

Appendix F

NIST Handbook 44 – Multiple Dimension Measuring Devices

Item 358-1:

Measurement of Bulk Material in Open-Top Truck and Trailer Units

**Load Volume Scanner Metrology, Test methods & Suitability for Use
by Loadscan Ltd.**

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Load Volume Scanner (LVS) Metrology, Test Methods and Suitability for Use



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Contents

<i>Introduction</i>	2
<i>Background</i>	2
<i>Principle of Operation</i>	3
<i>Metrological Characteristics</i>	5
<i>General Metrological Characteristics</i>	5
<i>Sources of Measurement Error</i>	8
<i>Accuracy Classification</i>	10
<i>Test Methods</i>	11
<i>Current Methods</i>	11
<i>Practical Constraints on Test Load Generation</i>	13
<i>Alternative Standardized Method</i>	14
<i>Suitability for Use</i>	15
<i>Primary Application Areas</i>	15
<i>Traditional Measurement Methods</i>	17
<i>Accuracy Limitations in Volumetric Load Determination</i>	18
<i>Key Advantages of the LVS</i>	19
<i>Limitations and Potential Objections</i>	19

Introduction

This document is intended to provide additional information about the LoadScan/TallyClerk Load Volume Scanner to assist trade measurement authorities in evaluating the instrument only. It is not intended as a general introduction to the product or its usage.

Background

The Load Volume Scanner (LVS) is a non-contact volumetric measurement instrument designed to measure loads of bulk loose solids in open-bin truck and trailer units. Typical applications are in civil construction, quarrying, mining, mulch manufacturing, debris cleanup, recycling and other industries where bulk materials are traded by the truck load and volume is the key quantity of interest or the most practical form of measure.

- The TallyClerk development project was initiated in 1998 to provide a solution to industry requirements for accurate tally of construction aggregate and spoil movements on, off and around civil construction sites.
- The LVS achieved type approval for trade use in New Zealand in 1999 and in Australia in 2010.
- TallyClerk has been re-branded to LoadScan and now has over 75 installations around the world, the majority in New Zealand.
- The LVS format includes fully mobile, portable and fixed-mount models.
- The LVS is now used to measure a wide range of bulk load materials in a full spectrum of truck designs across multiple industries.

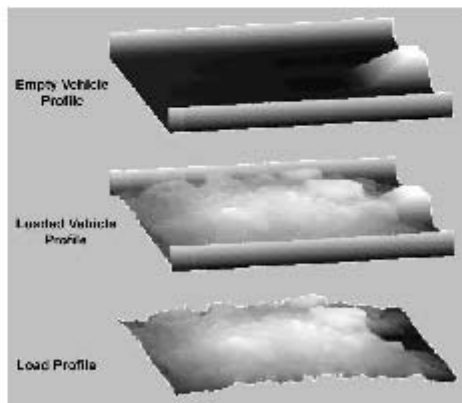


Principle of Operation

Trucks are "scanned" by driving slowly below an elevated **Scan Head**. This is essentially a mounting platform for two scanning laser range-finders, which we will refer to as **laser scanners**. When a truck crosses the **Scan Area** below the Scan Head it falls within the field of view of these laser scanners which perform thousands of distance measurements per second.

