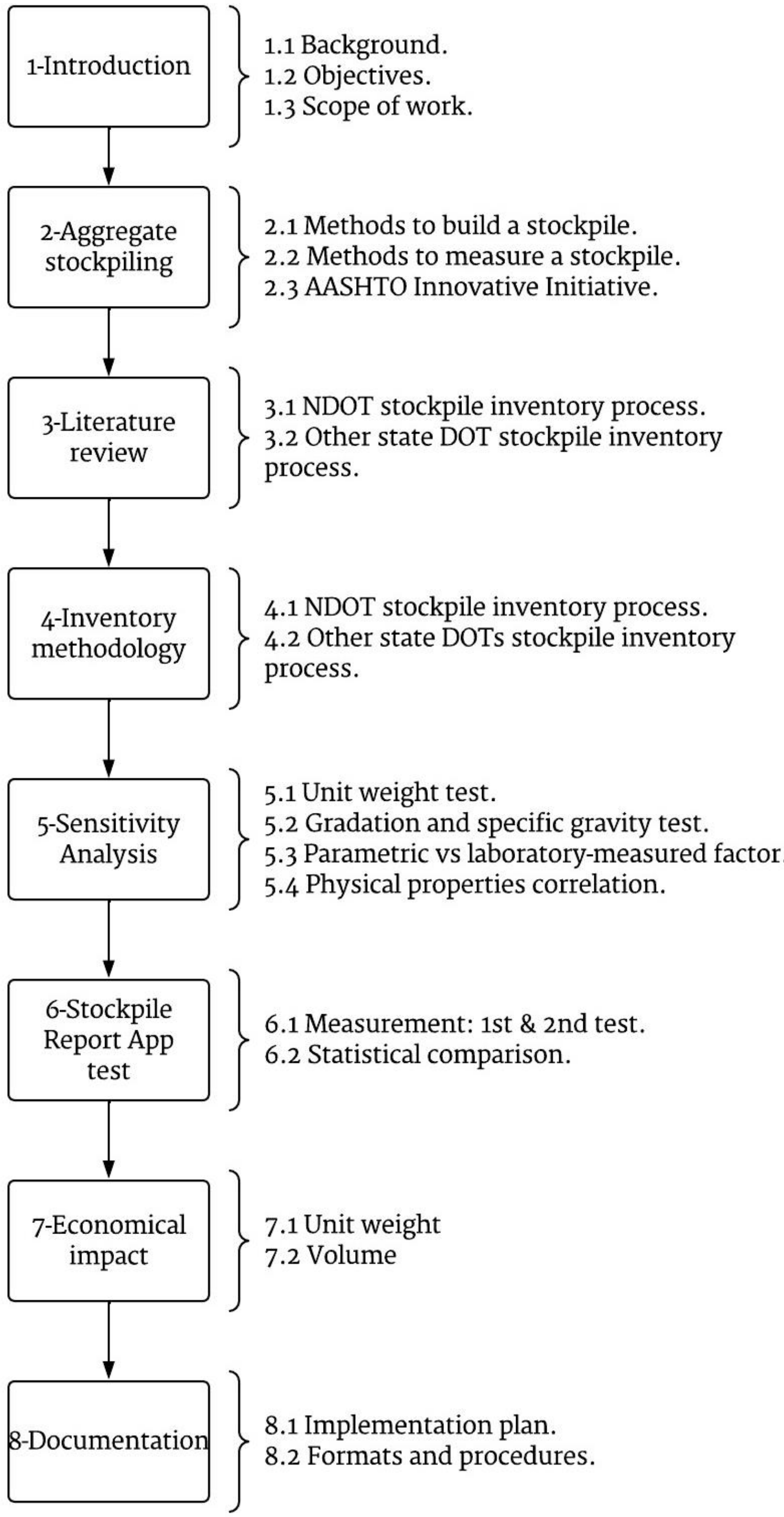


Figure 1. General Outline of Project Study

Chapter 2: Aggregate Stockpiling

2.1 Methods to Build a Stockpile

Before the different methods of measuring a stockpile are discussed, it is important to understand how they are shaped and built. Aggregate is constantly mobilized from the time it is mined; shovels, bulldozers, front loaders, conveyors, rail cars, haul trucks, and dump trucks transport and conform stockpiles in quarries, pits, aggregate plants, asphalt/concrete mixing plants, sheds, and storage yards. Multiple stockpile configurations may be used depending on available equipment and space. Although this research does not address the influence of the stockpile construction technique in gradation segregation, it must be noted that some stockpiling designs that create simpler shapes (e.g., conical) are also associated with greater segregation issues [4].

2.1.1 Belt Conveyor Stockpiling

Belt conveying is commonly used during the aggregate extraction, sizing, and classification processes. Generally, there are three belt conveyors based on the stockpiling method. Stationary stackers are fixed conveyors that create cone-shaped stockpiles. Radial stackers pivot along a radius to create a kidney-shaped stockpile. Finally, telescopic radial conveyors can translate and reduce or increase the inclination and length of the belt conveyor to generate windrow stockpiles [5].

2.1.2 Truck Stockpiling

Truck stockpiling is the most common method of stockpiling aggregates when the material needs to be transported to a NDOT Maintenance location. Typically, the trucks dump each load in a straight line, arranging the material in a series of coned-shaped piles. Despite the easiness and quickness of the operation, this method tends to highly segregate the material while the truck is dumping the aggregate if it is not a single sized aggregate [6], [7].

2.1.3 Front Loader & Bulldozer Stockpiling

The use of loaders and bulldozers allows contractors and agencies to manipulate the material for different applications when stockpiling Aggregate can be ramp-shaped with a bulldozer; different materials could be blended into a single pile or sub-pile with a front loader (e.g., building a 50/50 sand-salt stockpile). Sensitive aggregates like salt or deicing agents could be stored inside a shed to avoid significant material deterioration.

2.2 Methods to Measure a Stockpile

In general, and regardless of the stockpile shape, there are two different approaches used to measure them. The first involves standard techniques that do not require technology, such as loader bucket/loader scale count, storage shed capacity determination, and sometimes visual observation. These methods present a series of advantages and disadvantages. They are cost-effective, require limited training, and provide quick estimations. On the other hand, accuracy is not the best, and the effect on the general material inventory could lead to potential over/underestimations. The second approach implements the adoption of any technology such as GPS, laser, or photogrammetry to compute a three-dimension (3D) surface that is later transformed into a volume.

Although most State DOTs in the U.S. do not currently base their stockpile inventory on sophisticated technology, most State DOTs seek to migrate and adopt different procedures with greater accuracy, lower costs, and easy implementation for their maintenance crews

[8]. This chapter will highlight the advantages and disadvantages of various techniques and technologies for determining stockpile quantities.

2.2.1 Non-Technological Methods

The non-technological methods are based on the mathematical estimation of the stockpile or a volumetric reference that might contribute to its quantification. For instance, if a stockpile or sub-stockpile is built with a front loader, a backhoe loader, an excavator, or any other excavating/hauling machinery, one could determine the bucket volume and count the number of times the machine loads and unloads material. While this method is one of the quickest and easiest, it is profoundly inaccurate. The simple assumption that the equipment bucket is filled with the same known volume, is far from true. Each load carries a different volume, and the material might accommodate differently every time. Thus, this technique highly dependent on the equipment operator and the properties of the aggregate that influence the shape it while handled (gradation, particle shape and texture).

If the mentioned machinery is not available, the fastest method to estimate a volume is to measure the stockpile dimensions assuming a regular shape (right or truncated cone, rectangular prism, triangular prism, or trapezoid prism) with any measuring device available, such as a measuring tape, measuring wheel, steps, or simple estimation. Despite it seeming like an accurate method to establish the dimensions and perimeter of the stockpile, issues arise when the stockpile does not possess a regular shape. Because it is implied that the dimensions (length, width, and height, or diameter and height) will remain the same across the stockpile axes, it becomes challenging to establish average dimensions for irregular shapes. Moreover, in many cases, the height of a stockpile is not directly measured for personnel safety reasons and is estimated most of the time.

When the material is stored indoors, volume quantification is similarly performed. Once a sheds dimensions are known, the portion occupied by the aggregate is determined by considering the sheds geometric reference points. However, storage sheds are rarely filled to their maximum capacity, and the stockpile shape does not match the geometry, leading to similar problems observed with the previously described technique. Figure 2 shows an indoor container and a sand stockpile. The picture is an excellent example of the irregularity of a stockpile volume regardless of the fixed shed dimensions.

Figure 2. Aggregate Shed

2.2.2 Technological Methods

Methods that implement any modern technology to generate what is known as a digital terrain model (DTM), a model created from a finite sample of data points over the area of interest. Generally, two broad techniques exist to generate a DTM: raster-based interpolation and vector-based triangulation. In a raster, a DTM is structured as a regular grid consisting of a rectangular array of uniformly spaced and equally sized cells with sampled or interpolated z-values. In vector, the triangular irregular network (TIN) is constructed as a set of irregular nodes with z-values connected by edges to form contiguous, non-overlapping triangular facets [9].

In most cases, TIN modeling yields a higher resolution model when the surface is more complex, making it more reliable than the grid approach [10]. As a result, most geographic information systems (GIS) and computer-aided drawing and design (CAD) applications incorporate TIN modeling. In Figure 3, a stockpile surface model is illustrated that was generated using triangulation.

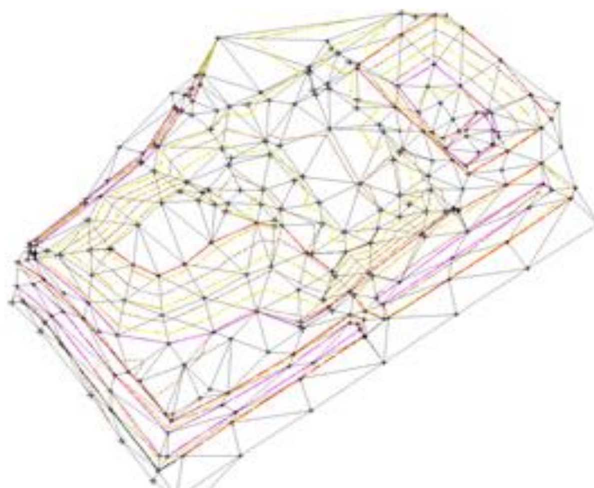


Figure 3. TIN Modeling

2.2.2.1 GPS

Global navigation satellite systems (GNSS) provide positioning, navigation, and timing services on a global or regional basis. The USA’s Global Positioning System (GPS) is the most established GNSS. GPS technologies have become an inseparable part of the geodetic world. GPS applications in civil engineering include coordinating control points, deformation monitoring, detail surveys, positioning, controlling, etc. [11].

The data can be gathered and post-processed after the raw data points are collected, or it can be calculated in real-time. The real-time kinematic (RTK) positioning survey technique requires at least two receivers. One is located on a precisely known ground coordinate as a base station, and another receiver moves and collects points, typically known as a rover station [12].

Currently, GPS is widely used to quantify stockpile volumes and is one of the easiest methods if the stockpile size is relatively small, as shown in Figure 4. Nonetheless, it is, at the same time, the riskiest procedure from a safety perspective due to the necessity to have a person climb on the stockpiles and it is one of the least accurate methods if the number of collected points is insufficient to generate an appropriate digital model.

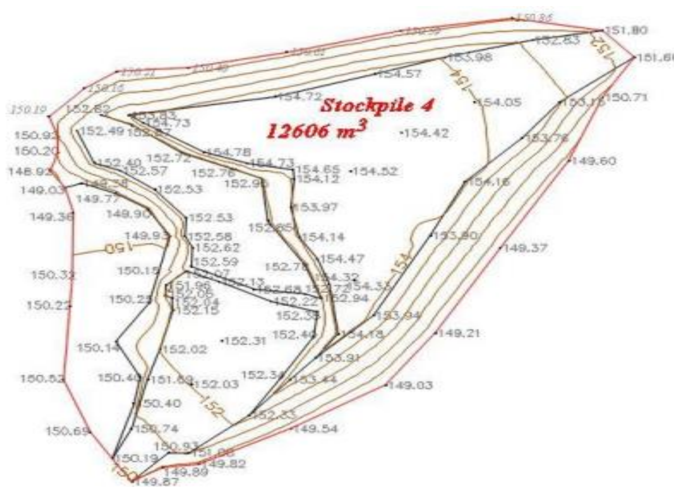


Figure 4. GPS Stockpile Surface

2.2.2.2 Laser

Laser technology works under the principle of sending and receiving pulses of laser light. A laser beam is projected to a solid surface, and a sensor calculates the time it takes for the reflected pulse to reach the device. Initially, the laser was used in construction to estimate distances and angles. However, with numerous software nowadays, it is possible to create a surface if several points are taken around the stockpile [13]. Laser is a much safer method as it does not depend on a person climbing on top of a stockpile to get the point. One potential drawback is the increased time required for back-sighting, which is equally limited to small stockpiles or low-density point models. Moreover, the presence of fog can disrupt the laser's ability to get an accurate reading.

A more advanced version of laser imaging is light detection and ranging (LIDAR), in which the equipment gets thousands of points after scanning the area. This type of measurement is considered the most accurate due to the number of generated points. The versatility of LIDAR makes the task possible in different ways. Some equipment can be carried out by hand, attached to a crane, on top of closed structures, belt conveyors, or work in conjunction with drones. Figure 5 illustrates an image generated by LIDAR.

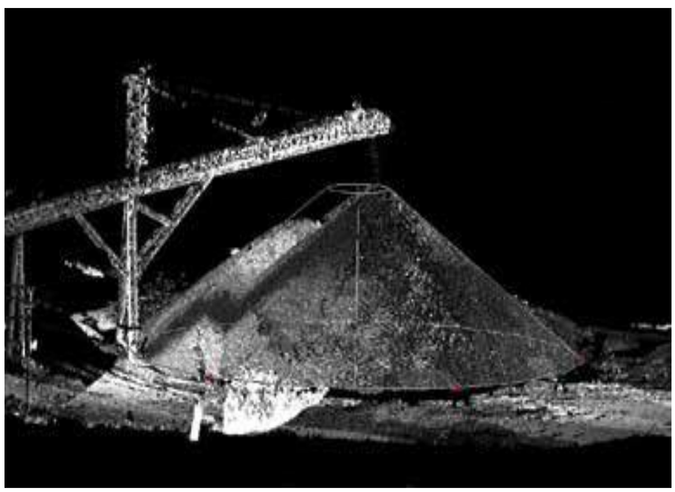


Figure 5. LIDAR Stockpile Surface

With the development of sensors and computer technology, 3D point cloud data can achieve better measuring accuracy and more detailed spatial morphology of the stockpiles. 3D point cloud collects the dense coordinates of a stockpile surface as well as quantitative parameters of the stockpile, such as height, floor area, and volume, can then be computed by processing 3D point cloud data [14].

Although volume calculation methods using point clouds have better speed and accuracy than conventional methods, there are still challenges. Most existing software needs to delineate the stockpile boundary on the point cloud manually. In addition, lidar-based equipment is expensive to purchase and maintain; and relies on skilled staff to collect accurate data.

2.2.2.3 Photogrammetry

Photogrammetry is the science of making reliable measurements using photographs, especially aerial ones [15]. It is perhaps one of the oldest technologies, tracing back to 1849 when Aimé Laussedat was the first to use terrestrial photographs for topographic map compilation. Photogrammetry improvement is closely tied to airplane development in 1909 since aerial photos were primarily taken from balloons before its invention [16].

Since the invention of the airplane, different aircraft have been used as photogrammetry tools; helicopters, airships, gliders, and unmanned aerial vehicles (UAVs). The latter technology has recently increased in popularity among numerous engineering spheres. Besides mapping and photogrammetric tasks, UAVs perfectly comply with the needs for engineering geodesy and mine engineering, particularly volume computation.

On the one hand, to perform accurate volume calculations, UAVs require high resolution from aerial images; thus, exact terrestrial measurements become incredibly time-consuming. On the other hand, photogrammetric techniques can cover large areas in great detail in arguably less time than other techniques [17].

To summarize, drones are the quickest and most convenient technology when the task demands the mapping of entire areas. However, it becomes a costly option when single and small stockpiles are measured. Figure 6 illustrates an aerial photo of a 16,500 yd^3 pit quarry taken at approximately 390 ft above the terrain level.

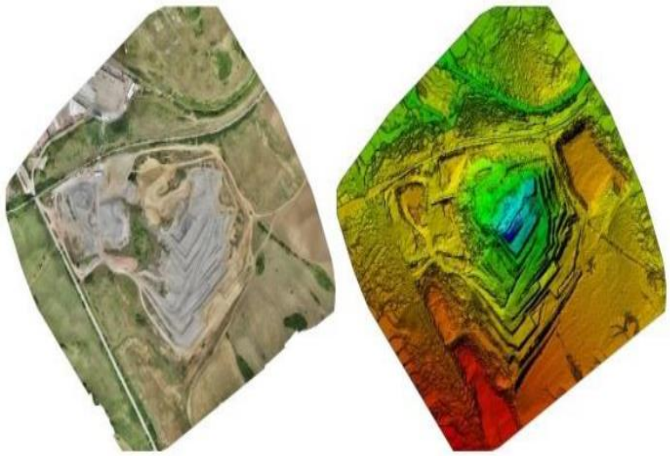


Figure 6. UAV Stockpile Image

2.2.2.4 Augmented Reality

The augmented reality approach is a combination of previous technologies, and the implementation is quite unique. Augmented reality (AR) requires real-time tracking to trace a user's or device's position and register it in the real world. Mobile devices such as smartphones have been recognized as potential tools for AR, considering that most smartphones today provide a combination of a camera, accelerometer, GPS, and other sensors, making it one of the most suitable devices to provide computer vision applications [18].

Currently, Stockpile Reports is the only known company with a patent able to quantify stockpile volumes with an iOS-based application. The application and web portal provide a standard map view of stockpiles at a site and a quick overview of a stockpile report [19]. The field procedure requires only one act of direct measurement: placing two standard safety cones 25 feet apart (via measuring tape or GPS) followed by the actual measure of the stockpile surrounding it with the camera pointing towards the desired pile. Figure 7 shows an example of a report generated after completing the measuring task and software processing.

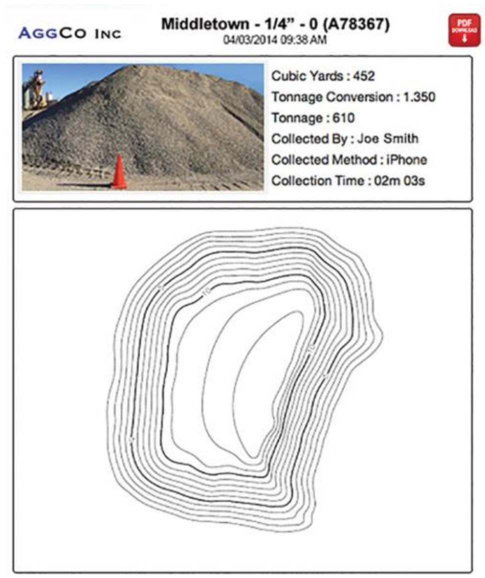


Figure 7. Stockpile Report Application Output

It is the most convenient procedure for a limited number of stockpiles to reduce the time, costs, and risks involved with the task. Additionally, it does not need complex training to be easily implemented by maintenance agencies. However, there are still some drawbacks to the use of this technology; there is little research besides the Texas Department of Transportation (TxDOT) study to validate the accuracy [3]; the device (iPhone, iPad, or iPod) must have an internet connection during the measurement; the accuracy is highly dependent on the surface coverage and climatic-related factors such as sun flare; and, the time to obtain the volume may be delayed due to connectivity problems despite the quickness of the measurement.

2.2.2.5 Other Technologies

All the previously discussed technologies quantify the volume once the aggregate has been stockpiled, but some modern inventions can calculate the transported volume or mass. For instance, loader scales utilize a group of devices to perform this task meticulously; pressure transducers connected to the hydraulic system; triggers to sense through the lift cycle; indicators programmed with proprietary weighing software; slope compensation kits designed to compensate for ground slope; printers that stamp and date in real-time; and data communication systems such as Wi-Fi, radio or GPS [20].

As stated before, assuming that the front loader bucket volume is constant will lead to significant error. However, loader scales determine the aggregate tonnage through a multi-point weighing system and could report the data in real time during the operation. A limitation of this method is manifested; it is highly inconvenient for inventory purposes because the loader does not measure all the material, but the portion used to fill trucks, aggregate sheds, or cold feed bins.

The second example of an alternative method to measure aggregate volume is vehicle scanners. It consists of an elevated laser scanner that compares the surface of empty and loaded trucks. At first, the empty truck slowly drives under the scanner head, allowing the software to record the volume if the truck bed. The trucks are recorded in the database and saved for subsequent visits. Thus, when a previously measured truck arrives with an aggregate load, the scanner will determine the added surface and quantify a volume [21]. An example of this technology is represented in Figure 8.

Like a load scale, the volume is just known at the moment of the truck's arrival. The initial volume will no longer match the actual quantity if the material is moved or used within an operation. Additionally, its results are ineffective for audit or inventory purposes as the scanner would not be able to measure the stockpiled material.

Figure 8. Vehicle Scanner

2.3 AASHTO Innovation Initiative

This chapter describes many new and emerging technologies that offer to improve stockpile quantification performance/effectiveness. These technologies have been developed through rigorous research and have been demonstrated in real-world applications. Some may have been gleaned from international technology scanning tours. In comparison, others evolved within the practice, but are not shared. To identify and award the implementation of a select few proven technologies, products, or processes that are likely to yield significant economic or qualitative benefits to the users, the AASHTO Board of Directors authorized the creation of the AASHTO Innovation Initiative (AII) reporting to the Standing Committee on Highways (SCOH) [22].

AII recognizes that traditional techniques of stockpile measurements are more expensive, less accurate, less efficient, and time-consuming. In this context, the AASHTO Innovation

Initiative supports adopting digital stockpile management (DSM) technology. DSM is a digital management process to measure and analyze material quantities efficiently, accurately, and consistently in real-time. The available digital technologies include smartphone applications, unmanned aerial systems, fixed-wing aircraft photogrammetry, terrestrial laser scanning and mapping, and cloud-based platforms, which are used in place of and, in some cases, in conjunction with traditional methods [23].