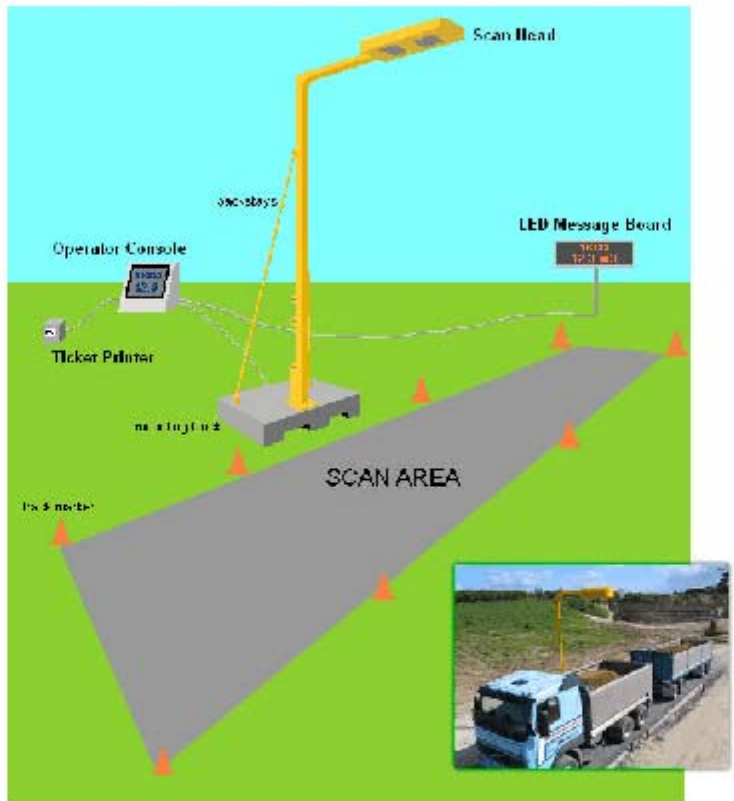


The LVS processes the distance data measured by the laser scanners as a truck passes below and constructs a composite 3D model or 'surface profile' in software. A vehicle is initially scanned empty and recorded into the system database as an **empty vehicle profile** (zero reference). Load volume is computed on subsequent scans by comparing each new **loaded vehicle profile** against the recorded empty profile. This involves aligning the empty and loaded vehicle profiles spatially in software and computing a **load profile** from the difference between them.



The LVS measures the load as it sits in the truck at the time of measurement. The measured volume is the "loose" volume generated by the surface contour and it makes no assumptions about product density or changes in volume over time.

The scanning process is fully automated and a touch-screen Operator Console provides for operator control and monitoring of the system. Trucks and trailers can be identified manually, or they can be fitted with RFID Tags that automatically identify the vehicle(s) when scanned. Measurement results are displayed on the Operator Console screen and loading tickets can be printed automatically with an optional Ticket Printer. Results are also displayed on a high visibility LED Message Board. Permanent records are saved to log files which can be transferred to other systems for analysis, invoice generation and reporting.



Metrological Characteristics

General Metrological Characteristics

Basic Specifications

Unit of Measure	Cubic metre (m ³) or cubic yard (yd ³) <i>according to regional requirements</i>
Measurement Range (per bin)	0 – 130 m ³ (0 – 170 yd ³) <i>or as set by regional trade measurement authorities</i>
Scale Interval (resolution)	0.1 m ³ / 0.1 yd ³ <i>or as set by regional trade measurement authorities</i>
Measurable Vehicle Types	Open bin road-legal truck, truck-trailer, semi-trailer and B-train combinations (including bottom-dump, side-tipper and belt unloaders); Road-trains with up to 4 bins; Rigid bodied and articulated off-highway dump trucks (mine, quarry, underground); solid sided rectangular tractor trailers. Maximum 3m (10') wide, 4.25m (14') high for standard fold-down LVS. Custom mounting may be required for larger trucks.
Measurable Bin Capacity (truck/trailer size)	1.5 – 130.0 m ³ (2.0 – 170 yd ³) <i>or as set by regional trade measurement authorities</i>
Measurable Load Types	<i>Except where limited by regional trade measurement authorities:</i> Flowable solids (bulk loose materials) including but not limited to: a) Earth, sand, gravel or other similar material b) Mulch, bark, compost or other similar landscaping products and raw constituent materials c) Woodchip or sawdust d) Unprocessed ore, coal or mining waste e) Bulk recycled materials in crushed, shredded or similar form f) Lumpy, irregular mixed materials where sold as waste or debris
Maximum Load Particle Diameter (average)	200 mm (7.8") <i>no limit for non-trade applications</i>
Typical Measurement Accuracy	Better than 1% to limit of resolution
Vehicle Speed (during scanning)	0.5 – 6.0 kmph (0.3 - 3.7 mph)
Power Requirements	24VDC, 13A max or 110 - 240 VAC, 50/60Hz, 4A max with AC power supply installed
Laser Protection Class	Class 1 (eye-safe)
Clearance (from Ground)	5.0 m (16.4') minimum (depends on mounting system and type of vehicles to be scanned)

Rated Operating Conditions

Operating Temperature	-30 – 50°C (-22 – 122 °F) Scan Head, LED Message Board 0 – 45°C (32 – 113 °F) Operator Console, Printer
Minimum Visibility	50 m (164') (dense fog)
Maximum Scan-Track Gradient	5 degrees (9%)
Maximum Scan-Track Camber	3 degrees (5%)

Type Classification

The LVS does not fit into any existing internationally recognized standard instrument classification defined for other types of measurement instruments and none exists specifically for the LVS. In New Zealand and Australia, where the LVS currently has type approvals, the trade measurement authorities have borrowed from and modified existing classifications to create type approval specifications for the LVS.