Chapter 3: Literature Review

3.1 NDOT Stockpile Inventory Method

The Nevada DOT has established some general guidelines to monitor stockpile inventory. After 2017 the NDOT migrated to the implementation of the Enterprise Asset Management Systems (EAMS) to help minimize life-cycle costs associated with managing and maintaining over 5,400 miles of roads, 1,100 bridges, and 60,000 stormwater drainage facilities through the company Agile Assets [24]. The following sources cover some aspects related to the NDOT aggregate stockpile inventory process and will be discussed comprehensively:

- NDOT: Maintenance Manual [2].
- NDOT: Fully-Compliant Transportation Asset Management Plan [25].
- NDOT: EAMS User Manual [26].

3.1.1 NDOT Maintenance Manual

The NDOT Maintenance Manual specifies maintenance stockpile procedures and the process for purchasing stockpile material [2]. Part III (Administrative Procedures), Chapter 1 (Accounting and Budgeting), covers maintenance funding, accounting, reporting, line item and Maintenance Management System (MMS) budgeting. In terms of inventory, each stockpile is assigned a six-digit number, starting with "4". The second digit represents the district or central maintenance station, the third and fourth digits represent the type of stockpile, and the fifth and sixth digits represent the stockpile sequential number.

In Part III, Chapter 2 (Acquisition and Disposal of Equipment and Materials), the purchasing policy is described. Purchasing of equipment, materials, and services for use by NDOT is conducted in accordance with the State Purchasing Act (administered by the State Purchasing Division) and Transportation Policy (TP) 1-3-2. Under these policies, purchasing authority is in the following order:

1. State Purchasing Division
2. Equipment Division
3. District Engineers

In the same chapter, the maintenance staff responsibilities are listed:

1. Ensuring that current stockpile records are accurate and complete, entered into the MMS system stockpile tasks.
2. Prompt and accurate reporting of costs and quantities of materials.
3. Ensuring labor, equipment, and other components incorporated into the stockpile, which alters its size and value, are accurate and current.
4. Annual verification of the book inventory of each type of stockpile by making actual physical measurements or counts of each stockpile. The measurement needs only to be a close estimate of the material located at each field stockpile site and does not require an engineered measurement by a survey crew.

The manual does not specify a specific method to quantify aggregate volume or a precision limit to validate the measurement accuracy. In addition to the personnel responsibilities, the chapter includes the assigned codes for each material that could be stockpiled as shown in Table 1.

Table 1. Stockpile Inventory Codes

01: Aggregate	07: Salt and sand	29: Signposts
02: Chips	09: Salt and brine	45: White traffic paint
03: Sand	12: Liquid asphalt	47: Yellow traffic paint
04: Cinder	13: Rubberized crack filler	50: Dry anti-icing agent
05: Premix	24: Signs	51: Liquid anti-icing agent
06: Salt and chlorides	26: Glass beads	

Part III, Chapter 3 (Materials Sampling and Testing) covers the quality assurance program (testing) and procedural requirements necessary to ensure that the Department obtains materials that conform to current specification requirements. It includes tables with specific sample frequencies, sample sizes, and remarks depending on the material or product. For instance, some of the aggregate materials could be submitted to one or multiple of the following tests, Table 2:

Table 2. Aggregate Physical Tests

Sieve analysis	Percentage of wear	Flat and elongated aggregate
Fracture faces	Moisture content	Flakiness index
Plasticity index	Abrasion	Specific gravity
Liquid limit	Soundness	
R-value	Absorption	

In Part IV (Maintenance Operations), Chapter 14 (Stockpiling), a brief description of the stockpile purchasing procedure is mentioned and includes:

1. Material is purchased using Form 072-002 (Combination request for supplies, equipment, and shipping record, or "Form 51") or Form O-3725 (Asphalt/Aggregate/Paint purchase requisition, APR).

2. At the delivery site, assign people to assist unloading material.
3. Unload and store all incoming products.

3.1.2 Transportation Asset Management Plan

To preserve and maintain the transportation system, NDOT adopted asset management principles to make cost-effective decisions that target agency priorities. This Transportation Asset Management Plan (TAMP) documents the asset management framework and outlines NDOT's plans for preserving its transportation network [25].

The TAMP content has been developed using processes certified by the Federal Highway Administration (FHWA) in 2018. It incorporates pavement, bridge, and ITS assets that NDOT maintains, and provides information about the number and condition of these assets as illustrated in Figure 9.

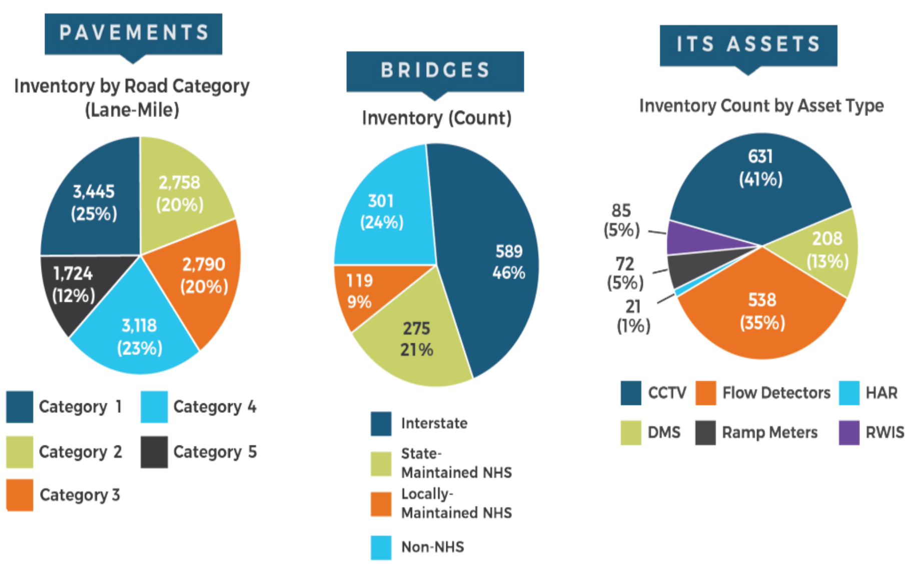


Figure 9. Nevada Transportation Inventory, 2019

Currently, NDOT is working with Agile Assets to develop a unified inventory system that will include Maintenance Management System (MMS), Bridge Management System

(BMS), Pavement Management System (PMS), and Stormwater Management System (SWS) data. As of today, stockpile inventory is managed through the MMS.

3.1.3 EAMS User Manual

The previous sources refer all aggregate stockpile inventory tasks to EAMS. In 2019 Agile Assets published a user guide for Nevada to practice and understand how the asset operation business processes can be carried out using the Agile Assets system [26]. It is essential to highlight that EAMS defines a stockpile as the place where materials belonging to an administrative unit are stored. (Warehouses, trucks, routes, etc.). In chapter 12 (Material stockpiles), the overall procedure to manage stockpiles in EAMS is defined:

- Material hauling: The process is carried out in the work orders window. This function allows you to haul materials from one location to another. To complete the task, the user must create a work order that is then reviewed and approved.
- Purchase/Receive material: This function allows you to buy materials. The system will ask for a determined quantity and cost to proceed with the task.
- Mixing activity: Mixing activities require combining existing raw materials to make new materials (e.g., sand-salt stockpiles). The tasks are performed using the process of creating work orders.

These three functions require a material quantity that could be either input as volume (yd^3) or mass (ton). The system uses a previously defined unit weight factor to report the tonnage. However, the conversion factor does not address the influence of different sources, physical properties, or moisture content. For example, a single aggregate unit weight factor of 1.5 tons/yd^3 is used for all base stockpiles statewide. Using a single factor for each material simplifies operations and reduces the time it would take to perform the unit weight test each time a measurement is required. However, a significant deviation between the parametric and the actual value could create and carry a series of errors on every measurement. To clarify and better understand the field measurement process and data processing through EAMS, the following chapter will include the interview results with NDOT staff, detailing the inventory process with greater insight.

3.2 Other State DOT Stockpile Inventory Methods

In 2017, the Minnesota DOT (MnDOT) and CTC & Associates LLC published a report titled "Monitoring stockpiles of solid winter maintenance materials" that aimed to detail the inventory method followed by each state in the country [8]. The report used a national survey of DOT experts to gather information about best management practices for accurately measuring solid winter maintenance materials using technology and other measurement methods.

Based on the reported survey, almost 50% of the country employed this kind of measurement practice; 20% (mostly the southeastern portion of the United States) of the states did not answer the survey; and the rest has adopted or are in the process of adopting any technology as shown in Figure 10. Although, it must be mentioned that some states have changed their inventory method since then; thus, the map distribution must be updated.

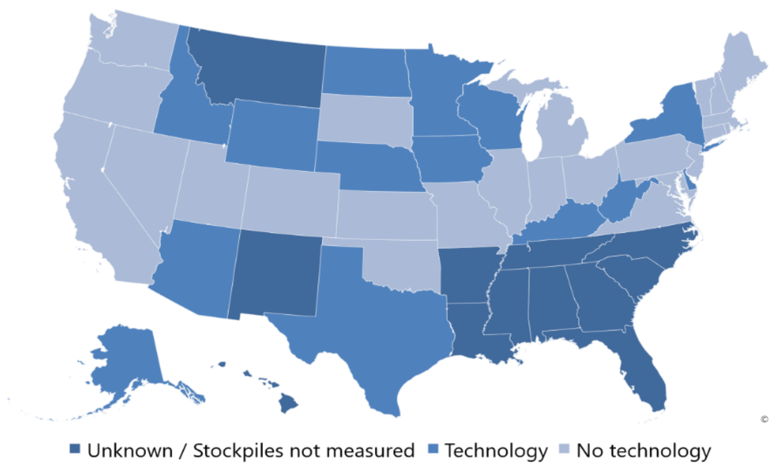


Figure 10. Methodology Used to Measure Stockpiles, MnDOT Survey

3.2.1 Non-Technological Methods

As previously described in chapter two, there are two alternatives for non-technological alternatives: directly calculate the volume/container or indirectly estimate it from loading bills, tickets, or scales. Figure 11 depicts the non-technological methods used by different state DOTs. It appears that most of the western and northeastern states, including Nevada, followed this approach.

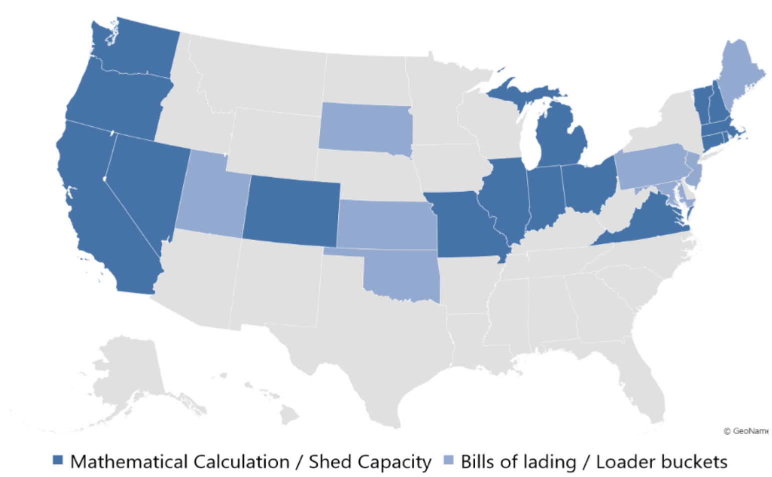


Figure 11. Non-Technological Methods Used to Measure Stockpiles, MnDOT Survey

Of all the interviewed states, only Oregon shared a document with the mathematical calculations its maintenance crews use to quantify different stockpiles. The report indicates that a member of Oregon DOT (ODOT) provided a four-page document that lists the calculations needed to estimate the volume considering two cases: a simple pile (regular shaped) or an irregularly shaped pile.

It is believed the document was used internally because it could not be traced outside the MnDOT report. Regarding stockpile quantification, only the ODOT Inspector’s Manual and the Standard Specifications for Construction address the situation [27], [28]. The stockpile measurement on a volume basis specifies the cross-section measurement or a digital terrain model of the completed neat stockpiles, with no allowance for settlement or shrinkage to compute the volume. Thus, it is implied that GPS, laser, or LIDAR technologies might be applied. However, both documents address the process contractors/inspectors must follow to measure stockpiles for payment purposes rather than inventory activities.

3.2.2 Technological Methods

Most states that include any sort of technology to determine their winter material stockpile inventory were found in the northern region of the United States. In most of these states, surveying equipment (laser, total station, GPS) is used to obtain the stockpile surface, and specialized software builds the DTM, while a minority used cameras inside sheds, lasers that map trucks, or a mobile phone application in the case of Texas (Stockpile Reports), Figure 12. However, after an interview with Stockpile Reports employees, it was found that at least eight states have been working with them to implement their technology to update the DOT inventory methodology. In the case of states such as Idaho or New York, there was an existing technology to measure stockpiles, but they have started to switch towards using the iPhone application. Other states like Oregon, Montana, Michigan, and Louisiana did not use any technological method before trying this new alternative. Figure 13 shows the migration from previous non-technological and technological methods toward Stockpile Reports.

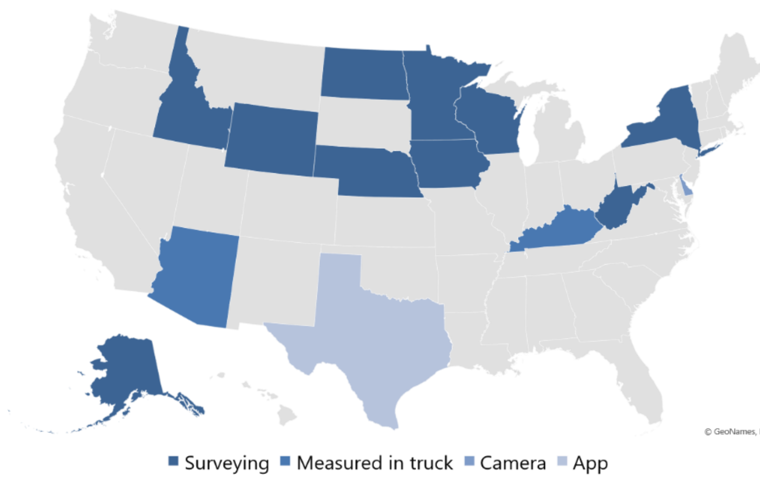


Figure 12. Technological Methods Used to Measure Stockpiles, MnDOT Survey

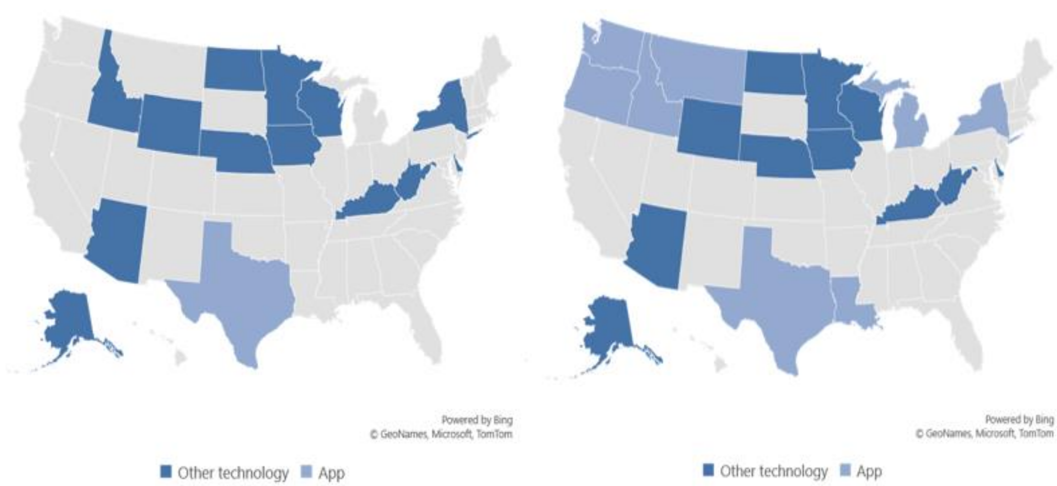


Figure 13. State Migration towards Stockpile Reports

Since 2013, Texas DOT has been developing processes and procedures to help ensure that TxDOT inventory is accurate, valid, and appropriate [29]–[31]. It created the Enterprise Resource Planning (ERP) system as the official system of record for the agency's inventory and the MMS for inventory and other planning purposes. In 2015, it tested the cellphone application from Stockpile Reports with positive results [3]. The measurement results showed that the application and GPS volume estimations varied by 1.46% and 1.74%, respectively, compared to Lidar measurements. Currently, the state has a Special Projects Coordination Division with more than 2,000 users measuring stockpiles with the iPhone application.

In the MnDOT study, it was reported that some states already used a specific brand. For instance, in 2015, Iowa DOT created a draft for the standard operating procedure (SOP) for scanning salt sheds/domes with the ZEB1 LiDAR Wand and Quick Terrain Modeler (QTM) to calculate the volume in tons. The equipment is a hand-held mobile mapping system that collects more than 43,000 points per second. As the operator walks around the area, the ZEB1 constantly oscillates to generate a considerable point cloud that is later refined [32]. The DOT reported that the handheld SLAM device produces a three-dimensional stockpile model in just a few minutes. Moreover, they guarantee that the level of accuracy and the data-capturing process has simplified the inventory process.

Other states allow the use of any equipment or software brand to measure their stockpile but specify the method, such as the case of Alaska. In 2010, Alaska DOT published a document titled "Development of GPS survey data management protocols/policy" that delineates the survey specifications and procedures for the State of Alaska Department of Transportation and Public Facilities survey services [33].

Despite the MnDOT report confirming the use of technology in different states, there is no information or documentation on the official website of many DOTs. Like Oregon DOT, Minnesota does not have an inventory manual for the agency personnel (despite the MnDOT report claims it uses a survey method) but specifies volumetric procedures for payment purposes. In the Standard Specification for Construction and the Field Guide to Document Construction Pay Items on Local Government Agency Projects, it is mentioned that the engineer will determine the cubic yards of stockpiled volume (SV) using the cross-section method or the digital surface model method to measure material in the stockpiled position [34]–[36]. Moreover, the contractor shall shape the stockpile to a condition directed by the engineer before measurement.

After reviewing and summarizing all the different methods to measure a stockpile in chapters two and three, the advantages and disadvantages of each method are presented in Table 3. The comparison allowed NDOT to favor adopting the Stockpile Reports application as its future inventory technology.

Table 3. Technological Methods Comparison

Method	Advantage	Disadvantage
Survey/GPS	Widely used Easy to perform Good for small stockpiles	Time-consuming Precise only if high number of points Risky (climb stockpile)
Laser	Widely used Easy to perform Good for small stockpiles	Time-consuming Precise if high number of points Fog/heat susceptibility
LIDAR	Versatility Highly accurate	Expensive Needs special training
Photogrammetry	Fast data collection Highly accurate	Expensive Needs special training
AR (app)	Limited training required Fast data collection Reasonably accurate	Requires internet connectivity A limited number of stockpiles Sun flare susceptibility

Chapter 4: Stockpile Inventory Methodology Interviews

The previous chapters discussed the possible alternatives a DOT could follow to measure a stockpile, illustrated specific cases from different states, and summarized the advantages and disadvantages considered for each method. The results were presented to the NDOT Maintenance and Asset Management Division members. Following a series of meetings, it was determined that the Stockpile Reports application would benefit NDOT at a lower cost than other technological approaches.

Before the application purchase, interviews with NDOT maintainers from all three districts were conducted to understand the entire stockpile inventory process, step by step. NDOT divides the state into three Districts with six subdistricts as shown in Figure 14. The six subdistricts are:

- District 1 – Las Vegas Sub District & Tonopah Sub District
- District 2 – Reno/Carson City Sub District
- District 3 – Elko Sub District, Ely Sub District & Winnemucca Sub District

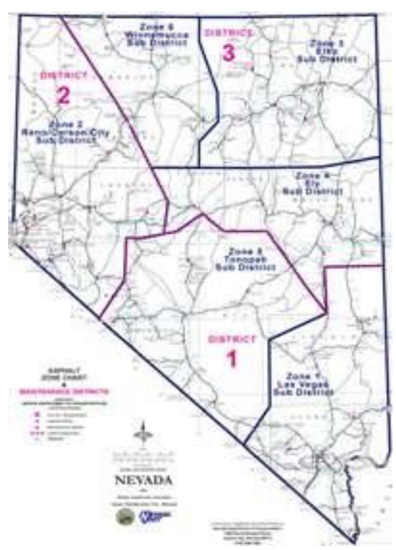


Figure 14. NDOT District and Subdistrict Division

In addition, four representatives from WASHTO states using Stockpile Reports software were contacted and interviewed to compare their opinions about the application performance. The states that belonged to WASHTO are depicted in Figure 15.

Figure 15. WASHTO States

4.1 NDOT Staff Interviews

The interviews consisted of 10 open-ended questions directed to the people in charge of performing the stockpile inventory (one Supervisor I and one Supervisor II from Districts 1, 2, and 3) and was completed in January 2022 before the Stockpile Report application purchase. The discussion focused on the type of aggregate stockpiles, measurement frequency, measurement time, volume estimation method, formats employed (if any), and the possible challenges they faced. The summary of interviews is presented in Table 4.

Table 4. NDOT Interview Results

Type of stockpiles	Indoors: Salt and chemical deicer Outdoors: Sand, Sand-salt, aggregate screenings, Riprap, base, and RAP grindings
Number of stockpiles	Approximately 200 stockpiles in total Between 15-30 stockpiles per maintenance crew
Measurement method	The volume is calculated through physical measurement of the base (walking wheel, measuring tape) and visual height estimation. The shape of the stockpile is assumed to be regular
Measurement frequency	It is required to measure each stockpile at least twice per year. However, some stockpiles are measured 2-3 times, 4-6 times, or more than 6 times per year
Measurement time	Approximately 10 minutes per stockpile
Format	There are no field formats to report the measurements performed. However, purchase orders and work orders are used to track the change in the stockpile quantity
Challenges	The irregularity of the stockpile shape is the leading cause of volume discrepancies. Moreover, a single unit weight conversion factor for each material is thought to increase the disparity between the measured volume and the inventory record (EAMS database)

After the key points were collected, a general NDOT stockpile inventory procedure was also generated. The purpose was to identify how the NDOT Maintenance and Asset Management Department organizes and sorts its staff in terms of this task. Figure 16 illustrates the overall data gathering and processing procedure.