In terms of principle of operation and unit of measure, the LVS is best compared to **Multi-Dimensional Measuring Instruments**¹ used for determining the dimensions and/or volume of objects for the purpose of calculating freight, storage, or postal charges based on the dimensions and/or volume occupied by the object. The scanning laser rangefinder technology utilized by the LVS is essentially the same as used by the latest generation of these instruments. However, the instrument design, metrological characteristics and application is significantly different and the LVS does not fit well into this type classification. Some of the existing guidelines for Multi-Dimensional Measuring Instruments can be applied to the LVS.

In terms of application, the LVS is better compared to instruments for **Vehicle Weighing in Motion**² such as axle weighers and other in-motion weighbridges. However, the technology is very different and these instruments measure weight, not volume. Some elements of the existing guidelines for Vehicle Weighing in Motion can be applied to the LVS.

Brim Measures or Dry Measures³ including front-end loader buckets or other measures of fixed capacity for the measurement of solids are also comparable in terms of unit of measure and type of materials measured.

Scan Head Mounting

The scan head support structure may be varied to suit the installation or portability requirements. In all cases the mechanical support mechanism provides stable mounting for the scan head, in the required location relative to the scan area and does not alter the metrological characteristics of the instrument. Standard clearance from ground is approximately 5.2m but this may be increased for scanning larger dump trucks.



Calibration

The LVS is not an analogue measurement instrument and cannot be "calibrated" in the traditional sense – it does not include any facility for scaling the measurements up or down or setting a zero point. Calibration from a metrological point of view corresponds to the alignment of the LVS scan head to set the laser scanners in the correct position and orientation relative to the scan track that trucks pass over. However, measurement accuracy does not have a direct linear or non-linear relationship to scan head alignment which can in no way be used to "calibrate" the measurements.

Zero Indication

The LVS does not have a zero indication, only a ready indication. Zero reference is set for each individual truck or trailer body by scanning empty and recording an **empty vehicle profile** in the system database.

¹ See for example: NIST Handbook 44 (2012), section 5.38, *Multiple Dimension Measuring Devices (USA)*
OIML R129 (2000), *Multi-dimensional measuring instruments (OIML)*

² See for example: OIML R 134-1 (2006), *Automatic instruments for weighing road vehicles in motion and measuring axle loads (2006, OIML)*

³ See for example: NIST Handbook 44 (2012), section 4.45, *Dry Measures (USA)*
NMI Certificate of Approval No. 4/8/0A (2008), *Brim Measures for the Determination of the Volume of Flowable Solids (Australia)*

Validation Checks

The LVS performs many validity checks designed to prevent the system being used fraudulently or outside the limitations specified. If any validation checks fail, an error is generated and no result is displayed. The following are some of the validation checks performed by the system:

- On start-up the LVS will not enter ready-state if it detects gradient or camber of the scan area (relative to the scan head) are outside tolerance.
- LVS prevents recording empty truck/trailer trays of less than about 1.5m³ (2.0 yd³) capacity (or as otherwise specified) into the system database.
- No measurement output if covered load detected (e.g. tarpaulin covering tray).
- No measurement output if vehicle speed is outside limits or speed is too uneven.
- No measurement output if tray is scanned with hoist in fully or partially raised position.
- No measurement output if truck turns, drives off-centre or passes at too great an angle through the scan area.
- No measurement output if the basic visible dimensions of the 'empty' and 'load' trays do not match.
- LVS will not enter ready-state if high levels of dust, fog or other "visual pollution" are detected.
- No measurement output if high levels of dust, fog or other "visual pollution" are detected within scanned vehicle profile data.

Safety and Compliance

Declarations, certifications and reports relating to electrical and mechanical safety and Electro-Magnetic Compatibility (EMC) of the LVS system components are retained on file by LoadScan Ltd. The LVS design meets FCC (radiation), FDA (laser) and UL (electrical safety) requirements for import into the USA.