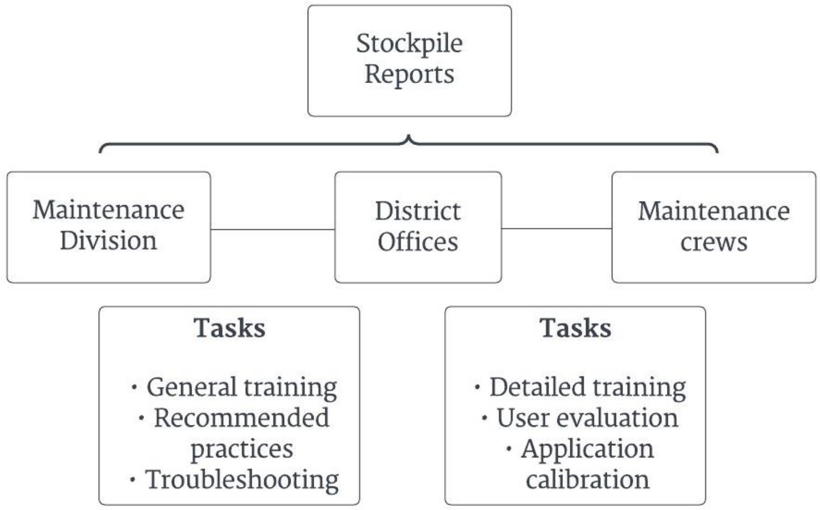


Figure 16. NDOT Stockpile Inventory Process

In general, the process is summarized in five steps:

- Step 1: The maintenance crews visit the location of each stockpile, measure the volume, and report the data to the district office personnel.
- Step 2: Each district could send the measured volume to the Maintenance Division or directly report the stockpile quantity to EAMS.
- Step 3: The Maintenance Division analyzes the information and verifies that the measurement matches the inventory record within a 5% tolerance level.
- Step 4: If the measurement exceeds the 5% tolerance level, the Maintenance Division will request that the district office verify the collected data or remeasure the stockpile.
- Step 5: The maintenance office will correct the reported information or remeasure the stockpile.

4.2 WASHTO States Interview

The WASHTO State interviews consisted of five open-ended questions directed to administration and coordination personnel from DOTs currently working with the Stockpile Reports iOS application. The discussion focused on the advantages/disadvantages of the application, Stockpile Reports company evaluation in aspects such as Q&A or troubleshooting, and the organizational structure required for the data acquisition and processing.

Before the interview, UNR contacted Stockpile Reports and asked for a list of states that had any partnership with them. Table 5 summarizes all the states that are working with the company and the type of application given to the product.

Table 5. Use of Stockpile Reports in Different States

DOT	Device	Use
Texas	iPhone	Stockpiled/Roadway inventory
Oregon	iPhone + Drone	90% activity for quarterly inventory 10% vendor measurements on highways
Idaho	iPhone	Salt reporting, salt sheds
Montana	iPhone	Salt & sand tracking Pre/post-storm measurement
New York Washington Louisiana	iPhone	Construction & maintenance
Michigan	Drone	Indoor salt reporting, salt sheds

From the list, two Texas DOT members, one Oregon DOT member, and one Montana DOT member agreed to participate in interviews. Table 6 shows the most relevant aspects from all the state interviews.

Table 6. WASHTO States Interview Results

Benefits	Accountability with automatic results
	Safety
	Mapped location
Challenges	User training
	System compatibility with MMS
	Internet connection requirement
	Climatic condition is critical (snow, rain, sun flare)
	Volume-mass relation is independent
Technical support	Good software vendor
	Questions are answered timely
	Several training videos and manuals on the website

Regarding organization and management, two concepts need to be defined: users and superusers. A user is responsible for collecting and verifying field data measurements while a superuser manages data and other users. According to the interviewed states, the general positions that they fit into these two categories:

- Superusers
  - Administrator: Reports to state department /division, coordinates staff, might verify data, and provide technical support.
  - Specialist: Assists administrator, manage users, verify data measurements, and provides technical support to users.

- Users
  - Point of Contact (POC): In large-scale organizations, this person channels data from a group of users (typically one POC per district).
  - Maintainer: Performs field measurements and updates inventory records.

Although the system is very similar in all the interviewed states, there were two types of approaches depending on the size of the state. In Oregon and Montana, where the number of users and superusers is around 200, the administrator has either none or few specialists and directly assists the users. In the case of Texas, where a combined 2,000 users and superusers are reported, there is one POC per district who directly communicates with any specialist. Thus, it could be said that Texas added two links between the administrator and the maintainers. Figure 17 illustrates the TXDOT organization system.

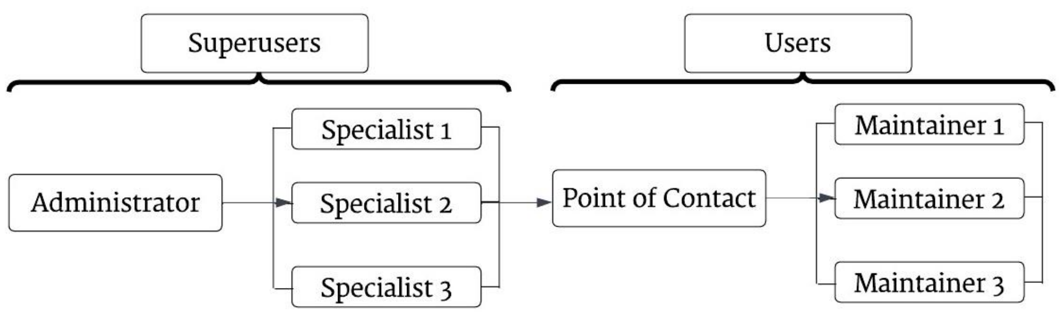


Figure 17. Organization Chart, TXDOT

Chapter 5: Sensitivity Analysis

While the literature review and the inventory methodology interviews were performed, laboratory testing was carried out in parallel to determine material physical properties. The primary focus was the unit weight test, conducted at four moisture contents and two compaction levels (rodded and loose), following the procedure in accordance with ASTM C29 [37]. Other physical parameters like gradation and specific gravity were tested as per AASHTO T 27, AASHTO T 84 and AASHTO T 85 [38]–[40]. The materials tested included base, deicing sand, and aggregate chips. There were three base sources, five deicing sand sources, and five aggregate chips sources from the three NDOT districts. Table 7 shows the district and sources of each material.

Table 7. Material Type per District and Source

Material	District	Source
Base	2	Fallon
	2	Fernley
	3	Elko
Deicing Sand	1	Tonopah
	1	Goldfield
	2	Fallon
	3	Hunewill
	3	Elko
Chips 3/8”	1	Tonopah
	3	Lund
Chips 1/2”	2	Fallon
	3	Hunewill
	3	Elko

5.1 Unit Weight

The unit weight test determines the bulk density of aggregate in a compacted or loose condition. This value is frequently used for establishing mass-volume relationships in purchase agreements. However, aggregates in hauling units and stockpiles usually contain absorbed and surface moisture, while the test is limited to determining the dry bulk density [37].

To calculate the unit weight, the measure (container) is weighed empty, filled with water, and weighed again. The result is divided by the unit weight of water at the registered temperature to determine the volume of the measure. Then, the measure is filled with the aggregate in three equal layers (rodded or not) and leveled to the surface. The unit weight is the division between the aggregate mass and the measured volume, Equation 1.

$$M = (G - T)/V \qquad \text{Equation 1}$$

where; M = Bulk density of aggregate, kg/m^3 [lb/ft^3];

G = Mass of the aggregate plus the measure, kg [lb];

T = Mass of the measure, kg [lb];

V = Volume of the measure, m^3 [ft^3].

Despite the standard limitation, different moisture levels were targeted to assess their impact on the unit weight factor. The following conditions were used for the test:

- Level of compaction:
    - Loose Unit Weight (to simulate the outer portion of the stockpile).
    - Rodded Unit Weight (to simulate the inner core of the stockpile).
    - Average of both measurements.

- Level of moisture
  - Base: 0%, 3%, 6%, and 9%.
  - Sand: 0%, 3%, 6%, and 9%.
  - Chips: 0%, 1%, 2%, and 3%.

Figures 18-20 illustrate the average unit weight factor per type of material and the current unit weight factor NDOT uses. NDOT assumes a value of 1.50, 1.20, and 1.25 ton/yd^3 for the base, deicing sand, and chips, regardless of the moisture content.

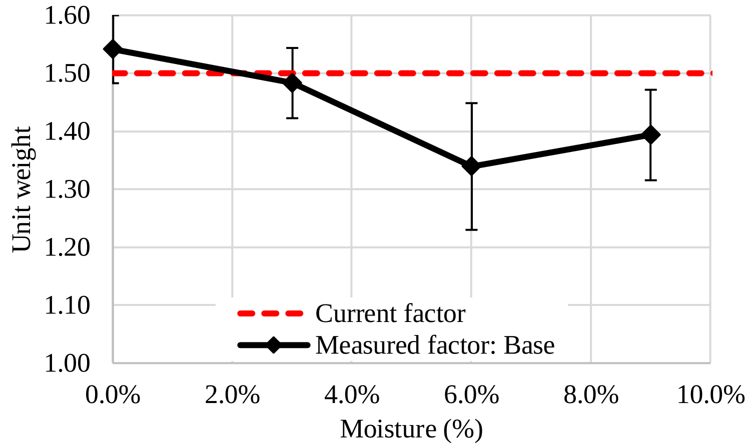


Figure 18. Average Unit Weight: Base (ton/yd^3)

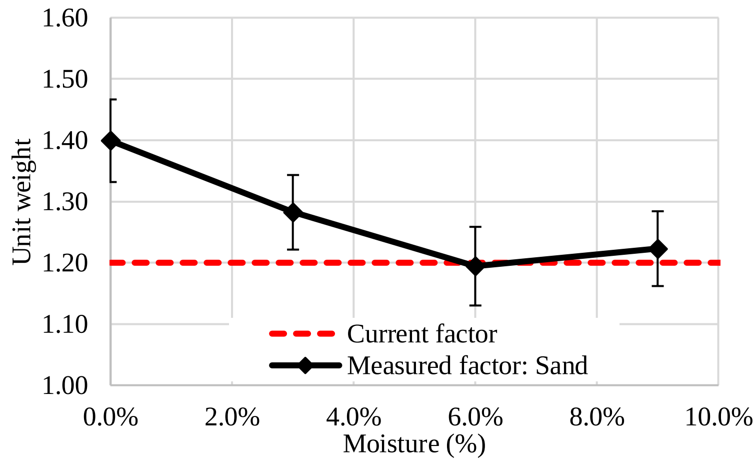


Figure 19. Average Unit Weight: Deicing Sand (ton/yd^3)

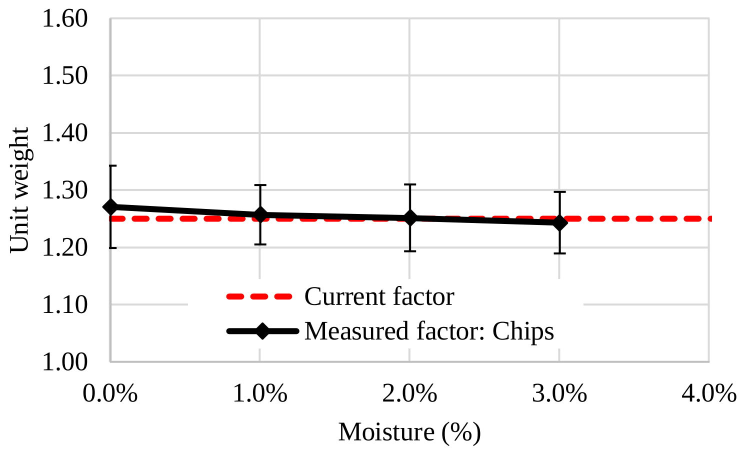


Figure 20. Average Unit Weight: Chips (ton/yd^3)

The whiskers in the figures represent the 95% confidence intervals associated with the variability of each source. It was observed that despite the parametric value employed by NDOT is not constant with a change in moisture content, and it is or is not statistically different at specific moisture contents depending on the material. In the case of the chips, the average factor from the five sources was found to very almost the same as the parametric value.

Once the unit weight factor for each moisture and compaction level was obtained, the water mass was subtracted to account for the actual aggregate mass per volume unit per Equation 2. Because NDOT unit weight factors are reported in ton/yd^3, the dry mass calculation assumes one yd^3. Table 8 summarizes the average results per type of material and moisture content. Appendix A includes the individual result of each material.

$$m_{dry} = \frac{m_{total}}{1+\omega} \qquad \text{Equation 2}$$

where; m_{dry} = Dry mass of aggregate per one yd^3, [ton];

m_{total} = Total mass of aggregate and water per one yd^3, [ton];

ω = Moisture content [%].

Table 8. Average Unit Weight Factor

Material	Parameter	Average Result			
Base	Moisture content	0%	3%	6%	9%
	Unit weight (ton/yd^3)	1.54	1.48	1.34	1.39
	Actual tons per 1 yd^3	1.54	1.44	1.26	1.28
Deicing Sand	Moisture content	0%	3%	6%	9%
	Unit weight (ton/yd^3)	1.40	1.28	1.19	1.22
	Actual tons per 1 yd^3	1.40	1.24	1.13	1.12
Chips	Moisture content	0%	1%	2%	3%
	Unit weight (ton/yd^3)	1.27	1.26	1.25	1.24
	Actual tons per 1 yd^3	1.27	1.24	1.23	1.21

It is evident that the difference between the estimated tons of material using the parametric value and the laboratory-measured value increases after subtracting the water mass. Figure 21 illustrates the mass difference in percent between the parametric and the laboratory-measured factor for each type of material at the tested moisture contents after subtracting the water mass.

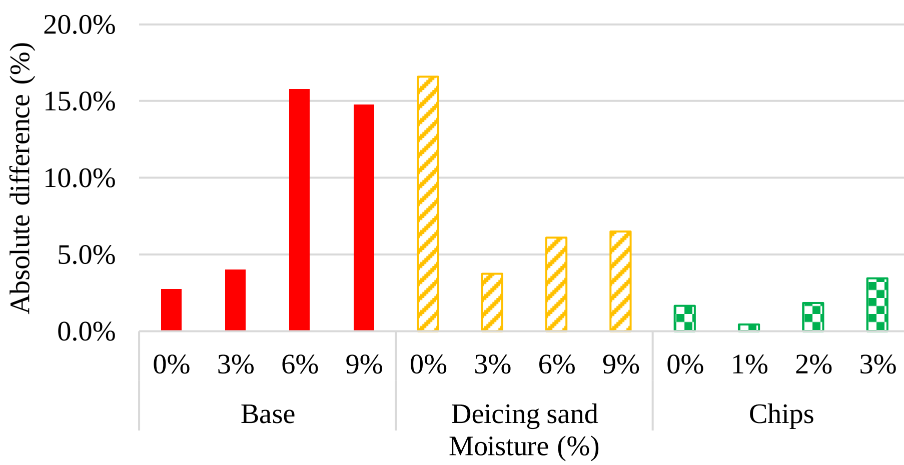


Figure 21. Absolute Difference in Calculated Tons

5.2 Sieve Analysis

The sieve analysis test is use to determine of particle size distribution of fine and coarse aggregates by sieving [38]. The requirements for type 2 base, sand blotter, and grade 2 screenings were plotted as per the Standard Specifications for Road and Bridge Construction [41]. Figures 22 through Figure 25 show the gradation results for each material. Appendix B includes the materials' gradation charts for the materials.

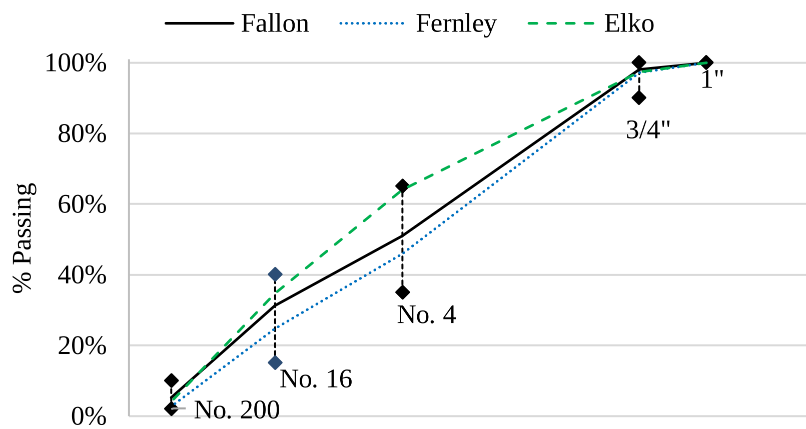


Figure 22. Gradation Plot: Base

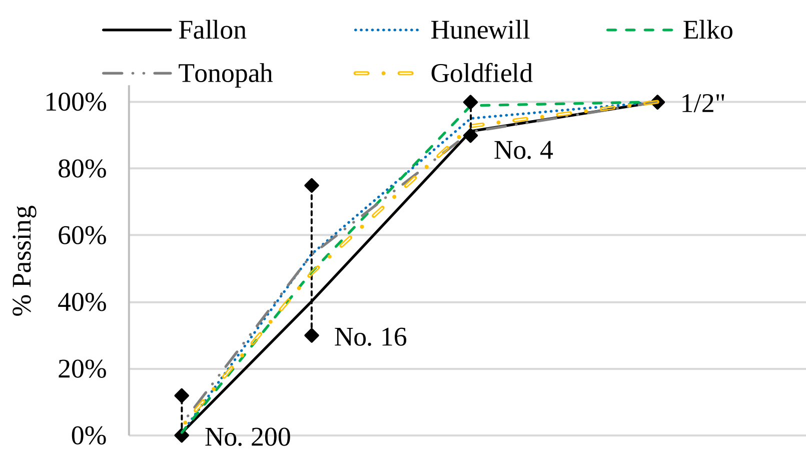


Figure 23. Gradation Plot: Deicing Sand

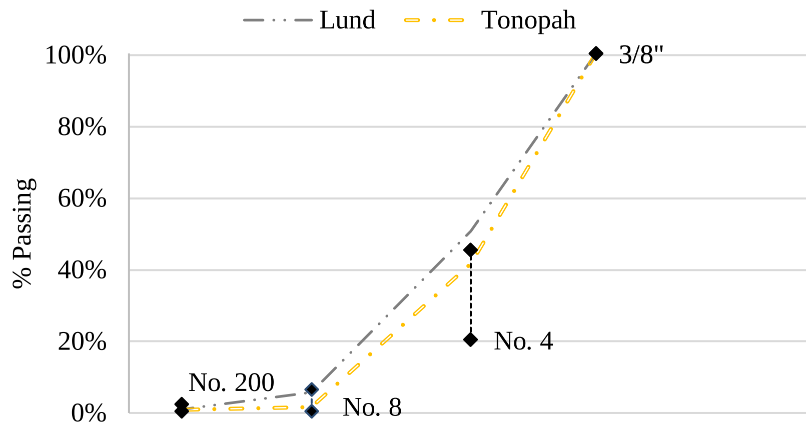


Figure 24. Gradation Plot: 3/8” Chips

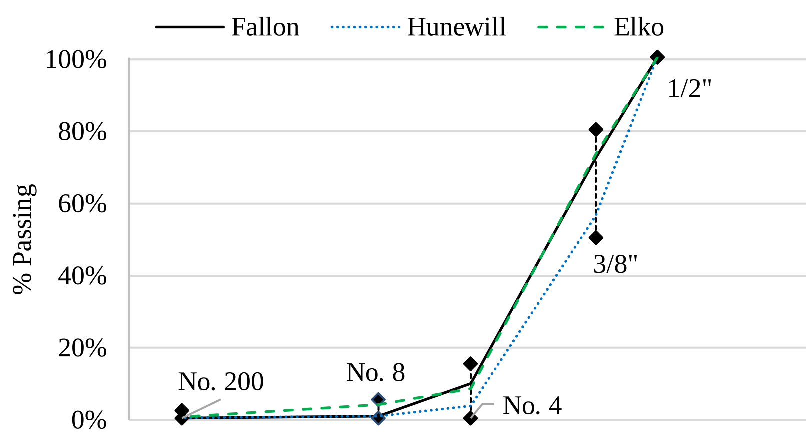


Figure 25. Gradation Plot: ½” Chips

5.3 Specific Gravity

The specific gravity test cover the determination of bulk, surface-saturated-dry (SSD), and the apparent specific gravity of fine and coarse aggregate [39], [40]. For the fine aggregate testing, approximately six percent moisture was added to the samples, and the samples remained covered for 15 to 19 hours before the provisional cone test was performed. In the case of coarse aggregate testing, the material was soaked under water for a similar period of 15 to 19 hours. Based on the gradation results, the overall specific gravity was calculated employing a weighted mean, Equation 3.

$$SG_{combined} = \frac{P_{fine}+P_{coarse}}{\frac{100}{SG_{fine}}+\frac{100}{SG_{coarse}}} \qquad \text{Equation 3}$$

where; $SG_{combined}$ = Overall specific gravity of the aggregate;

SG_{fine} = Fine specific gravity;

SG_{coarse} = Coarse specific gravity;

P_{fine} = Fine fraction = percent passing No. 4 sieve [%];

P_{coarse} = Coarse fraction = percent retained No. 4 sieve [%].

Table 9 depicts the overall specific gravity for each source. Appendix C presents the results for both the fine and coarse fractions.

Table 9. Specific Gravity Results

Material	Source	Specific Gravity
Base	Fallon	2.455
	Fernley	2.438
	Elko	2.354
Deicing Sand	Tonopah	2.454
	Goldfield	2.446
	Fallon	2.578
	Hunewill	2.543
	Elko	2.538
Chips 3/8”	Tonopah	2.374
	Lund	2.290
Chips 1/2”	Fallon	2.610
	Hunewill	2.565
	Elko	2.522

5.4 Physical Properties Correlation

After the laboratory testing was concluded, a model that could predict the measured unit weight based on the gradation, specific gravity, and absorption was developed for each material. The independent variables that were considered to model the base, deicing sand, and chips were moisture content (M), percent passing sieve No. 4 (P_4), percent passing sieve No. 200 (P_{200}), the overall specific gravity (SG), and the overall absorption (A). Minitab software was employed to develop the model, assuming linear behavior [42]. To determine the most suitable variables, the software used the stepwise regression tool, an automated tool used in the exploratory stages of model building to identify a useful subset of predictors. The process systematically adds the most significant variable or removes the least significant variable during each step.

Table 10 shows the average predicted unit weight model (U) for each material and the corresponding adjusted goodness of fit (R^2_{adj}). Furthermore, all parameters were standardized to evaluate the degree of influence of each variable. The standardized model includes the subscript (STD).

Table 10. Average Predicted Unit Weight Model

Material	Model	R^2_{adj}
Base	$U = 3.223 - 1.646M - 0.696SG$	73.59%
	$U_{(STD)} = -0.774M_{(STD)} - 0.430SG_{(STD)}$	
Deicing Sand	$U = 1.401 - 2.055M - 1.990P_{200}$	58.94%
	$U_{(STD)} = -0.756M_{(STD)} - 0.246P_{200\,(STD)}$	
Chips	$U = -0.412 - 0.882M + 0.172P_4 + 13.550P_{200} + 0.650SG$	66.36%
	$U_{(STD)} = -0.230M_{(STD)} + 0.771P_{4(STD)} + 0.598P_{200(STD)} + 1.830SG_{(STD)}$	

Figure 26 represents the three models for the base, deicing sand, and chips, respectively.

For all materials, the predicted unit weight lays above the line of equality at low factors but is then found below the line as the unit weight factor increases.

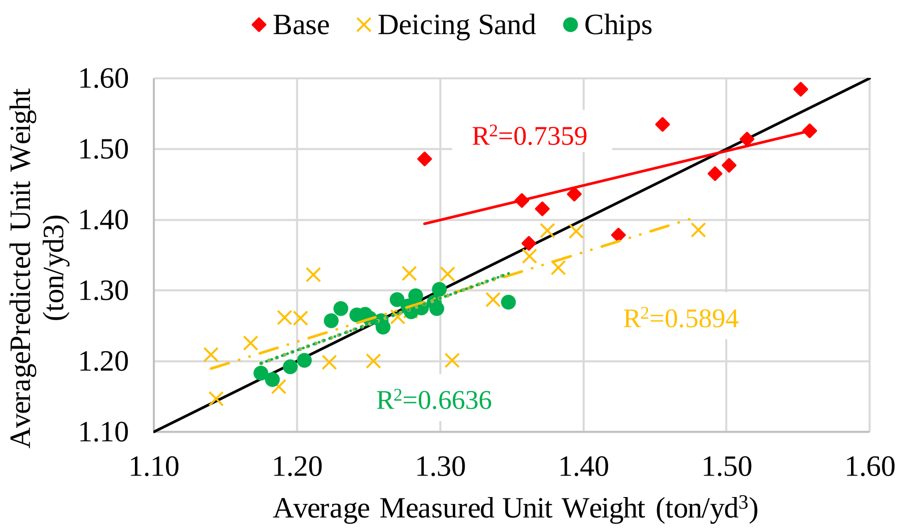


Figure 26. Unit Weight Model: Predicted vs. Measured

As stated, the actual aggregate mass is reduced after the moisture is subtracted. In the same way as the unit weight, the average actual tons (T) were predicted from the material's physical properties using Minitab. Table 11 shows two models: with and without the standardized variables.

Table 11. Average Predicted Mass Model

Material	Model	R^2_{adj}
Base	$T= 1.526 - 3.218M$	81.54%
	$T_{(STD)}= -0.912M_{(STD)}$	
Deicing Sand	$T= 1.398 - 3.166M - 1.870P_{200}$	77.45%
	$T_{(STD)}= -0.876M_{(STD)} - 0.173P_{200\,(STD)}$	
Chips	$T= -0.388 - 2.090M + 0.168P_4 + 13.51P_{200} + 0.640SG$	72.83%
	$T_{(STD)}= -0.493M_{(STD)} + 0.683P_{4(STD)} + 0.540P_{200(STD)} + 1.632SG_{(STD)}$	

Figure 27 represents the three models for the base, deicing sand, and chips. The three material mass models seem to follow the equality line better than the unit weight model. Moreover, the goodness of fit in all cases was increased by approximately 10%.

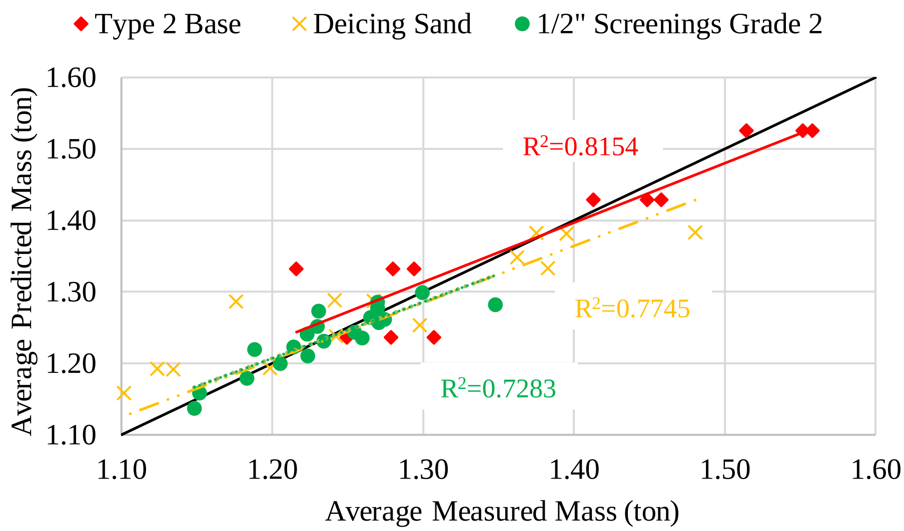


Figure 27. Mass Model: Predicted vs. Measured

Chapter 6: Stockpile Report Application Test

In chapters two and three, different methods to measure a stockpile were mentioned, and examples from other states were presented. After it was decided that using a mobile application would bring the most significant benefit for NDOT, it purchased the Stockpile Report annual subscription with a capacity of 200 stockpiles per year and unlimited users. After a brief training, a few stockpiles were selected to test the accuracy between the mobile application and the current method performed by NDOT Maintainers. Following the first test, a second one was conducted in conjunction with Granite Construction. For this test, the iOS-based application was compared against drone measurements of stockpiles.

The first test was performed between August and October 2022 within NDOT maintenance yards in Reno, Fernley, and Fallon. The second test was completed in November 2022 in the Granite Construction Lockwood facility. In Figure 28 shows all the stockpile measurement locations. The red marks indicate NDOT locations, while the yellow mark refers to the Granite Lockwood facility.

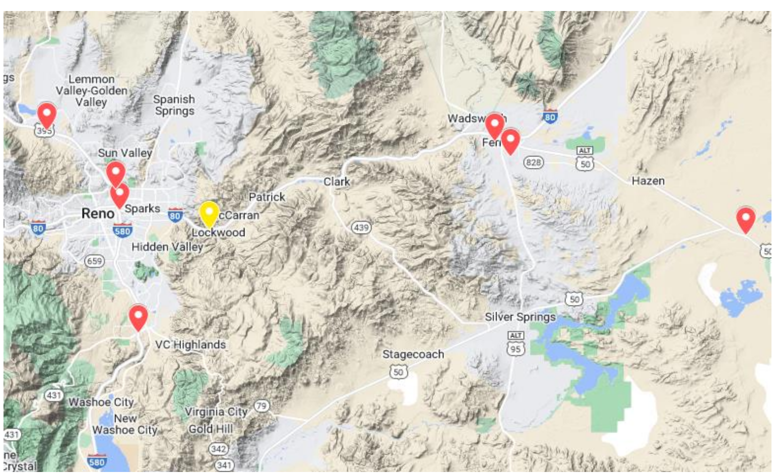


Figure 28. Stockpile Measurement Locations

6.1 First Test: NDOT Material

A total of 14 stockpiles were measured, including base, sand, chips, salt, sand-salt, and asphalt grindings. Although NDOT approximates stockpiles as a rectangular prism, several other shapes were used to estimate the stockpile volumes. Besides the iOS application method, the stockpile volume was approximated using six figures:

- F1: Rectangular prism (requires length, width, and height).
- F2: Rectangular prism dividing the height by two (current method).
- F3: Triangular prism (requires length, width, and height).
- F4: Trapezoidal prism (requires length, width, height, and slope).
- F5: Truncated cone (requires length, width, height, and slope).
- F6: Cone (requires diameter and height).

Each stockpile was measured by three different users with their own devices to evaluate the application variability. Three measurements were taken by a single user in the case of the methods that approximate a regular shape. To achieve this, each stockpile base was measured (length and width) with a measuring wheel, and the height was recorded from visual estimation. Then, a margin of ± 0.5 ft was considered if the stockpile was estimated to be smaller than 12 ft or ± 1.0 ft if the stockpile was estimated to be higher than 12 ft.

It was determined that a multiple-user measurement would not represent the actual procedure and would lead to a highly variable average. When maintainers measure a stockpile in the field, a single dimension value is picked for the length, width, and height, regardless of the number of people assigned to the task. However, as height is the only dimension that is not directly measured, it is more likely that the base dimensions remain constant while the height can be subjected to minor adjustments if needed.

Before the calculation of the statistical parameters, three assumptions were made:

1. Based on the margin between the iOS measurements and the drone value, it was assumed that the application contains a bias.
2. The collected measurements follow a normal distribution.
3. Bias and precision error could be added to determine a total measurement error.

Precision is defined as the measure of mutual agreement among individual measurements of the same property usually under prescribed similar conditions, also known as random error. Bias, on the other hand, is a persistent distortion of a measurement process that causes errors in one direction and is typically known as a systematic error [43]. Accuracy is frequently represented as a combination of both precision and bias but, it is substituted by bias when a clear distinction between precision and bias can be distinguished. Precision and bias are usually quantified in terms of the total error (random error plus systematic error) Equations 4 through 8 are used to calculate the error terms. Due to the small number of tests, the t-statistic value is used for the random error determination. At the same time, because the bias error and the precision error are added, a 90% confidence interval t-statistic value was used as 5% of data will be covered by the bias error from one side of the tail.

$$TE^2 = RE^2 + SE^2,\ \ {TE_{\%}}^2 = {RE_{\%}}^2 + {SE_{\%}}^2 \qquad \text{Equation 4}$$

where; $TE/TE_{\%}$ = Total error [yd^3] or [%];

$RE/\ RE_{\%}$ = Random error [yd^3] or [%];

$SE/\ SE_{\%}$ = Systematic error [yd^3] or [%].

$$RE = \frac{t_{2T-90\%} * S}{\sqrt{n}} \qquad \text{Equation 5}$$

$$RE_{\%} = \frac{t_{2T-90\%} * CV}{\sqrt{n}} \qquad \text{Equation 6}$$

where; $t_{2T-90\%}$ = two-tailed t-statistic value, 90% confidence interval;

S = Sample standard deviation [yd^3];

CV = Coefficient of variation [yd^3];

n = Number of measurements for each pile.

$$SE = |\mu - \bar{X}| \qquad \text{Equation 7}$$

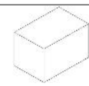
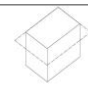
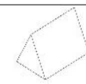
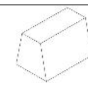
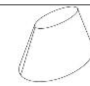
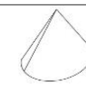
$$SE_{\%} = \frac{|\mu - \bar{X}|}{\mu} \qquad \text{Equation 8}$$

where; $\bar{X}$ = Sample mean [yd^3];

μ = True measurement [yd^3].

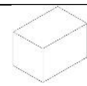
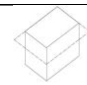
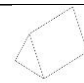
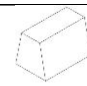
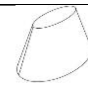
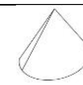
When the calculated values were compared against the inventory record (EAMS database), it was found that the accuracy level could not be established, which was caused mainly by two factors. First, the purchased material quantity had not been updated for some stockpiles, reflecting null values for the existing aggregate. Second and most importantly, the way EAMS considers some stockpiles does not necessarily reflect the physical constituents of some stockpiles. For example, EAMS might contain a single sand record of 1,000 $yd^{3,}$ while in the maintenance location, the material is divided into four piles of 250 yd^3 each. Thus, for the first test, only the precision value was calculated. Table 12 compares the average value from the Stockpile Report application and the regular shape volume approximation methods.

Table 12. Average Volume (yd^3): NDOT Material

Material	Source	App						
Base	Reno	330	741	370	247	476	312	196
	Reno	858	2,000	1,000	667	1,311	1,042	570
	Fernley	485	1,467	733	489	1,008	613	385
Deicing Sand	Reno	767	1,400	700	467	734	729	455
	Fernley	304	622	311	207	321	163	166
Chips	Reno	275	859	430	286	552	396	233
	Fernley	144	311	156	104	163	83	88
	Fallon	145	519	259	173	307	185	136
Salt	Fernley	111	233	117	78	166	108	61
Sand-Salt	Reno	265	467	233	156	244	173	126
	Fallon	350	640	320	213	329	216	172
Grindings	Reno	1,746	2,196	1,098	732	1,469	1,174	629
	Reno	348	533	267	178	279	218	147
	Fallon	3,789	9,593	4,796	3,198	8,053	5,678	2,529

It is observed that the quantified volume by the Stockpile Reports application and the estimation performed with NDOT methodology yield similarity of about 25% from the measured piles. Compared to the other figure approximation volumes, assuming a rectangular shape and dividing the height by two leads to the most significant similarity with the application. However, as the bias is unknown, it does not mean that either the application or the NDOT method is more accurate. Table 13 shows the random error in percentage.

Table 13. Random Error (%): NDOT material

Material	**Source**	**App**						
Base	Reno	8%	20%	20%	20%	9%	12%	20%
	Reno	16%	34%	34%	34%	16%	19%	34%
	Fernley	1%	34%	34%	34%	19%	12%	34%
Deicing	Reno	14%	34%	34%	34%	22%	19%	34%
Sand	Fernley	3%	29%	29%	29%	29%	9%	29%
Chips	Reno	12%	20%	20%	20%	9%	13%	20%
	Fernley	11%	34%	34%	34%	34%	7%	34%
	Fallon	2%	20%	20%	20%	6%	11%	20%
Salt	Fernley	2%	34%	34%	34%	20%	8%	34%
Sand-Salt	Reno	3%	20%	20%	20%	2%	11%	20%
	Fallon	8%	34%	34%	34%	36%	6%	34%
Grindings	Reno	22%	34%	34%	34%	17%	20%	34%
	Reno	8%	20%	20%	20%	2%	12%	20%
	Fallon	8%	29%	29%	29%	24%	23%	29%

The average value obtained by approximating a regular shape is close to the calculated value by Stockpile Reports; the variability is higher even after assuming that the height would vary by either ±0.5 ft or ±1.0 ft. Thus, the Stockpile Report application was determined to be more precise than any other method within the measured piles by the participating operators.

6.2 Second Test: Granite Construction Stockpiles

As it was determined in the first test that the accuracy level associated with each measurement method could not be established. Therefore, a second test was performed in conjunction with Granite Construction at its Lockwood Nevada Quarry. According to

Granite personnel, stockpile records are updated twice a month based on drone flights with very reliable results. Thus, for the second test, it was assumed that the obtained volume from the drone flight was the actual quantity (μ), and either the iOS application or the regular shape approximation method would be compared to it.

A total of seven stockpiles were measured, including crusher fines #4, 3/8" chips, ½" chips, 1" chips, and 6" riprap. The same volume approximation was used as in the first test, estimating six different regular shapes. In the case of the iOS application, only two users measured each stockpile. However, due to connectivity issues, three measurements were only performed by one user (these quantifications were not considered for statistical purposes). Figure 29 shows the 6" rip rap DTM generated by the drone and the Stockpile Report application.

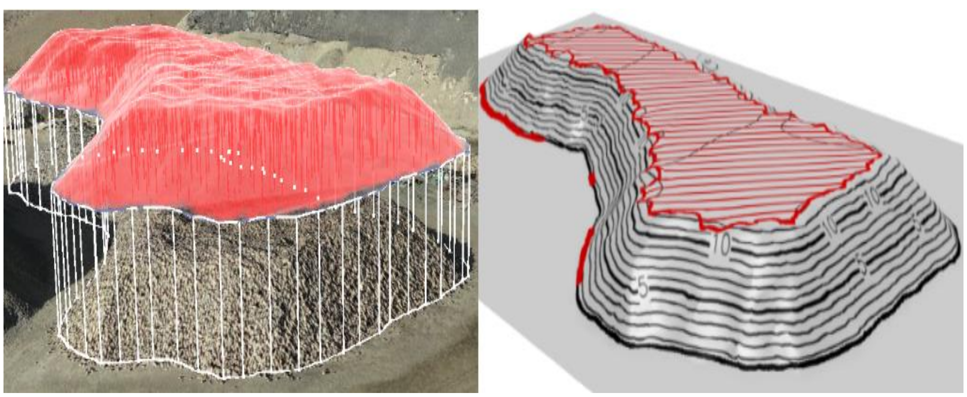
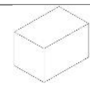
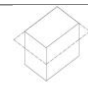
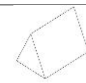
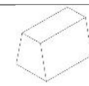
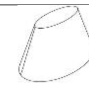
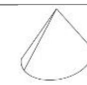


Figure 29. Riprap DTM. Left: Drone. Right: Stockpile Reports

Table 14 summarizes the average volume calculated for each method and the volume based on Granite's drone flight measurement. In the case of two 1" chips piles and the 3/8" chips pile, only one user measured them with the iOS application. Thus, the standard deviation or coefficient of variability between two or more measurements could not be established.

Table 14. Average Volume (yd^3): Granite Material

Material	Drone	App						
6” Rip rap	3,653	4,158	5,689	2,844	1,896	4,465	3,566	1,676
1” Chips	1,831	1,990	2,667	1,333	889	2,055	1,316	699
	853	922	1,600	800	533	1,141	669	419
	84	87	116	58	39	66	44	31
½” Chips	679	766	1,067	533	356	551	364	314
3/8” Chips	1,434	1,558	2,078	1,039	693	1,427	1,060	570
#4 Fines	966	1,050	2,000	1,000	667	1,235	1,087	612

The random error was calculated for each method and is presented in Table 15. When the measurements were compared against the drone measured volumes, it was found that a positive margin (overestimation) exists between these two values. This difference was assumed to be a bias and is shown in Table 16. It is theorized that the truncation process of high stockpiles consistently adds a significant volume of material for the Stockpile Report measurements. Figure 30 depicts this with two cases: a short stockpile in which the toe and top are visible versus a tall stockpile in which the top is truncated because of the surface modeling algorithm.

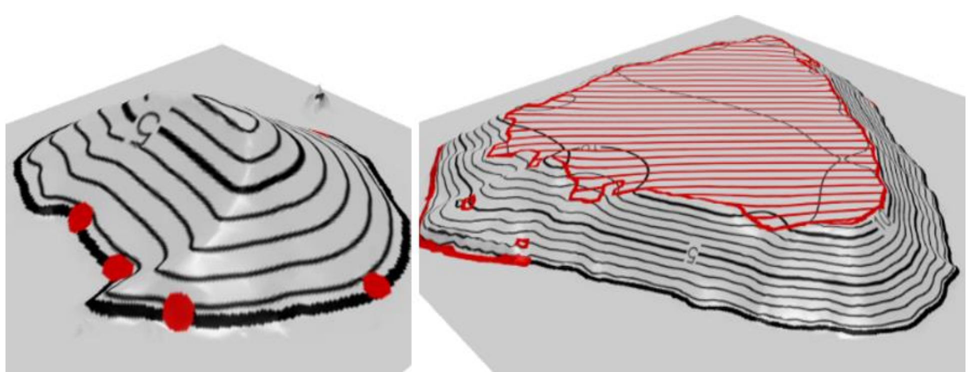


Figure 30. Stockpile Surface Approximation. Left: Visible Top. Right: Invisible Top

Table 15. Random Error (%): Granite Material

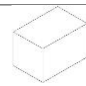
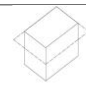
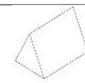
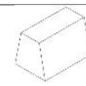
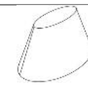
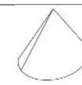
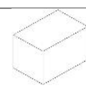
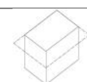
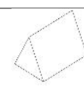
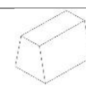
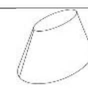
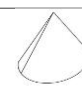
Material	Drone	App						
6" Rip rap	-	14%	34%	34%	34%	25%	26%	34%
1" chips	-	/	34%	34%	34%	24%	17%	34%
	-	/	34%	34%	34%	20%	12%	34%
	-	4%	34%	34%	34%	9%	19%	34%
1/2" chips	-	5%	25%	25%	25%	25%	5%	25%
3/8" chips	-	/	34%	34%	34%	19%	18%	34%
#4 Fines	-	13%	34%	34%	34%	13%	21%	34%

Table 16. Absolute Systematic Error (%): Granite Material

Material	Drone	App						
6" Rip rap	-	14%	56%	22%	48%	22%	2%	54%
1" chips	-	9%	46%	27%	51%	12%	28%	62%
	-	8%	88%	6%	37%	34%	22%	51%
	-	2%	37%	32%	54%	22%	48%	64%
1/2" chips	-	13%	57%	21%	48%	19%	46%	54%
3/8" chips	-	9%	45%	28%	52%	0%	26%	60%
#4 Fines	-	9%	107%	4%	31%	28%	13%	37%

The use of the Stockpile Reports application led to more precise averages, roughly 9%. Furthermore, the percent difference between the drone flight volume (assumed to be the actual volume) and the calculated value from the application is the smallest one (around 10%) compared to the other methods. Figure 31 plots both the random and systematic errors. If the measurement is more unbiased, the vertical point coordinate will be smaller.

If the measurement is more precise, the point horizontal coordinate will be smaller.