System Security

The LVS has built in security features to prevent tampering or misuse. These features include:

- Access to system software and settings is not possible without access procedures and passwords held by LoadScan Ltd.
- Laser scanner serial numbers are stored in the system computer so that scanners or computer cannot be replaced except by staff with the appropriate maintenance password and procedures.
- Access to user configuration and installation settings is limited by a 'System' password.
- Access to database functionality and historical measurement records can be limited by a 'User' password.

Database Records

Empty vehicle profiles are recorded into the system database as 'Reference Scans'. These form the zero references for each tray and have a 12-month expiry (or less as required by regional trade measurement authorities), after which they must be updated. Reference scans must also be updated any time that significant structural changes are made to the shape of a truck or trailer tray (e.g. adding or removing topper boards or cover systems). It is still possible to use existing reference scans after expiry, but 'REFERENCE SCAN EXPIRED' will be displayed or printed with all measurement indications.

Measurement Records

In addition to screen and sign indications and optional printed tickets, the LVS stores all results and additional details in log-files on electronic media. These files are secure and encrypted. They cannot be modified and create a secure audit trail. Non-encrypted copies of these files are available for download via network connection or USB drive without restriction (user password may be required). Additionally, for every scan, a record of the raw laser measurement data is saved to a file. These files provide a further audit trail and can be downloaded by LoadScan Ltd if necessary. They are automatically deleted after 60 days.

Extended Indication (Test Mode)

A password protected Extended Indication mode to assist in accuracy testing is available. In this mode the scale interval is $0.01\text{m}^3/\text{yd}^3$ across the full measurement range.

Access Log

An entry is automatically created in a secured access log file every time maintenance level configuration setting changes, software upgrades or scanner or computer hardware replacements are made. This log file can be downloaded (password required).

Sources of Measurement Error

A full theoretical error analysis is not feasible due to the complex interaction of thousands of variables. But the LVS has been extensively tested and the accuracy range demonstrated.

The metrologically significant factors that affect measurement accuracy are:

- Distance Measurements (Laser Scanners)
- Data Processing (Software)
- Scan Head Alignment (Installation)
- Environmental Conditions

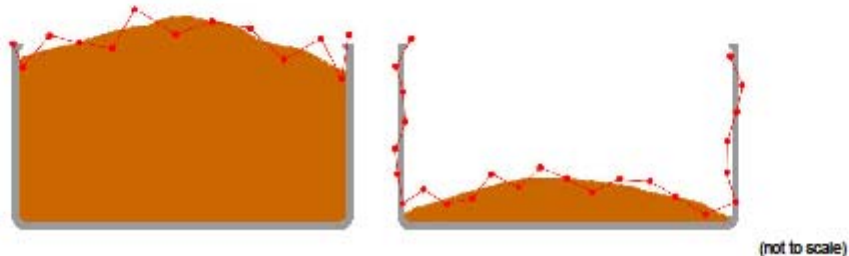
Distance Measurements (Laser Scanners)

The laser scanners perform thousands of individual distance measurements every second.

- Rated absolute accuracy (typical): $\pm 12\text{ mm}$ ($\pm 0.47\text{ in}$).⁴
- The LVS application is affected by the relative error between individual points, not the absolute error relative to scanner zero location. This significantly reduces the effective error.
- No re-calibration of laser scanners is required. Built-in reference targets enable on-the-fly calibration which ensures that the measurement accuracy remains the same throughout the life time of the units.

The error in individual distance measurements has no relationship to the size of the truck/trailer bin, size of the load or instrument range settings.

In practice, each individual distance measurement at a single point can be modeled as largely independent from every other measurement with an equal probability of a positive or negative error within a range of statistical variance:



⁴ Manufacturer's specifications for current model used in LVS (Sick LMS511-20100).

Data Processing (Software)

There are thousands of variables involved in the measurement data processing and error can only be determined by testing. However, an integral part of the LVS design is that every metrologically significant software process determines a 'confidence level' based on its input data quality and generates a 'no measurement' error condition if the confidence level is not acceptable.

The LVS outputs no measurement if it is not confident of the result.

Software processing error is not directly dependent on the size of the truck/trailer bin, size of the load or instrument range settings. Error probability does however increase roughly proportionally to the visible upper surface area of the load. This surface area is constrained by the physical dimensions of the truck/trailer tray it is contained in. So absolute error tends to increase as load volume increases but level off at higher volumes.