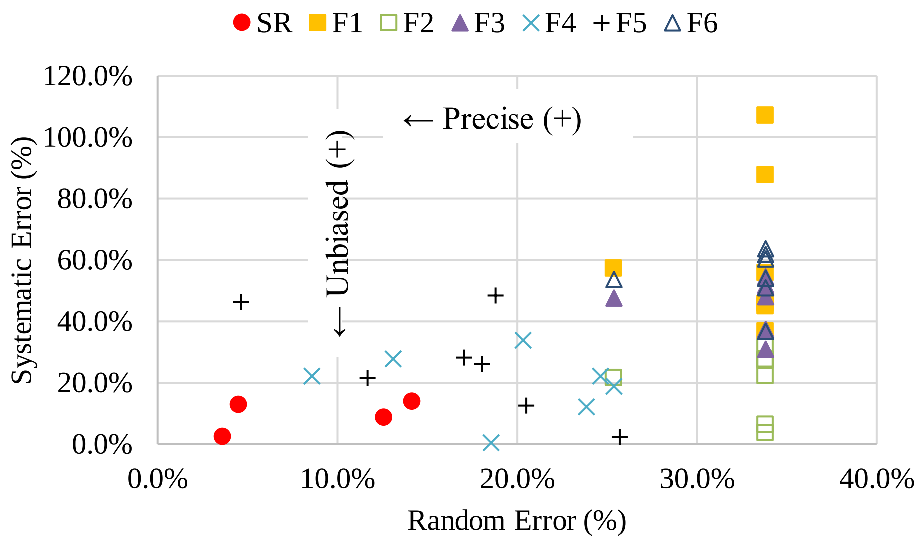


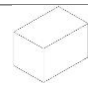
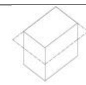
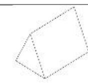
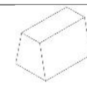
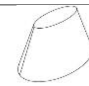
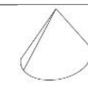
Figure 31. Systematic Error vs. Random Error

Some shape approximations lead to more accurate results for a specific stockpile measurement. However, if the overall accuracy is considered, Stockpile Reports is roughly 10% above the actual volume, regardless of the pile size.

Based on the measured data, the Stockpile Reports application is likely to provide more accurate and precise data compared to the other methods. However, it is observed that some figure approximations lead to accurate measurements, despite the obtained variability when the height dimension is assumed to vary by ± 1.0 ft.

In Table 17, the total error in percent is presented for each method. As stated, adding both errors result in the minimum margin for the considered methods. Similarly, Figure 32 illustrates the total error versus the measured volume. From the plot, it seems that the total error from the Stockpile Report application follows a logarithmic trend with an error below 15% when the approximated volume is found within 0 to 1,000 yd^3.

Table 17. Total Error (%): Granite Material

Material	**Drone**	**App**						
6" Rip rap	-	20%	65%	40%	59%	33%	26%	64%
1" chips	-	/	57%	43%	62%	27%	33%	70%
	-	/	94%	34%	51%	39%	25%	61%
	-	4%	50%	46%	64%	24%	52%	72%
1/2" chips	-	14%	62%	33%	54%	32%	47%	59%
3/8" chips	-	/	56%	44%	62%	19%	32%	69%
#4 Fines	-	15%	112%	34%	46%	31%	24%	50%

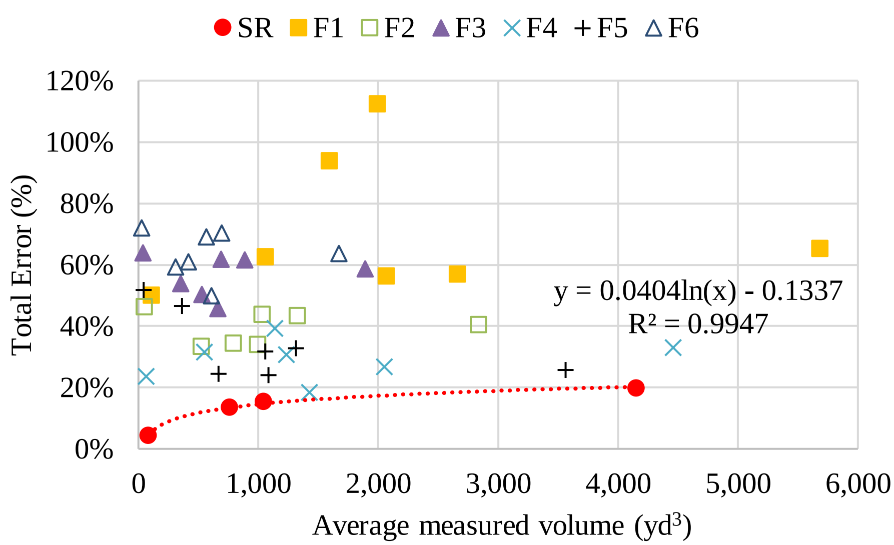


Figure 32. Total Error vs. Average Measured Volume

Chapter 7: Economical Impact of the Unit Weight and Volume

The influence of the moisture content on the unit weight determination variability of the measurement methods was evaluated in Chapters 5 and 6, respectively. Both elements affect the mass, which is the input value in EAMS. To reflect the variability of these parameters, a known NDOT material purchase contract was analyzed. The associated variability from the unit weight and the volume was reported in dollar amount separately to distinguish the individual effect from each parameter.

The open term contract (OTC) contains the following information regarding aggregate, rip rap, chips, and concrete sand for the contract period January 12, 2022 through December 31, 2022 [44]:

- Material type.
- Vendor.
- Plant location.
- Purchased quantity in tons.
- Price per ton.

From the entire contract, only the base and chips purchases were counted and added. Table 18 summarizes the total amount of type 2 base, ½" chips, and 3/8" chips. To calculate the dollar amount, the purchased quantity was multiplied by the material price. Also, the average price of the material as well as the price range (minimum and maximum) is included.

Table 18. OTC Contact Sample Information

Material	Average Price ($)	Price Range ($)	Purchased Material (ton)	Dollar Amount ($)
Type 2 base	$15.99	$9.25 - $30.44	56,000	$37,333
3/8” chips	$24.85	$15.57 - $32.00	105,750	$2,669,561
½” chips	$27.06	$13.57 - $32.00	84,540	$2,056,151
Total				**$4,763,045**

As part of the OTC conditions, NDOT includes a note about the moisture content. Moisture of 5% is allowable on all aggregate material purchases. If the moisture content of the ordered material is above the allowable 5%, the moisture above 5 % will be deducted from the total weight on the invoice. Thus, it is assumed that the purchased material in the OTC contract contains a moisture content between 0 to 5% with an average of 2.5%.

Based on this assumption, the unit weight of base and chips with 2.5% moisture could be interpolated from the laboratory-measured unit weight. At that level of moisture, the base is expected to have a unit weight factor of 1.49 ton/yd^3 while the unit weight factor would be 1.25 ton/yd^3 for the chips with a confidence interval of 0.06 and 0.07 ton/yd^3 respectively. If the water mass is subtracted, the actual aggregate mass is reduced to 1.46 and 1.22 tons per cubic yard, with the exact confidence interval. The parametric values employed by NDOT are 1.50 ton/yd^3 for base and 1.25 ton/yd^3 for chips regardless of the moisture content. In the case of the volume, the total error calculated in chapter six will be employed to determine the probable dollar amount variability.

Table 19 shows the maximum percent difference for these parameters: the parametric and the laboratory-measured unit weight difference for moisture; the current NDOT and the Stockpile Report method volume difference for volume.

Table 19. Maximum Dollar Amount Difference

Material	**Moisture**		**Volume**	
	Maximum Difference (%)	Dollar Amount Difference ($)	Maximum Difference (%)	Dollar Amount Difference ($)
Type 2 base	4.5%	$1,644	26.1%	$9,743
3/8" chips	5.9%	$158,558	26.1%	$696,716
½" chips	5.9%	$122,124	26.1%	$536,625
Total	**5.9%**	**$282,345**	**26.1%**	**$1,243,085**

The results show that the difference between the use of a parametric unit weight factor and the laboratory-measured factors might yield an approximate of 6% difference, or about $300,000. However, the impact of measuring the pile with the current methodology or with the iOS application escalates to roughly 26%, resulting in a $1.2 million difference. In other words, while the use of the current method could yield a total average error of 39%, the associated total error of the Stockpile Reports would be 13% on average. Therefore, the impact of the volume method selection is five times greater than the impact of the unit weight factor selection.

Chapter 8: Documentation

In the previous chapter, the effect of the volume quantification method proved to be more impactful than the unit weight factor selection to calculate the total tonnage; thus, it was decided that focus would be placed on volume determination. In chapter four, feedback from state DOTs using the Stockpile Reports application was provided addressing the effectiveness of the tool. However, the field measurement trials revealed the specific challenges that the application and users face with NDOT stockpiles. Consequently, the implementation plan and the procedure to measure and report the stockpile volume must consider these factors and inform future users about the possible implications.

8.1 Implementation Plan

To improve consistency of measurements, user training and development will be advantageous. According to Stockpile Reports and the interviewed members from other state DOTs using Stockpile Reports, poor performance by users causes the most problems and inconsistencies with the measurement method due to a lack of training. Thus, it is suggested that NDOT Maintenance and Asset Management Division staff assist the district staff with training to improve the successful use of the tool with limited variability.

Figure 33 portrays a proposed overall implementation plan that includes the Maintenance and Asset Management staff training District Maintenance leadership staff who would then train District maintenance crew members that would have responsibility for measuring stockpiles with the tool.

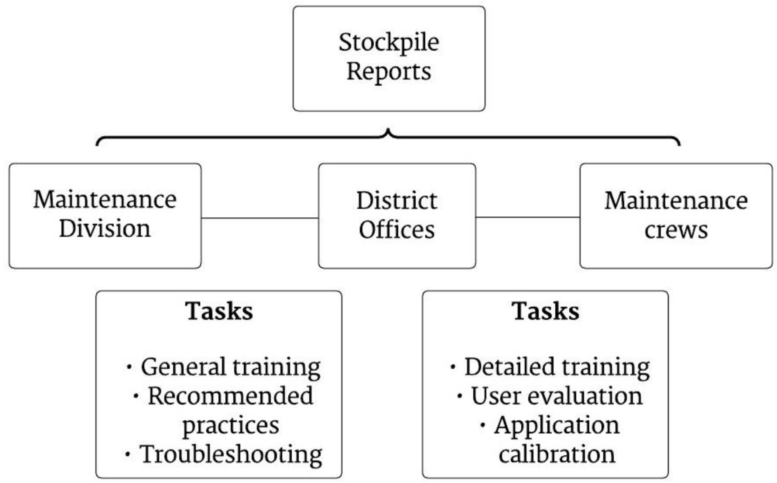


Figure 33. Implementation Plan

8.2 Stockpile Inventory Verification Procedure

This section incorporates the Stockpile Reports application in the current methodology that NDOT follows to verify inventory records. The procedure was defined to encompass three primary steps: Material purchase/use, field measurement and verification, and inventory record comparison. As presented in chapters three and four, NDOT updates material inventory through EAMS by inputting the quantity that has been purchased or used. This step is the basis of the process because the inventory record serves as the reference quantity for the field measurements. In the second step, the utilization of the Stockpile Reports application is proposed to determine the volume and either the parametric or specific unit weight factors could be input to obtain the mass. Finally, data must be thoroughly scrutinized and compared against the inventory record. If a difference of 5% or more is observed, several options are proposed to remedy it. Figure 34 illustrates the proposed procedure. The steps and sub steps are further described in Appendix D.

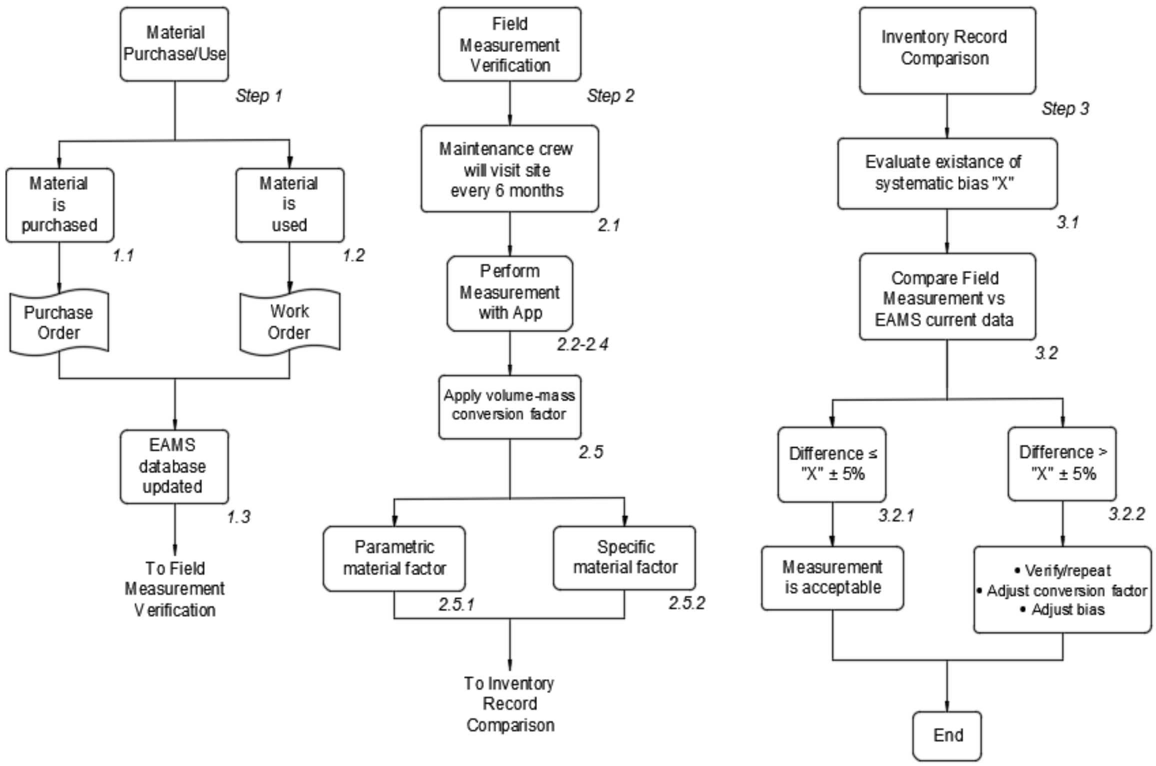


Figure 34. General Inventory Verification Procedure

The flowchart delineates the proposed steps in a generalized view. However, specific recommendations for users concerning field measurements were not included. A simple pamphlet was proposed to summarize the most critical elements that maintainers must consider prior to any measurement and is illustrated in Figure 35. The critical elements are combined to create the acronym “PILES”:

1. People (P): With one user, at least two measurements are required (three suggested); with two users, at least one measurement per user (three per user suggested).
2. Identification (I): If the pile perimeter can be covered, it must be considered a freestanding pile even if it is stored in a shed. Otherwise, it must be considered a bunker pile even if it is stored outdoors.

3. Luggage (L): A measuring tape is required despite using a mobile phone as well as a portable charger to account for the battery demand caused by the application and fixed-length cones would shorten the measuring time.
4. External variability (E): It is important to consider any external factors that could incorporate sources of variability such as sinking, material removal caused by the weather, bunker configuration, or top/toe visibility.
5. Sun flare (S): Sunset and sunrise should be avoided to prevent sun flare. Additionally, weather conditions and internet connectivity must be considered.

Figure 35. Proposed Pamphlet for Field Measurements

Chapter 9: Findings and Recommendations

9.1 Findings

The present study aimed to review sufficient literature from different state DOTs concerning technological approaches to quantify aggregate stockpiles while at the same time compiling and summarizing the current methodology in Nevada. The effort revealed that the implementation of the iOS-based Stockpile Reports tool could benefit NDOT and could lead to more accurate stockpile quantity estimations. Thus, the two components that affect the mass, unit weight and volume, were individually evaluated.

The sensitivity analysis intended to correlate the moisture content and other physical parameters with the unit weight factor, comparing it against the parametric values that NDOT currently uses. It was found that moisture tends to decrease the average unit weight factor in the tested materials (base, deicing sands, and chips), the percent difference was not significant if the moisture level remains under 6% and the confidence interval for the laboratory-measured data was considered. Moreover, NDOT OTC establishes a maximum moisture content of 5% for all purchased material below which there is no economic penalty. Based on this provision, it was assumed that an average of 2.5% moisture is expected for most purchased materials. When the interpolated unit weight factor at 2.5% moisture was compared against the parametric one, a maximum of 5% difference was observed between these numbers.

Field measurements were performed to quantify the precision and bias associated with the iOS Stockpile Reports application, the NDOT current methodology as well as similar figure-approximation methods. It was found that for some stockpiles, the data inventory record in EAMS differed significantly from amount of material estimated using historical and the Stockpile Reports method. Given the possible hypothesis for this situation in chapter six, it was decided that only the precision between operators would be measured and a second test would be performed to determine the accuracy level. As per the first test results, it was observed that stockpiles with an approximate volume of 500 yd^3 or less were measured with an average precision (random error) of 5% with the Stockpile Reports application and escalated to roughly 15-20% when the measured volume was above 500 yd^3. In the case of the measurements based on the NDOT methodology with the assumption of ± 1.0 ft if the stockpile was estimated to be higher than 12 ft, the random error increased almost 4 times. Thus, it was determined that to reduce the precision error, operators would have to estimate a stockpile height within a quarter of a foot between them.

Later when the second test was performed at the Granite Construction Lockwood facility, a consistent overestimation was observed between the drone and the Stockpile Reports application measurement. The difference was considered a systematic bias of approximately 10%. Similarly, the current NDOT method led to an underestimation of the "true" value with an approximate difference of 20%. After measuring the precision between operators, a similar pattern with respect to the first test was established for each method, concluding that the random error is likely to remain constant regardless of the stockpile source.

9.2 Recommendations

Based on the research performed the following recommendations are made to the NDOT Maintenance and Asset Management Division:

1. Implement use of the Stockpile Reports measurement tool for quantifying Maintenance Division stockpile quantities.
2. Provide training for the users of the Stockpile Reports measurement tool to improve accuracy and minimize operator variability. Interviewed employees from different state DOTs confirmed the importance of personnel training and overall consistency in the organization when the field measurements are performed.
3. Verify that the standard procedure presented in Figure 34 and documented in Appendix X accurately represent the desired outcomes associate the NDOT Maintenance stockpile inventory verification and share with NDOT Maintenance staff to assure understanding of the procedure requirements. To facilitate the implementation of Stockpile Reports it is recommended that the EAMS database be updated to reflect the most recent actual material inventory that the NDOT Maintenance possesses and defines if each stockpile is single or multiple stockpiles at a maintenance station.
4. Monitor user performance and specific material/storing conditions with implementation that includes variation in the data caused by the user, the measuring device, or the measured object itself using a measurement system analysis. One of the best examples is a Gage R-R study where two components of measurement system variability are frequently generated: repeatability and reproducibility. Repeatability represents the variability when the gage is used to measure the same

object by the same operator. Reproducibility refers to the variability from different operators measuring the same part. Consequently, the highest contribution to variability is found and tied to either the operator, the device or the measured object [45].

5. Identify the Maintenance Division staff that will have responsibility to managing the overall Stockpile Reports system from implementation through steady-state use. This would include managing new and existing users, validating measured data, troubleshooting, and general training on use of the application.

References

[1] R. Brown, P. S. Kandhal, F. L. Roberts, R. Kim, D.-Y. Lee, and T. W. Kennedy, "Maintenance," in *Hot Mix Asphalt Materials, Mixture Design, and Construction*, Third Edit., 2009, pp. 660–663.

[2] Nevada Department of Transportation, *Maintenance Manual*. 2017.

[3] Texas Department of Transportation, "Stockpile Measurement Pilot Project," 2015. [Online]. Available: https://www.stockpilereports.com/stockpile-measurement-methods-that-work/.

[4] Miller-Warden Associates, *Effects of Different Methods of Stockpiling Aggregates. Interim Report*. national Cooperative Highway Research Program Report, 1964.

[5] Kemper Equipment, "Understanding the Different Conveyor Types – And How to Find the Right Conveyors for Your Project Needs Processing." https://www.kemperequipment.com/blog/how-to-find-the-right-conveyors-for-your-project-needs/.

[6] Vulcan Materials Company, "Aggregate Stockpiling and Handling," 2019.

[7] Georgia Department of Transportation and Georgia Crushed Stone Association, "Stockpiling Techniques for Clean Stone." .

[8] CTC & Associates LLC, "Monitoring Stockpiles of Solid Winter Maintenance Materials," 2017.

[9] D. N. Siriba, S. M. Matara, and S. M. Musyoka, "Improvement of Volume Estimation of Stockpile of Earthworks Using a Concave Hull-Footprint," *Int. Sci. J. Geo-SEE Inst.*, vol. 9000, no. 5, pp. 11–25, 2015.

[10] M. R. Meenar and J. A. Sorrentino, "Dealing with 3D Surface Models: Raster and TIN in Hassan A. Karimi," in *Handbook of Research on Geoinformatics.*, 2009, pp. 73–81.

[11] G. W. Roberts, X. Tang, and C. Brown, "A Review of GNSS for Civil Engineering Applications," *Proc. Inst. Civ. Eng. Civ. Eng.*, vol. 168, no. 4, pp. 185–192, 2015, doi: 10.1680/cien.15.00013.

[12] Khomsin, D. G. Pratomo, I. M. Anjasmara, and F. Ahmad, "Analysis of the Volume Comparation of 3'S (TS, GNSS and TLS)," *E3S Web Conf.*, vol. 94, 2019, doi: 10.1051/e3sconf/20199401014.

[13] I. Atterbury Consultants, "Stockpile Volume Calculation," vol. C, pp. 1–9, 2008.

[14] X. Yang, Y. Huang, and Q. Zhang, "Automatic stockpile extraction and measurement using 3d point cloud and multi-scale directional curvature," *Remote Sens.*, vol. 12, no. 6, 2020, doi: 10.3390/rs12060960.

[15] Merriam Webster Dictionary, "Photogrammetry." .

[16] G. Harris, "Early Developments," in *History of photogrammetry*, 2006, pp. 62–77.

[17] P. L. Raeva, S. L. Filipova, and D. G. Filipov, "Volume computation of a stockpile - A study case comparing GPS and uav measurements in an open pit quarry," *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. - ISPRS Arch.*, vol. 2016-Janua, no. July, pp. 999–1004, 2016, doi: 10.5194/isprsarchives-XLI-B1-999-2016.

[18] S. Y. Tan, H. Arshad, and A. Abdullah, "Distinctive accuracy measurement of binary descriptors in mobile augmented reality," *PLoS One*, vol. 14, no. 1, pp. 1–18,

2019, doi: 10.1371/journal.pone.0207191.
[19] XYHT Digital Magazine, “Stockpile Reports,” 2021. https://www.xyht.com/lidarimaging/stockpile-reports/.
[20] Trimble, “LOADRITE Wheel Loader Scales,” 2016. .
[21] Load Management Solutions, “LOADSCAN.” .
[22] AASHTO, “About the AASHTO Innovation Initiative,” 2021. https://aii.transportation.org/Pages/AIIBackground.aspx.
[23] AASHTO, “Digital Stockpile Management,” 2021. http://aii.transportation.org/Pages/Digital-Stockpile-Management.aspx.
[24] Agile Assets, “Nevada Department of Transportation Selects AgileAssets for Statewide Enterprise Asset Management System,” 2017. https://www.agileassets.com/press-releases/nevada-department-of-transportation-selects-agileassets-for-statewide-enterprise-asset-management-system/.
[25] Nevada Department of Transportation, “Fully-Compliant Transportation Asset Management Plan,” 2019. doi: 10.31826/9781463240134-toc.
[26] Nevada Department of Transportation, “Operations Management (Web) TM User Manual.” 2019.
[27] Oregon Department of Transportation, *ODOT Inspector’s Manual*. 2014.
[28] Oregon Department of Transportation, *Standard Specifications for Construction*. 2018.
[29] Texas Department of Transportation, “Internal Audit Follow-Up Report,” 2015.
[30] Texas Department of Transportation, “Internal Audit Follow-Up Report,” 2016.
[31] Texas Department of Transportation, “Internal Audit Follow-Up Report,” 2017.
[32] Geoslam, “Words by Tina Greenfield, Iowa DOT,” 2019. https://geoslam.com/wp-content/uploads/2019/12/Iowa-DOT-Volumes.pdf.
[33] Alaska Department of Transportation, *Development of GPS Survey Data Management Protocols / Policy*, no. August. 2010.
[34] Minessota Department of Transportation, *Standard Specification for Construction*, vol. 2. 2020.
[35] Minessota Department of Transportation, *Standard specifications for solvents*, vol. 1. 2020.
[36] Minessota Department of Transportation, *Field Guide to Document Construction Pay Items on Local Government Agency Projects*. 2018.
[37] ASTM, “C29/C29M-09. Standard Test Method for Bulk Density (‘ Unit Weight ’) and Voids in Aggregate,” *ASTM Int.*, vol. i, no. c, pp. 1–5, 2009, doi: 10.1520/C0029.
[38] AASHTO, “T27-20. Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates,” 2020.
[39] AASHTO, “T84-17. Standard Method of Test for Specific Gravity and Absorption of Fine Aggregate,” 2017.
[40] AASHTO, “T85-22. Standard Method of Test for Specific Gravity and Absorption of Coarse Aggregate,” 2022.
[41] Nevada Department of Transportation, “Standard Specifications for Road and Bridge Construction,” 2014.
[42] Minitab® 21, “Using stepwise regression and best subsets regression,” 2022.

https://support.minitab.com/en-us/minitab/21/help-and-how-to/statistical-modeling/regression/supporting-topics/basics/using-stepwise-regression-and-best-subsets-regression/.

[43] L.-D. Chen, "Appendix A : Determining Accuracy and Precision of Measurements : Using Calibration to Estimate Bias and Precision Errors," in *Experimental Engineering. Lecture Notes.*, Department of Mechanical Engineering. The University of Iowa, 1996, pp. 4–7.

[44] Nevada Department of Administration. Purchasing Division., "OTC. Bid 80DOT-S1831," 2022.

[45] Minitab® 21, "Overview for Crossed Gage R&R Study," 2022. https://support.minitab.com/en-us/minitab/21/help-and-how-to/quality-and-process-improvement/measurement-system-analysis/how-to/gage-study/crossed-gage-r-r-study/before-you-start/overview/.

Appendix A

Table A1. Unit Weight Results: Base

	Moisture (%)	**0.0%**	**3.0%**	**6.0%**	**9.0%**
Fallon	Loose factor (ton/yd^3)	1.46	1.39	1.24	1.23
	Rodded factor (ton/yd^3)	1.57	1.59	1.51	1.49
	Average factor (ton/yd^3)	1.51	1.49	1.37	1.36
	Moisture (%)	**0.0%**	**3.0%**	**6.0%**	**9.0%**
Fernley	Loose factor (ton/yd^3)	1.49	1.40	1.24	1.29
	Rodded factor (ton/yd^3)	1.63	1.61	1.47	1.56
	Average factor (ton/yd^3)	1.56	1.50	1.36	1.42
	Moisture (%)	**0.0%**	**3.0%**	**6.0%**	**9.0%**
Elko	Loose factor (ton/yd^3)	1.50	1.36	1.17	1.33
	Rodded factor (ton/yd^3)	1.60	1.55	1.40	1.46
	Average factor (ton/yd^3)	1.55	1.46	1.29	1.39

Table A2. Unit Weight Results: Deicing Sand

	Moisture (%)	0.0%	3.0%	6.0%	9.0%
Tonopah	Loose factor (ton/yd^3)	1.33	1.20	1.06	1.08
	Rodded factor (ton/yd^3)	1.43	1.36	1.22	1.20
	Average factor (ton/yd^3)	1.38	1.28	1.14	1.14
	Moisture (%)	**0.0%**	**3.0%**	**6.0%**	**9.0%**
Goldfield	Loose factor (ton/yd^3)	1.31	1.25	1.07	1.11
	Rodded factor (ton/yd^3)	1.41	1.42	1.27	1.26
	Average factor (ton/yd^3)	1.36	1.34	1.17	1.19
	Moisture (%)	**0.0%**	**3.0%**	**6.0%**	**9.0%**
Fallon	Loose factor (ton/yd^3)	1.29	1.18	1.08	1.16
	Rodded factor (ton/yd^3)	1.46	1.43	1.30	1.35
	Average factor (ton/yd^3)	1.38	1.31	1.19	1.25
	Moisture (%)	**0.0%**	**3.0%**	**6.0%**	**9.0%**
Hunewill	Loose factor (ton/yd^3)	1.43	1.21	1.19	1.21
	Rodded factor (ton/yd^3)	1.53	1.35	1.35	1.40
	Average factor (ton/yd^3)	1.48	1.28	1.27	1.31
	Moisture (%)	**0.0%**	**3.0%**	**6.0%**	**9.0%**
Elko	Loose factor (ton/yd^3)	1.35	1.11	1.12	1.15
	Rodded factor (ton/yd^3)	1.44	1.31	1.29	1.30
	Average factor (ton/yd^3)	1.40	1.21	1.20	1.22

Table A3. Unit Weight Results: 3/8” Chips

	Moisture (%)	**0.0%**	**1.0%**	**2.0%**	**3.0%**
Tonopah	Loose factor (ton/yd^3)	1.21	1.21	1.21	1.20
	Rodded factor (ton/yd^3)	1.33	1.35	1.35	1.30
	Average factor (ton/yd^3)	1.27	1.28	1.28	1.25
	Moisture (%)	**0.0%**	**1.0%**	**2.0%**	**3.0%**
Lund	Loose factor (ton/yd^3)	1.15	1.13	1.11	1.11
	Rodded factor (ton/yd^3)	1.26	1.26	1.24	1.25
	Average factor (ton/yd^3)	1.21	1.20	1.17	1.18

Table A4. Unit Weight Results: 1/2” Chips

	Moisture (%)	**0.0%**	**1.0%**	**2.0%**	**3.0%**
Fallon	Loose factor (ton/yd^3)	1.23	1.21	1.23	1.23
	Rodded factor (ton/yd^3)	1.37	1.35	1.36	1.37
	Average factor (ton/yd^3)	1.30	1.28	1.30	1.30
	Moisture (%)	**0.0%**	**1.0%**	**2.0%**	**3.0%**
Hunewill	Loose factor (ton/yd^3)	1.17	1.17	1.19	1.20
	Rodded factor (ton/yd^3)	1.29	1.32	1.33	1.33
	Average factor (ton/yd^3)	1.23	1.24	1.26	1.26
	Moisture (%)	**0.0%**	**1.0%**	**2.0%**	**3.0%**
Elko	Loose factor (ton/yd^3)	1.30	1.23	1.20	1.19
	Rodded factor (ton/yd^3)	1.40	1.34	1.30	1.26
	Average factor (ton/yd^3)	1.35	1.29	1.25	1.22

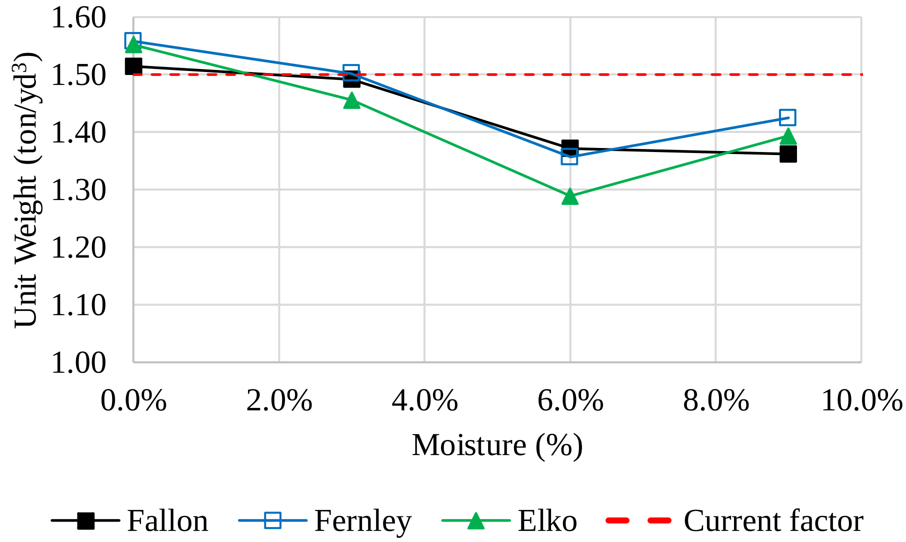


Figure A1. Unit Weight Results: Base

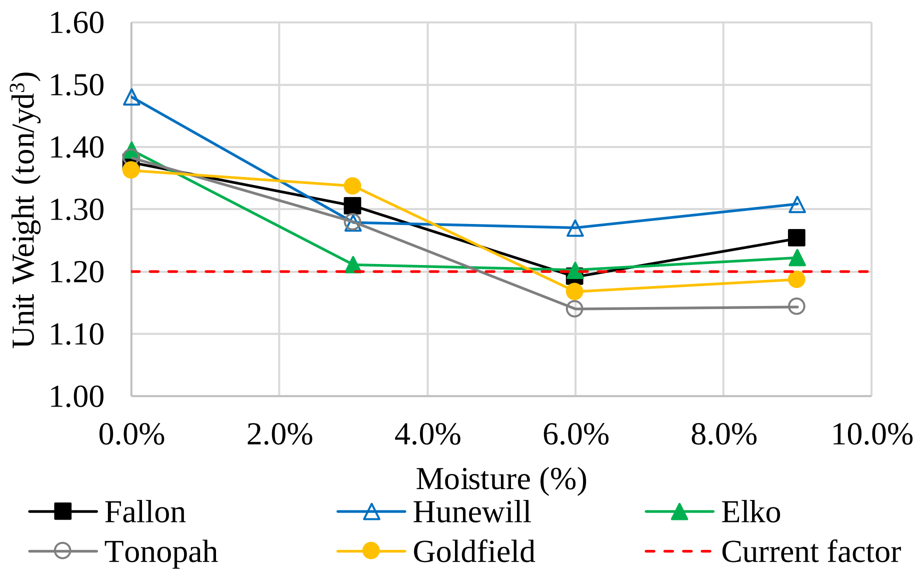


Figure A2. Unit Weight Results: Deicing Sand

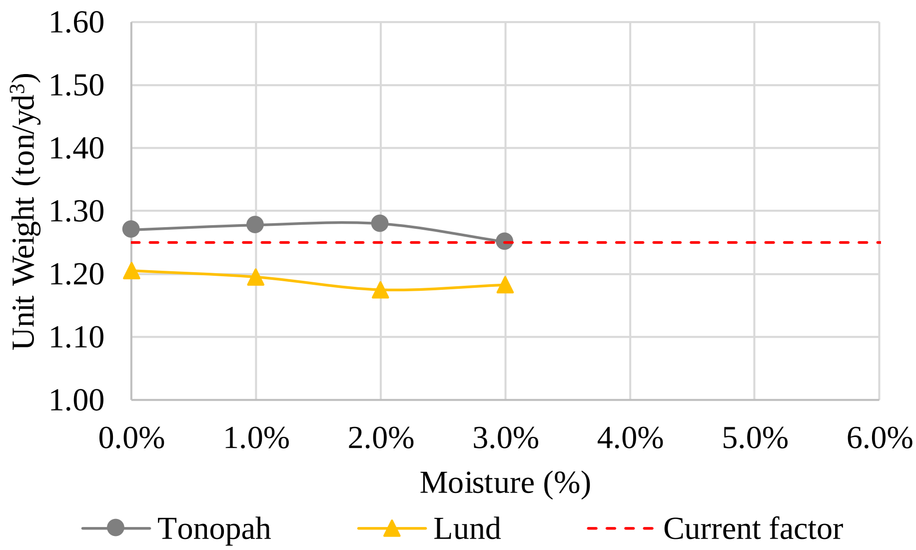


Figure A3. Unit Weight Results: 3/8” Chips

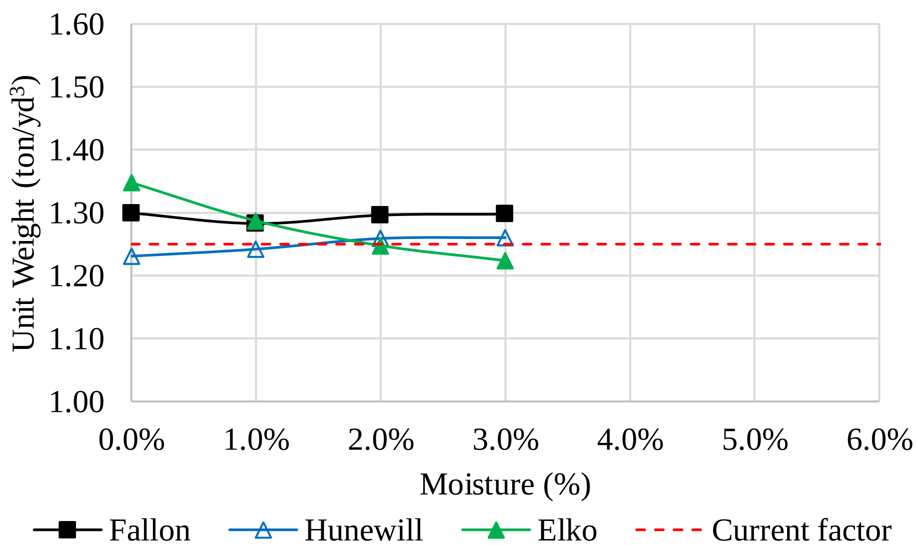


Figure A4. Unit Weight Results: 1/2” Chips

Table A5. Aggregate Tons per yd^3: Base

	Moisture (%)	**0.0%**	**3.0%**	**6.0%**	**9.0%**
Fallon	Loose factor (ton/yd^3)	1.46	1.35	1.17	1.13
	Rodded factor (ton/yd^3)	1.57	1.55	1.42	1.37
	Average factor (ton/yd^3)	1.51	1.45	1.29	1.25
	Moisture (%)	**0.0%**	**3.0%**	**6.0%**	**9.0%**
Fernley	Loose factor (ton/yd^3)	1.49	1.36	1.17	1.18
	Rodded factor (ton/yd^3)	1.63	1.56	1.39	1.43
	Average factor (ton/yd^3)	1.56	1.46	1.28	1.31
	Moisture (%)	**0.0%**	**3.0%**	**6.0%**	**9.0%**
Elko	Loose factor (ton/yd^3)	1.50	1.32	1.11	1.22
	Rodded factor (ton/yd^3)	1.60	1.50	1.32	1.34
	Average factor (ton/yd^3)	1.55	1.41	1.22	1.28

Table A6. Aggregate Tons per yd^3: Deicing Sand

	Moisture (%)	0.0%	3.0%	6.0%	9.0%
Tonopah	Loose factor (ton/yd^3)	1.33	1.16	1.00	0.99
	Rodded factor (ton/yd^3)	1.43	1.32	1.15	1.10
	Average factor (ton/yd^3)	1.38	1.24	1.08	1.05
	Moisture (%)	**0.0%**	**3.0%**	**6.0%**	**9.0%**
Goldfield	Loose factor (ton/yd^3)	1.31	1.21	1.01	1.02
	Rodded factor (ton/yd^3)	1.41	1.38	1.20	1.16
	Average factor (ton/yd^3)	1.36	1.30	1.10	1.09
	Moisture (%)	**0.0%**	**3.0%**	**6.0%**	**9.0%**
Fallon	Loose factor (ton/yd^3)	1.29	1.15	1.02	1.06
	Rodded factor (ton/yd^3)	1.46	1.39	1.22	1.24
	Average factor (ton/yd^3)	1.38	1.27	1.12	1.15
	Moisture (%)	**0.0%**	**3.0%**	**6.0%**	**9.0%**
Hunewill	Loose factor (ton/yd^3)	1.43	1.17	1.12	1.11
	Rodded factor (ton/yd^3)	1.53	1.31	1.28	1.29
	Average factor (ton/yd^3)	1.48	1.24	1.20	1.20
	Moisture (%)	**0.0%**	**3.0%**	**6.0%**	**9.0%**
Elko	Loose factor (ton/yd^3)	1.35	1.08	1.03	1.05
	Rodded factor (ton/yd^3)	1.44	1.27	1.21	1.19
	Average factor (ton/yd^3)	1.40	1.18	1.13	1.12

Table A7. Aggregate Tons per yd^3: 3/8” Chips

	Moisture (%)	0.0%	1.0%	2.0%	3.0%
Tonopah	Loose factor (ton/yd^3)	1.21	1.19	1.19	1.17
	Rodded factor (ton/yd^3)	1.33	1.34	1.32	1.26
	Average factor (ton/yd^3)	1.27	1.27	1.25	1.21
	Moisture (%)	**0.0%**	**1.0%**	**2.0%**	**3.0%**
Lund	Loose factor (ton/yd^3)	1.15	1.12	1.09	1.08
	Rodded factor (ton/yd^3)	1.26	1.25	1.22	1.22
	Average factor (ton/yd^3)	1.21	1.18	1.15	1.15

Table A8. Aggregate Tons per yd^3: 1/2” Chips

	Moisture (%)	0.0%	1.0%	2.0%	3.0%
Fallon	Loose factor (ton/yd^3)	1.23	1.20	1.21	1.19
	Rodded factor (ton/yd^3)	1.37	1.34	1.34	1.33
	Average factor (ton/yd^3)	1.30	1.27	1.27	1.26
	Moisture (%)	**0.0%**	**1.0%**	**2.0%**	**3.0%**
Hunewill	Loose factor (ton/yd^3)	1.17	1.16	1.17	1.16
	Rodded factor (ton/yd^3)	1.29	1.30	1.30	1.29
	Average factor (ton/yd^3)	1.23	1.23	1.23	1.22
	Moisture (%)	**0.0%**	**1.0%**	**2.0%**	**3.0%**
Elko	Loose factor (ton/yd^3)	1.30	1.22	1.17	1.15
	Rodded factor (ton/yd^3)	1.40	1.33	1.27	1.23
	Average factor (ton/yd^3)	1.35	1.27	1.22	1.19

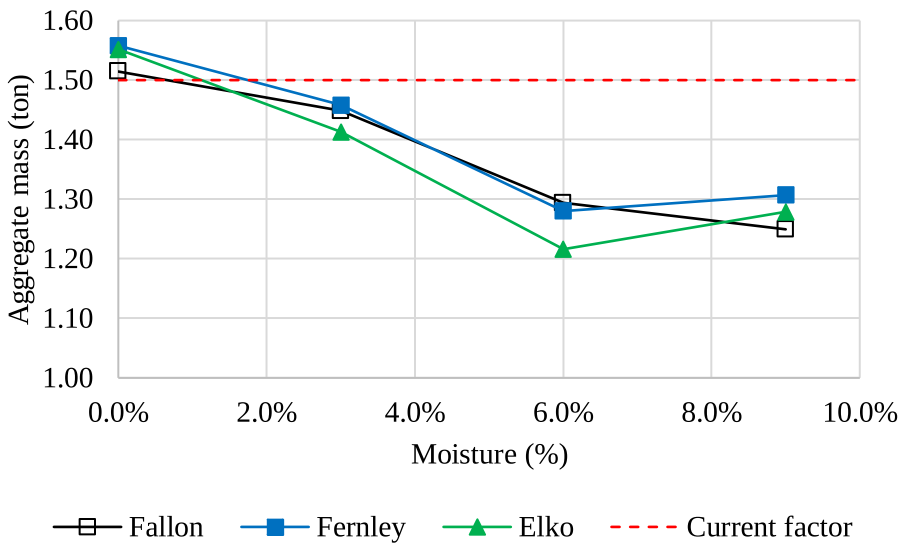


Figure A5. Aggregate Tons per yd^3: Base

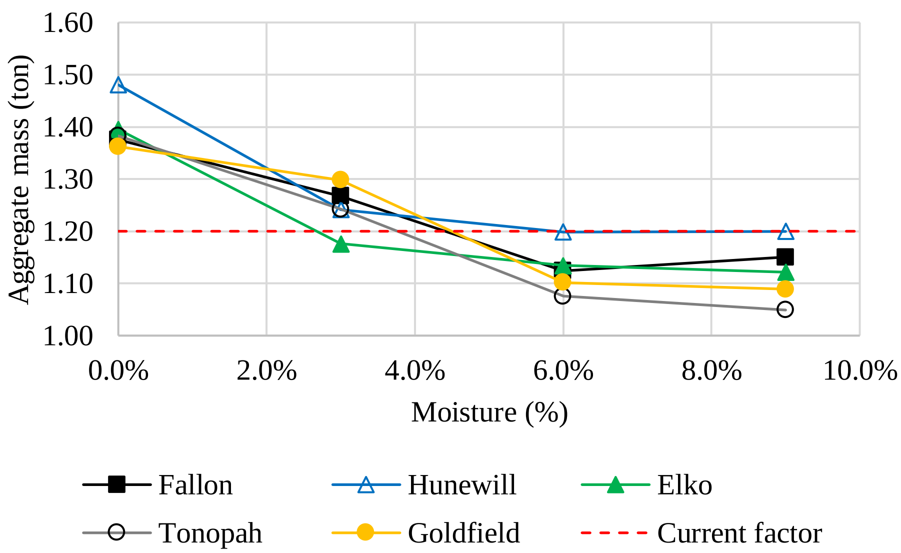


Figure A6. Aggregate Tons per yd^3: Deicing Sand

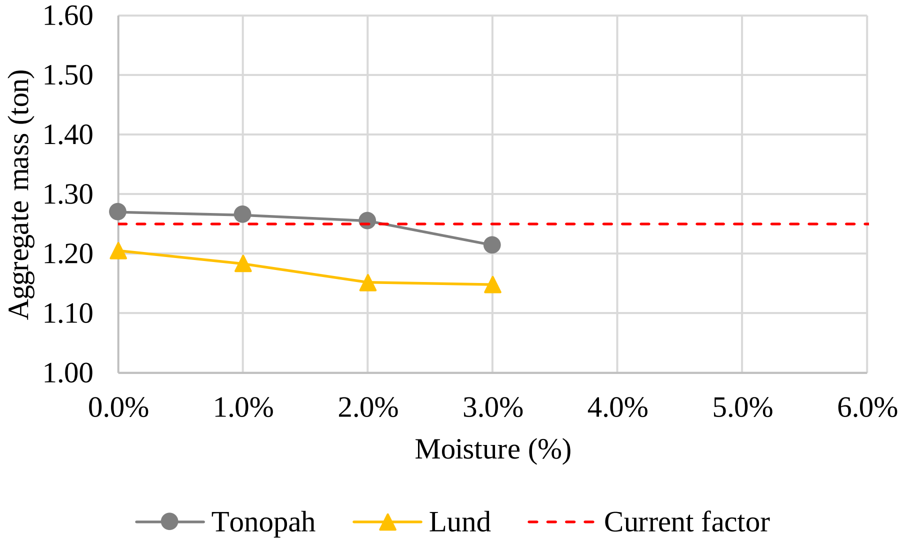


Figure A7. Aggregate Tons per yd^3: 3/8” Chips

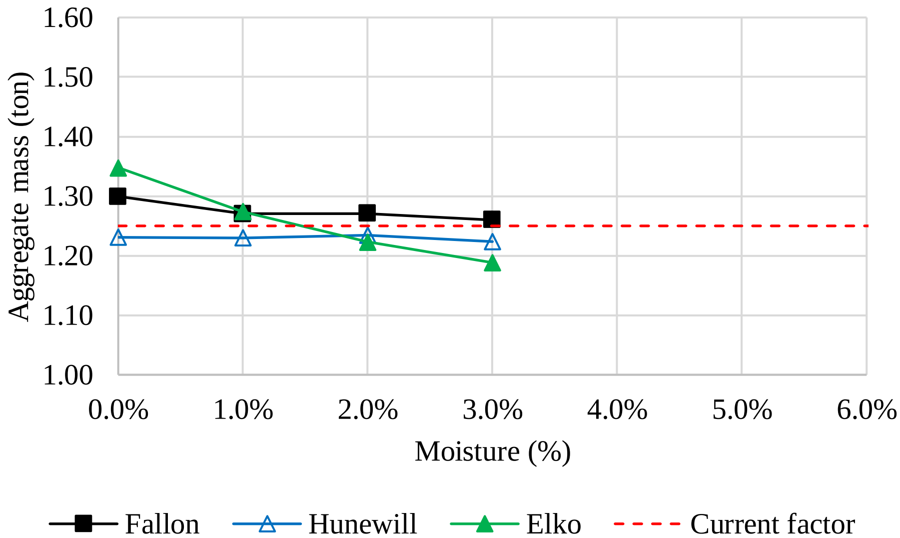


Figure A8. Aggregate Tons per yd^3: 1/2” Chips

Table A9. Unit Weight Difference Against Parametric Value: Base

Fallon	**Moisture (%)**	**0.0%**	**3.0%**	**6.0%**	**9.0%**
	Loose factor difference (%)	2.8%	7.2%	17.7%	17.8%
	Rodded factor difference (%)	-4.7%	-6.1%	-0.5%	0.6%
	Average factor difference (%)	-1.0%	0.5%	8.6%	9.2%
Fernley	**Moisture (%)**	**0.0%**	**3.0%**	**6.0%**	**9.0%**
	Loose factor difference (%)	0.8%	6.8%	17.1%	14.1%
	Rodded factor difference (%)	-8.6%	-7.0%	1.9%	-4.1%
	Average factor difference (%)	-3.9%	-0.1%	9.5%	5.0%
Elko	**Moisture (%)**	**0.0%**	**3.0%**	**6.0%**	**9.0%**
	Loose factor difference (%)	0.0%	9.1%	21.7%	11.6%
	Rodded factor difference (%)	-6.9%	-3.2%	6.4%	2.6%
	Average factor difference (%)	-3.5%	3.0%	14.1%	7.1%

Table A10. Unit Weight Difference Against Parametric Value: Deicing Sand

Tonopah	**Moisture (%)**	**0.0%**	**3.0%**	**6.0%**	**9.0%**
	Loose factor difference (%)	-11.0%	0.3%	11.4%	9.7%
	Rodded factor difference (%)	-19.4%	-13.5%	-1.4%	-0.2%
	Average factor difference (%)	-15.2%	-6.6%	5.0%	4.7%
Goldfield	**Moisture (%)**	**0.0%**	**3.0%**	**6.0%**	**9.0%**
	Loose factor difference (%)	-9.2%	-4.2%	11.1%	7.3%
	Rodded factor difference (%)	-17.8%	-18.6%	-5.7%	-5.1%
	Average factor difference (%)	-13.5%	-11.4%	2.7%	1.1%
Fallon	**Moisture (%)**	**0.0%**	**3.0%**	**6.0%**	**9.0%**
	Loose factor difference (%)	-7.8%	1.5%	9.6%	3.4%
	Rodded factor difference (%)	-21.4%	-19.1%	-8.2%	-12.3%
	Average factor difference (%)	-14.6%	-8.8%	0.7%	-4.5%
Hunewill	**Moisture (%)**	**0.0%**	**3.0%**	**6.0%**	**9.0%**
	Loose factor difference (%)	-19.4%	-0.5%	1.0%	-1.1%
	Rodded factor difference (%)	-27.3%	-12.6%	-12.7%	-16.9%
	Average factor difference (%)	-23.4%	-6.5%	-5.9%	-9.0%
Elko	**Moisture (%)**	**0.0%**	**3.0%**	**6.0%**	**9.0%**
	Loose factor difference (%)	-12.6%	7.1%	6.7%	4.3%
	Rodded factor difference (%)	-19.9%	-9.0%	-7.1%	-8.0%
	Average factor difference (%)	-16.3%	-0.9%	-0.2%	-1.9%

Table A11. Unit Weight Difference Against Parametric Value: 3/8” Chips

	Moisture (%)	**0.0%**	**1.0%**	**2.0%**	**3.0%**
Tonopah	Loose factor difference (%)	3.6%	3.5%	3.2%	3.8%
	Rodded factor difference (%)	-6.8%	-7.9%	-7.9%	-3.9%
	Average factor difference (%)	-1.6%	-2.2%	-2.4%	-0.1%
	Moisture (%)	**0.0%**	**1.0%**	**2.0%**	**3.0%**
Lund	Loose factor difference (%)	7.9%	9.6%	11.4%	11.1%
	Rodded factor difference (%)	-0.7%	-0.8%	0.6%	-0.3%
	Average factor difference (%)	3.6%	4.4%	6.0%	5.4%

Table A12. Unit Weight Difference Against Parametric Value: 1/2” Chips

	Moisture (%)	**0.0%**	**1.0%**	**2.0%**	**3.0%**
Fallon	Loose factor difference (%)	1.9%	2.8%	1.7%	2.0%
	Rodded factor difference (%)	-9.8%	-8.1%	-9.0%	-9.6%
	Average factor difference (%)	-4.0%	-2.6%	-3.7%	-3.8%
	Moisture (%)	**0.0%**	**1.0%**	**2.0%**	**3.0%**
Hunewill	Loose factor difference (%)	6.3%	6.6%	4.7%	4.4%
	Rodded factor difference (%)	-3.3%	-5.4%	-6.1%	-6.0%
	Average factor difference (%)	1.5%	0.6%	-0.7%	-0.8%
	Moisture (%)	**0.0%**	**1.0%**	**2.0%**	**3.0%**
Elko	Loose factor difference (%)	-4.1%	1.2%	4.2%	5.1%
	Rodded factor difference (%)	-11.6%	-7.2%	-3.9%	-0.9%
	Average factor difference (%)	-7.8%	-3.0%	0.2%	2.1%

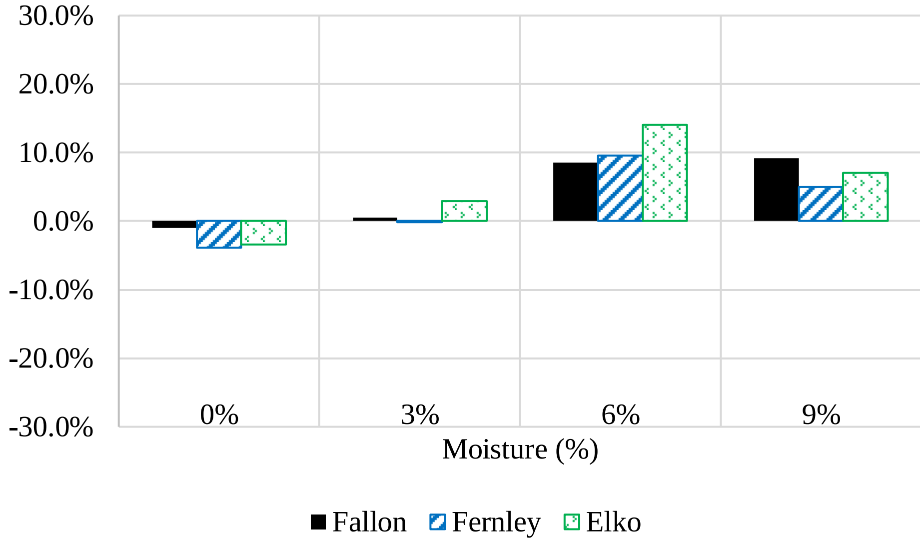


Figure A9. Unit Weight Difference Against Parametric Value: Base

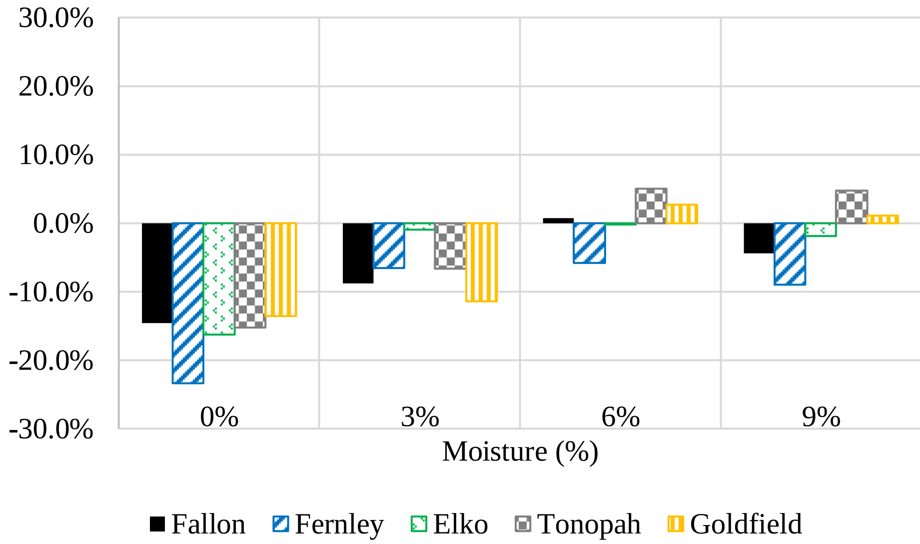


Figure A10. Unit Weight Difference Against Parametric Value: Deicing Sand

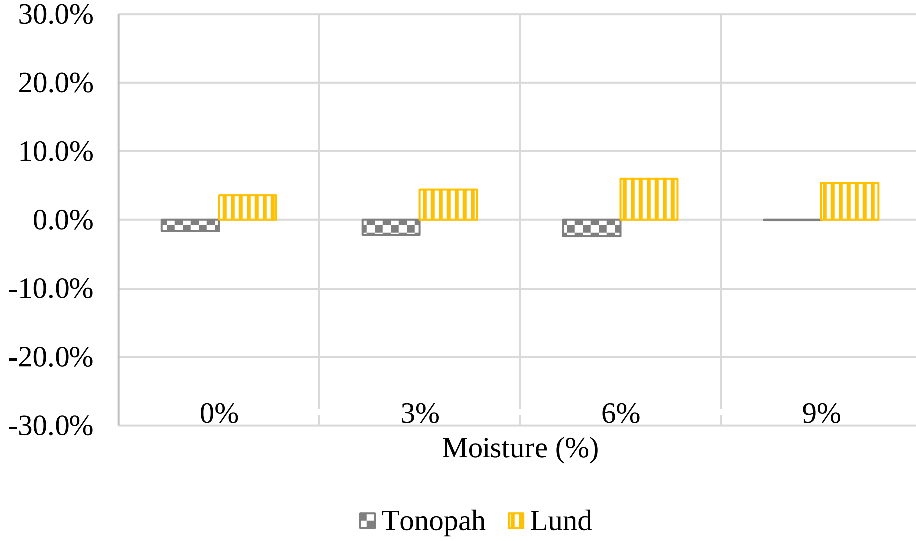


Figure A11. Unit Weight Difference Against Parametric Value: 3/8” Chips

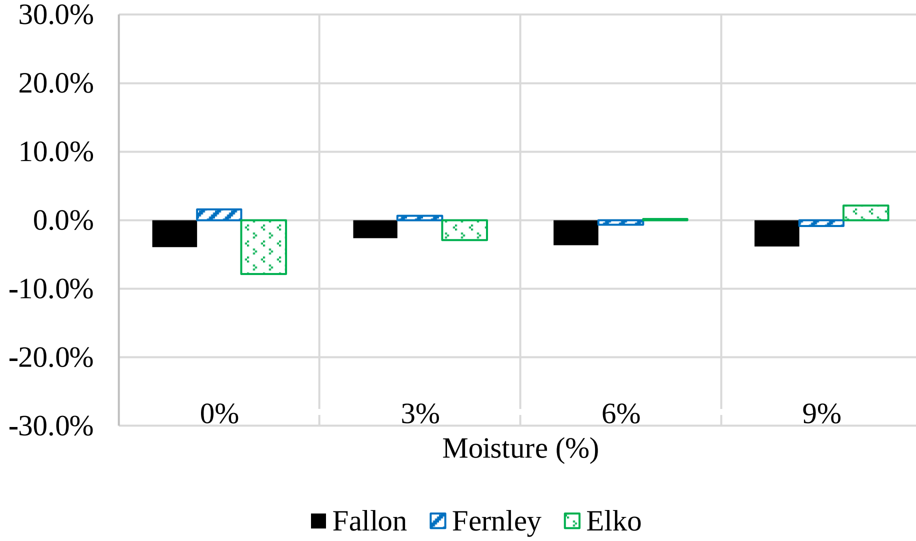


Figure A12. Unit Weight Difference Against Parametric Value: 1/2” Chips

Table A13. Aggregate Tons Difference Against Parametric Value: Base

Fallon	**Moisture (%)**	**0.0%**	**3.0%**	**6.0%**	**9.0%**
	Loose factor difference (%)	2.8%	9.9%	22.3%	24.6%
	Rodded factor difference (%)	-4.7%	-3.0%	5.2%	8.8%
	Average factor difference (%)	-1.0%	3.4%	13.7%	16.7%
Fernley	**Moisture (%)**	**0.0%**	**3.0%**	**6.0%**	**9.0%**
	Loose factor difference (%)	0.8%	9.5%	21.8%	21.2%
	Rodded factor difference (%)	-8.6%	-3.9%	7.5%	4.5%
	Average factor difference (%)	-3.9%	2.8%	14.7%	12.9%
Elko	**Moisture (%)**	0.0%	3.0%	6.0%	9.0%
	Loose factor difference (%)	0.0%	11.7%	26.1%	18.9%
	Rodded factor difference (%)	-6.9%	-0.2%	11.7%	10.7%
	Average factor difference (%)	-3.5%	5.8%	18.9%	14.8%

Table A14. Aggregate Tons Difference Against Parametric Value: Deicing Sand

	Moisture (%)	**0.0%**	**3.0%**	**6.0%**	**9.0%**
Tonopah	Loose factor difference (%)	-11.0%	3.2%	16.4%	17.1%
	Rodded factor difference (%)	-19.4%	-10.2%	4.3%	8.0%
	Average factor difference (%)	-15.2%	-3.5%	10.4%	12.6%
	Moisture (%)	**0.0%**	**3.0%**	**6.0%**	**9.0%**
Goldfield	Loose factor difference (%)	-9.2%	-1.1%	16.1%	14.9%
	Rodded factor difference (%)	-17.8%	-15.2%	0.3%	3.6%
	Average factor difference (%)	-13.5%	-8.2%	8.2%	9.2%
	Moisture (%)	**0.0%**	**3.0%**	**6.0%**	**9.0%**
Fallon	Loose factor difference (%)	-7.8%	4.4%	14.7%	11.3%
	Rodded factor difference (%)	-21.4%	-15.6%	-2.1%	-3.0%
	Average factor difference (%)	-14.6%	-5.6%	6.3%	4.2%
	Moisture (%)	**0.0%**	**3.0%**	**6.0%**	**9.0%**
Hunewill	Loose factor difference (%)	-19.4%	2.5%	6.6%	7.2%
	Rodded factor difference (%)	-27.3%	-9.4%	-6.3%	-7.3%
	Average factor difference (%)	-23.4%	-3.4%	0.1%	0.0%
	Moisture (%)	**0.0%**	**3.0%**	**6.0%**	**9.0%**
Elko	Loose factor difference (%)	-12.6%	9.8%	14.4%	12.2%
	Rodded factor difference (%)	-19.9%	-5.8%	-1.1%	0.9%
	Average factor difference (%)	-16.3%	2.0%	5.5%	6.5%

Table A15. Aggregate Tons Difference Against Parametric Value: 3/8” Chips

Tonopah	**Moisture (%)**	**0.0%**	**1.0%**	**2.0%**	**3.0%**
	Loose factor difference (%)	3.6%	4.5%	5.1%	6.6%
	Rodded factor difference (%)	-6.8%	-6.9%	-5.8%	-0.9%
	Average factor difference (%)	-1.6%	-1.2%	-0.4%	2.8%
Lund	**Moisture (%)**	**0.0%**	**1.0%**	**2.0%**	**3.0%**
	Loose factor difference (%)	7.9%	10.5%	13.2%	13.7%
	Rodded factor difference (%)	-0.7%	0.2%	2.5%	2.6%
	Average factor difference (%)	3.6%	5.3%	7.8%	8.1%

Table A16. Aggregate Tons Difference Against Parametric Value: 1/2” Chips

Fallon	**Moisture (%)**	**0.0%**	**1.0%**	**2.0%**	**3.0%**
	Loose factor difference (%)	1.9%	3.8%	3.6%	4.8%
	Rodded factor difference (%)	-9.8%	-7.0%	-6.9%	-6.4%
	Average factor difference (%)	-4.0%	-1.6%	-1.7%	-0.8%
Hunewill	**Moisture (%)**	**0.0%**	**1.0%**	**2.0%**	**3.0%**
	Loose factor difference (%)	6.3%	7.6%	6.6%	7.2%
	Rodded factor difference (%)	-3.3%	-4.3%	-4.0%	-2.9%
	Average factor difference (%)	1.5%	1.6%	1.3%	2.1%
Elko	**Moisture (%)**	**0.0%**	**1.0%**	**2.0%**	**3.0%**
	Loose factor difference (%)	-4.1%	2.2%	6.1%	7.9%
	Rodded factor difference (%)	-11.6%	-6.1%	-1.8%	2.0%
	Average factor difference (%)	-7.8%	-1.9%	2.1%	4.9%

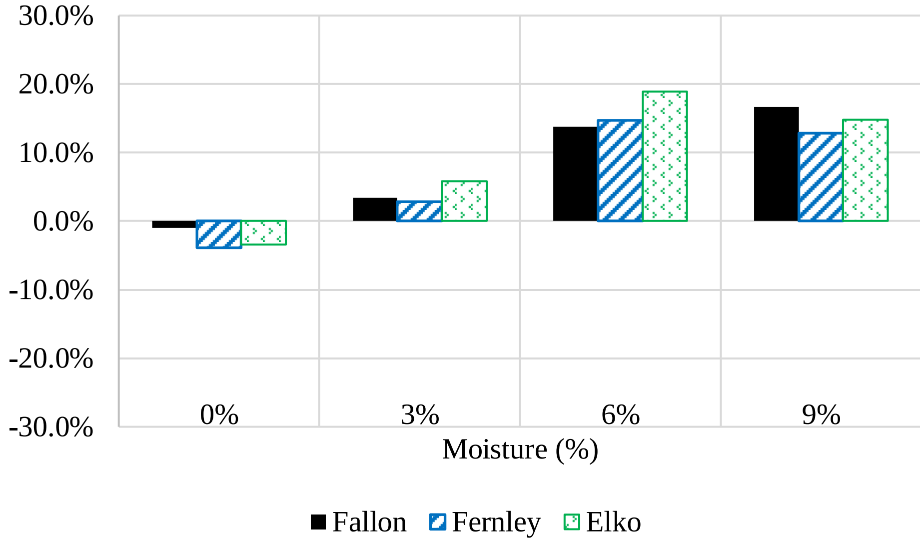


Figure A13. Aggregate Tons Difference Against Parametric Value: Base

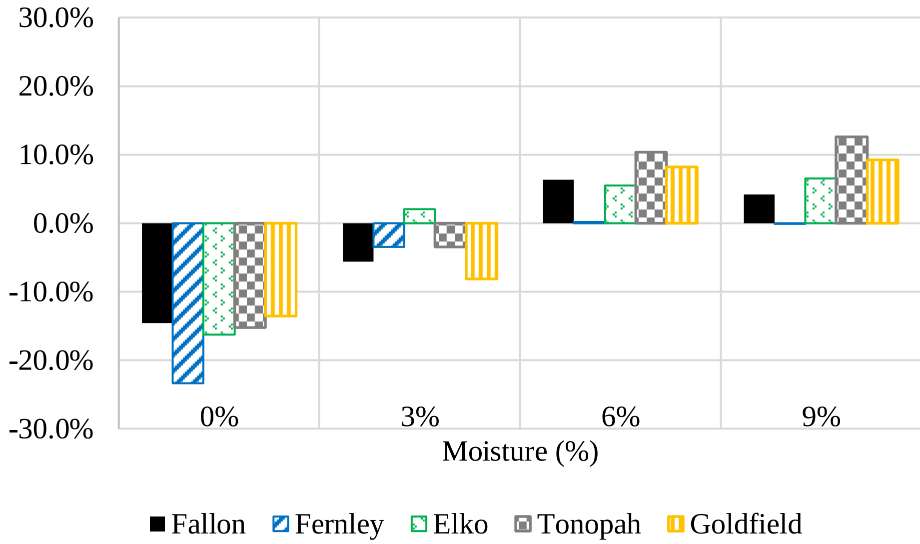


Figure A14. Aggregate Tons Difference Against Parametric Value: Deicing Sand

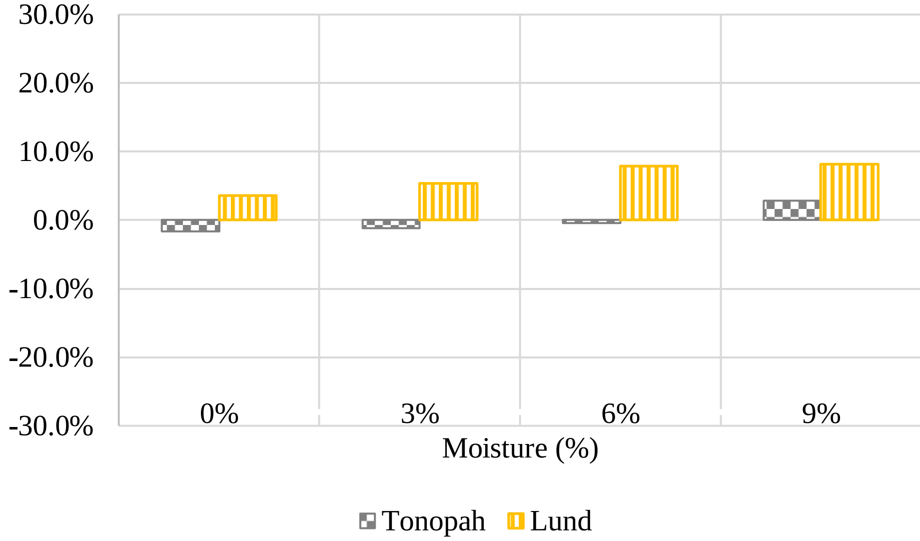


Figure A15. Aggregate Tons Difference Against Parametric Value: 3/8” Chips

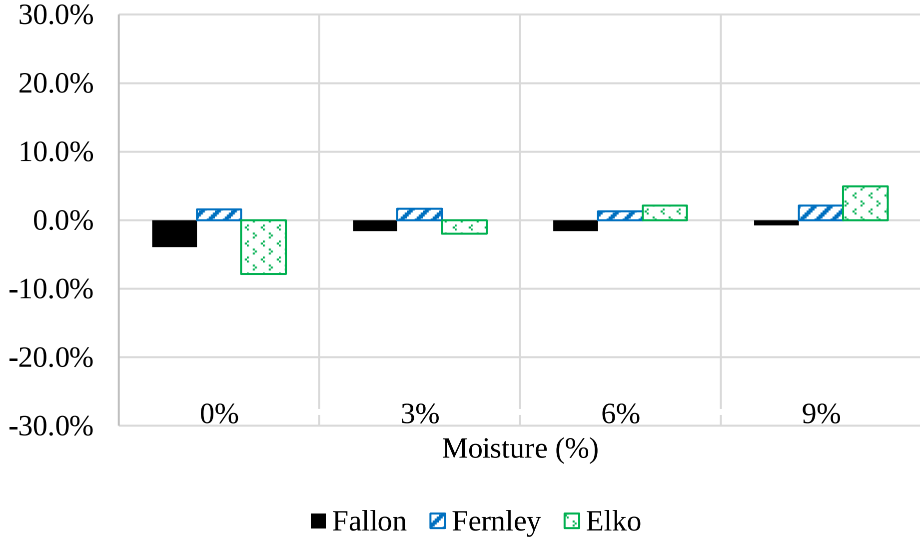


Figure A16. Aggregate Tons Difference Against Parametric Value: 1/2” Chips

Appendix B

Table B1. Gradation Results: Base

	Sieve size	Passing (%)	1S (%)	D2S (%)
Fallon	1" (25.0 mm)	100%	0.00%	0.00%
	3/4" (19.0 mm)	98%	0.28%	0.40%
	No. 4 (4.75 mm)	51%	0.79%	1.11%
	No.16 (1.18 mm)	31%	0.47%	0.66%
	No. 200 (0.075 mm)	5.3%	0.25%	0.35%
	Sieve size	**Passing (%)**	**1S (%)**	**D2S (%)**
Fernley	1" (25.0 mm)	100%	0.00%	0.00%
	3/4" (19.0 mm)	97%	0.35%	0.50%
	No. 4 (4.75 mm)	46%	0.64%	0.90%
	No.16 (1.18 mm)	25%	0.86%	1.21%
	No. 200 (0.075 mm)	2.8%	0.21%	0.30%
	Sieve size	**Passing (%)**	**1S (%)**	**D2S (%)**
Elko	1" (25.0 mm)	100%	0.00%	0.00%
	3/4" (19.0 mm)	97%	0.06%	0.09%
	No. 4 (4.75 mm)	64%	0.35%	0.50%
	No.16 (1.18 mm)	35%	0.61%	0.87%
	No. 200 (0.075 mm)	4.1%	0.28%	0.40%

Table B2. Gradation Results: Deicing Sand

	Sieve size	Passing (%)	1S (%)	D2S (%)
	1/2" (12.5 mm)	100%	0.00%	0.00%
Tonopah	No. 4 (4.75 mm)	91%	0.25%	0.35%
	No.16 (1.18 mm)	54%	0.72%	1.01%
	No. 200 (0.075 mm)	3.5%	0.01%	0.01%
	Sieve size	**Passing (%)**	**1S (%)**	**D2S (%)**
	1/2" (12.5 mm)	100%	0.00%	0.00%
Goldfield	No. 4 (4.75 mm)	93%	0.29%	0.42%
	No.16 (1.18 mm)	49%	0.02%	0.02%
	No. 200 (0.075 mm)	2.6%	0.13%	0.19%
	Sieve size	**Passing (%)**	**1S (%)**	**D2S (%)**
	1/2" (12.5 mm)	100%	0.00%	0.00%
Fallon	No. 4 (4.75 mm)	91%	0.37%	0.53%
	No.16 (1.18 mm)	40%	0.78%	1.10%
	No. 200 (0.075 mm)	0.8%	0.14%	0.20%
	Sieve size	**Passing (%)**	**1S (%)**	**D2S (%)**
	1/2" (12.5 mm)	100%	0.00%	0.00%
Hunewill	No. 4 (4.75 mm)	95%	0.28%	0.40%
	No.16 (1.18 mm)	54%	1.13%	1.59%
	No. 200 (0.075 mm)	0.8%	0.15%	0.21%
	Sieve size	**Passing (%)**	**1S (%)**	**D2S (%)**
	1/2" (12.5 mm)	100%	0.00%	0.00%
Elko	No. 4 (4.75 mm)	99%	0.10%	0.14%
	No.16 (1.18 mm)	49%	2.65%	3.75%
	No. 200 (0.075 mm)	0.9%	0.02%	0.03%

Table B3. Gradation Results: 3/8” Chips

	Sieve size	**Passing (%)**	**1S (%)**	**D2S (%)**
Tonopah	1/2" (12.5 mm)	100%	0.00%	0.00%
	No. 3/8" (9.50 mm)	100%	0.00%	0.00%
	No. 4 (4.75 mm)	41%	0.49%	0.70%
	No. 8 (2.36 mm)	1%	0.13%	0.18%
	No. 200 (0.075 mm)	0.4%	0.01%	0.01%
	Sieve size	**Passing (%)**	**1S (%)**	**D2S (%)**
Lund	1/2" (12.5 mm)	100%	0.00%	0.00%
	No. 3/8" (9.50 mm)	100%	0.00%	0.00%
	No. 4 (4.75 mm)	50%	0.13%	0.18%
	No. 8 (2.36 mm)	5%	0.47%	0.66%
	No. 200 (0.075 mm)	0.5%	0.08%	0.12%

Table B4. Gradation Results: 1/2" Chips

	Sieve size	**Passing (%)**	**1S (%)**	**D2S (%)**
Fallon	1/2" (12.5 mm)	100%	0.00%	0.00%
	No. 3/8" (9.50 mm)	72%	0.18%	0.25%
	No. 4 (4.75 mm)	10%	0.53%	0.75%
	No. 8 (2.36 mm)	0%	0.08%	0.12%
	No. 200 (0.075 mm)	0.0%	0.00%	0.00%
	Sieve size	**Passing (%)**	**1S (%)**	**D2S (%)**
Hunewill	1/2" (12.5 mm)	100%	0.00%	0.00%
	No. 3/8" (9.50 mm)	56%	0.93%	1.32%
	No. 4 (4.75 mm)	3%	0.49%	0.70%
	No. 8 (2.36 mm)	1%	0.12%	0.17%
	No. 200 (0.075 mm)	0.1%	0.00%	0.00%
	Sieve size	**Passing (%)**	**1S (%)**	**D2S (%)**
Elko	1/2" (12.5 mm)	100%	0.00%	0.00%
	No. 3/8" (9.50 mm)	73%	0.30%	0.42%
	No. 4 (4.75 mm)	8%	0.00%	0.00%
	No. 8 (2.36 mm)	4%	0.02%	0.03%
	No. 200 (0.075 mm)	0.3%	0.05%	0.07%

Appendix C

Table C1. Coarse Specific Gravity Results: Base

	SG (bulk)	SG (SSD)	SG (apparent)	Absorption (%)
Fallon	2.473	2.585	2.785	4.5%
Fernley	2.416	2.473	2.561	2.3%
Elko	2.491	2.546	2.634	2.2%

Table C2. Fine Specific Gravity Results: Base

	SG (bulk)	SG (SSD)	SG (apparent)	Absorption (%)
Fallon	2.437	2.535	2.704	4.1%
Fernley	2.464	2.555	2.710	3.7%
Elko	2.284	2.411	2.617	5.6%

Table C3. Combined Specific Gravity Results: Base

	SG (bulk)	SG (SSD)	SG (apparent)	Absorption (%)
Fallon	2.473	2.437	2.455	4.3%
Fernley	2.416	2.464	2.438	2.8%
Elko	2.491	2.284	2.354	3.6%

Table C4. Coarse Specific Gravity Results: Deicing Sand

	SG (bulk)	**SG (SSD)**	**SG (apparent)**	**Absorption (%)**
Tonopah	2.704	2.734	2.788	1.1%
Goldfield	2.321	2.442	2.642	5.2%
Fallon	2.548	2.617	2.738	2.7%
Hunewill	2.448	2.498	2.578	2.1%
Elko	2.493	2.546	2.632	2.1%

Table C5. Fine Specific Gravity Results: Deicing Sand

	SG (bulk)	**SG (SSD)**	**SG (apparent)**	**Absorption (%)**
Tonopah	2.356	2.432	2.55	3.2%
Goldfield	2.368	2.456	2.596	3.7%
Fallon	2.497	2.581	2.727	3.4%
Hunewill	2.512	2.548	2.607	1.5%
Elko	2.497	2.539	2.608	1.7%

Table C6. Combined Specific Gravity Results: Deicing Sand

	SG (bulk)	**SG (SSD)**	**SG (apparent)**	**Absorption (%)**
Tonopah	2.704	2.432	2.454	2.7%
Goldfield	2.321	2.456	2.446	3.8%
Fallon	2.548	2.581	2.578	3.3%
Hunewill	2.448	2.548	2.543	1.5%
Elko	2.493	2.539	2.538	1.7%

Table C7. Coarse Specific Gravity Results: 3/8” Chips

	SG (bulk)	**SG (SSD)**	**SG (apparent)**	**Absorption (%)**
Tonopah	2.231	2.352	2.537	5.4%
Lund	2.363	2.442	2.565	3.3%

Table C8. Fine Specific Gravity Results: 3/8” Chips

	SG (bulk)	**SG (SSD)**	**SG (apparent)**	**Absorption (%)**
Tonopah	2.381	2.451	2.56	2.9%
Lund	2.384	2.523	2.768	5.8%

Table C9. Combined Specific Gravity Results: 3/8” Chips

	SG (bulk)	**SG (SSD)**	**SG (apparent)**	**Absorption (%)**
Tonopah	2.363	2.384	2.374	4.2%
Lund	2.231	2.381	2.29	4.0%

Table C10. Coarse Specific Gravity Results: 1/2” Chips

	SG (bulk)	**SG (SSD)**	**SG (apparent)**	**Absorption (%)**
Fallon	2.619	2.677	2.781	2.2%
Hunewill	2.568	2.608	2.675	1.6%
Elko	2.530	2.570	2.635	1.6%

Table C11. Fine Specific Gravity Results: 1/2” Chips

	SG (bulk)	**SG (SSD)**	**SG (apparent)**	**Absorption (%)**
Fallon	2.399	2.526	2.748	5.3%
Hunewill	2.349	2.479	2.700	5.5%
Elko	2.439	2.506	2.615	2.8%

Table C12. Combined Specific Gravity Results: 1/2” Chips

	SG (bulk)	**SG (SSD)**	**SG (apparent)**	**Absorption (%)**
Fallon	2.619	2.526	2.610	2.3%
Hunewill	2.568	2.479	2.565	1.6%
Elko	2.530	2.439	2.522	1.7%

Appendix D

Stockpile Measurement Procedure

Purpose

This procedure describes the process for measuring aggregate stockpiles and managing the generated data.

Scope

The scope of this procedure is divided into 4 basic processes: Material Purchase, Initial Stockpile Measurement, Periodic Stockpile Measurement, and Inventory Records Update.

Definitions

District Maintenance Office	Decentralized administration strategically located statewide that is responsible for the Department-maintained highway system by developing work plans, policies, program objectives, budget, and available resources. District offices: Las Vegas (District I), Reno (District II), and Elko (District III).
Maintenance and Asset Management Division	Part of the Operations Section of the Nevada Department of Transportation (NDOT). It operates in support of the district objectives and is responsible for coordinating the delivery of the district programs within the statewide philosophy and policy guidelines.
Maintenance Crew	Personnel assigned by the District Maintenance Office to inspect and quantify the stockpile inventory. Facility

locations include District Offices, Subdistricts in Winnemucca, Tonopah, and Ely as well as numerous Maintenance stations strategically distributed statewide. It may consist of one or multiple personnel from the following positions:

- Maintenance Manager.
- Assistant District Engineers.
- Supervisor I, II.
- Highway Maintenance Worker I, II, III, IV.

For this procedure, the members of a maintenance crew will be called maintainers.

Purchasing Authority Capacity granted to entities responsible for obtaining materials, supplies, and equipment at the most reasonable cost to the taxpayers. Under these policies, purchasing authority is in the following order:

- State Purchasing Division.
- Equipment Division.
- District Staff.

In terms of stockpile material purchase alone, the purchasing authority has been typically delegated to the Maintenance Staff (Supervisor I, II).

EAMS Enterprise Asset Management System. Software used by NDOT to manage its portfolio of roads, bridges, stormwater facilities, and other transportation assets.

Stockpile Reports Software based on augmented reality to measure a stockpile volume utilizing imagery techniques from either cell phone, tablet, or drone technology.

Procedure

1. Material Purchase/Usage

Stockpiles are constantly changing due to the addition and subtraction of material. The two activities that modify the existing stockpile volume/mass are material purchase and material usage.

1.1. Material purchase is conducted as follows:

1.1.1. Purchasing of equipment, materials, and services for use by NDOT is conducted in accordance with the State Purchasing Act and Transportation Policy (TP) 1-3-2.

1.1.2. Before the material is requested, the purchase method must be defined according to the following types:

- Requisitions to the State Purchasing Division.
- Open-term contract awarded through the State Purchasing Division.
- Agency or local purchases as approved by the State Purchasing Division.
- Transfers from one agency to another upon approval of the Purchasing Administrator

1.1.3. Once the corresponding purchasing authority requests the material, a *Purchase Order* is generated.

1.1.4. Based on the requested quantity, EAMS inventory database is updated. Refer to *Operations Management (Web)* ™ *User Manual* for more information.

1.1.5. The EAMS database inventory record requires basic information to be input:

- Material ID.
- Transaction Type.
- Administrative Unit.
- Location.
- Material Class Code.
- Quantity.
- Cost.

1.2. Material usage is conducted as follows:

1.2.1. The Maintenance and Asset Management Division estimates a defined amount of material to be used for maintenance purposes.

1.2.2. A *Work Order* is then generated, and EAMS inventory database is updated. *Work Orders* are eight-digit numbers, starting with "2". The second digit identifies the responsible division. The remaining six digits are a unique identifier for the work order.

1.2.3. An assigned *Work Order* number is used for identifying and coding labor, equipment, and material used in the maintenance activities. Therefore, a single stockpile can be associated with different work orders that will change the initial quantity.

1.3. After a P*urchase Order* or a *Work Order* is generated and accepted, the EAMs database will be automatically updated to reflect the addition or subtraction of material.

2. Stockpile Measurement

The constant stockpile inventory update through p*urchase orders* and *work orders* requires periodic monitoring of the true in-situ inventory.

2.1. Each district will assign different maintenance crews to visit each stockpile location and verify compliance between the inventory records and the actual quantity. The stockpile measurement must be performed at least every six months.

2.2. The stockpile volumetric measurement will be performed and reported through the *Stockpile Report App*. To do so, each maintenance crew member must have a *Stockpile Report account* and possess one of the following devices to run the application:

- iPhone with iOS 13.0 or later.
- iPad with iPadOS 13.0 or later.
- iPod touch with iOS 13.0 or later.

2.3. Before the measurement is performed, the maintainer must introduce the initial parameters to identify the stockpile of interest:

- District.
- Site.
- Product (Type of material e.g., base, sand, salt).
- Condition (By default all stockpiles are assumed to be freestanding but the app contains a bunker option for 1-sided, 2-sided, and 3-sided rectangular bunkers).

2.4. The stockpile volume quantification proceeds as follows:

2.4.1. Verify that the stockpile is mostly clean and free of contaminants such as snow or vegetation that might affect the result.

2.4.2. Verify that the stockpile perimeter does not have any obstruction that prevents the maintenance crew from walking around it. When the stockpile is located inside a bunker, a specific walking pattern is needed in order to complete the task. For more information, refer to the *Bunker Piles Walking Path* field guide.

2.4.3. Place 2 cones 25 ft. apart (±2 in) in a straight line at the base of the stockpile. If the stockpile length is less than 25 ft., the app allows a reduction to 12.5 ft.

2.4.4. Open the Stockpile Report App on the mobile phone containing the application, select the corresponding location, and fill in the basic input.

2.4.5. To start measuring the stockpile, point the camera of the mobile phone towards the stockpile and start walking around the pile while always facing the stockpile. Verify that both the toe and the tip of the stockpile fit in the camera screen of the mobile phone. To fully capture the stockpile surface, the maintenance crew inspector might need to take some steps back at the beginning of the measurement.

2.4.6. Once the stockpiled perimeter has been fully covered, the application will automatically generate a report with the outcome of the measurement:

- Total Volume.
- Toe Coverage Confidence.
- Surface Area Confidence.

- Date & Time.
- Responsible for the measurement.
- Measurement time.

2.4.7. To obtain a good estimate, at least three different people must measure the stockpile, or the assigned maintainer must measure it three consecutive times. For more information, refer to the *Measuring Stockpiles with the Stockpile Reports iPhone app* field guide.

2.5. To obtain the mass, the maintainer must introduce the unit weight of the stockpile. There are two alternatives to selecting a reasonable volume-mass factor.

2.5.1. Use parametric values: Although a unique conversion factor may be established for every stockpile and material, NDOT uses parametric values for each material, regardless of the source. These factors are also implemented in EAMS database and are automatically selected depending on the type of material (e.g., base, sand, salt).

2.5.2. Determine the in-situ value: If the maintenance crew desires to develop their own conversion factors for a specific site or material, it is necessary to perform the unit weight test and determine the moisture content. It must be noted that the study performed by UNR could assist in the determination of alternative unit weight factors due to the evaluation of the moisture impact on different materials.

2.6. It must be noted that whether the parametric values or the in-situ values are used, both must not differ significantly resulting in completely different mass estimates.

2.7. The calculated mass is then compared against the inventory record (Step 3).

3. Inventory Record Verification

After the measurement is performed, Headquarters Maintenance will analyze the reported data.

3.1. Prior to comparing the field-generated data and the inventory record, a reasonable discrepancy percent "X" must be established to account for external factors that could modify the original quantity (e.g., floor sinking, wind, material loading, etc.).

3.2. Once the stockpile measurement is compared against the inventory record data, the following cases may appear:

3.2.1. A deviation equal or less than "X" ±5% between the measurement and the inventory. If the accuracy is found to be within this level, the field measurement will be considered valid, and results are reported for audit purposes.

3.2.2. A deviation greater than "X" ±5% between the measurement and the inventory. If the accuracy is found to be within this level, a set of revisions and corrections are suggested:

3.2.2.1. First, a thorough inspection of P*urchase Orders* and *Work Orders* must be performed to discard any possible mistakes after purchasing or using the material.

3.2.2.2. Second, if the problem has not been solved, the unit weight factor could be changed (steps 2.5-2.7). This change must be addressed and kept for future measurements and verifications. If the unit weight factor is being constantly updated, this step must not be used.

3.2.2.3. In the case that an anomaly persists, the District Engineer, Maintenance Administrator or the corresponding authority could request the EAMS database inventory to be updated. After the data is updated, results are reported for audit purposes.

References Documents

- Nevada Revised Statues. Title 27, Chapter 333: Purchasing: State (Purchasing Policy), 2011.
- NDOT. Maintenance Manual, 2017.
- NDOT. Operations Management (Web) TM User Manual, 2019.
- NDOT. Test Method Nev. T112: Moisture Content, 2016.
- Stockpile Reports. Measuring Stockpiles with the Stockpile Reports iPhone app field guide, 2022.
- Stockpile Reports. Bunker Piles Walking Path field guide, 2022.