Scan Head Alignment (Installation)

The LVS scan head must be installed in the correct position and orientation relative to the scan area (track) that trucks drive over and the scan area should be well defined. The type of mounting structure can vary and installation, alignment and track marking procedures do not require special skills or qualifications. They can be performed by the system operator.

The better the alignment of the scan head and quality of the scan track, the smaller the statistical variance in measurement error. But this is equally dependent on the position, angle and speed of the truck on the scan track during a scan and does not directly affect the magnitude or sign of average error.

Scan head alignment does not directly affect the direction of error (i.e. whether volume is over-reported or under-reported) and cannot be used to calibrate the instrument.

To ensure only good quality measurements, the LVS monitors the ground profile and analyzes scan data to determine if the scan head alignment is out or if truck position, angle or speed on the scan track is outside acceptable limits. The system has many built-in checks to automatically generate 'no measurement' error conditions in such cases. If the alignment is not correct or trucks are not following the designated path and speed then they will not be able to get measurements.

The process of aligning the scan head and defining the scan track does not significantly improve the measurement accuracy – it reduces the chances of getting "no measurement" error conditions.

Environmental Conditions

The effect of environmental conditions such as temperature, humidity, electro-magnetic interference and visibility on raw distance measurements is insignificant compared to other systematic errors and the laser scanners are rated for a very wide range of environmental conditions.⁵

Dense fog, steam or dust in the air can potentially block the view of the load surface and give false distance measurements. However, the LVS analyzes scan data to detect 'visual pollution' and generates a 'no measurement' error condition if this occurs.

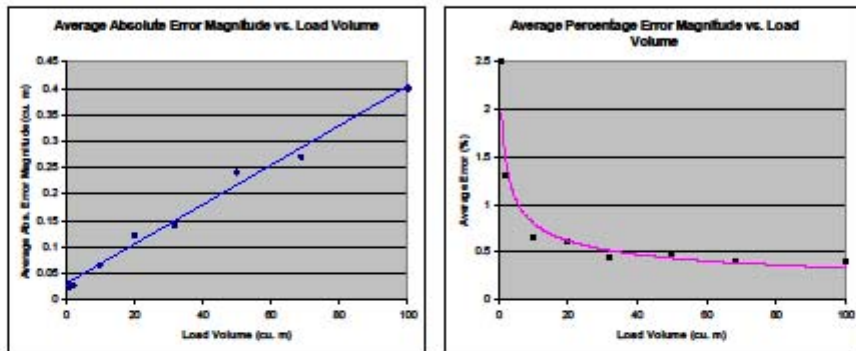
The LVS does not attempt to measure a load if its view of the target is significantly obstructed.

⁵ Manufacturer's specifications for current model used in LVS (Sick LMS511-20100).

Accuracy Classification

LVS measurement error does not theoretically have a directly proportional relationship to measured load volume. However, in practice, in real world conditions, over a full range of truck designs, installation conditions and load types, absolute error magnitude increases roughly proportionally to load volume.

The following charts are indicative only. They are compiled from informal in-house accuracy testing and formal type approval testing results over a 12 year period. A variety of test load constructions, with varying degrees of uncertainty were used, test volumes are not evenly spaced and the number of measurements at each test volume varies. However the trend is clearly demonstrated:

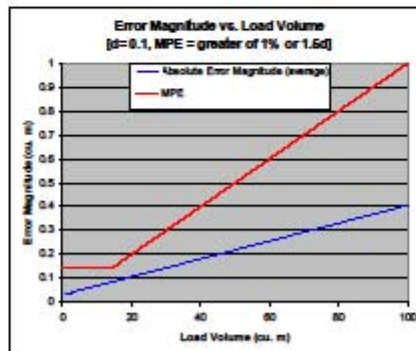


Absolute error magnitude tends to increase roughly proportionally to measured volume. Percentage error magnitude tends to a relatively constant (or slightly improving) value with increasing volume.

Where *d* is the scale interval, one possible best-fit MPE (tolerance) for the LVS is:

Maximum Permissible Error (MPE)
$\pm 1.00\% \text{ or } 1.5d \text{ (whichever is the greater)}$

This is based on the 'Class 2' Weighing In Motion (WIM) accuracy class as specified by OIML⁶ but with the same MPE for Acceptance and Maintenance (the approach used by NMI for LVS type approval in Australia). The resultant MPE (in cubic metres, with *d* = 0.1) is as below:



There are other possibilities. LVS type approval in New Zealand uses a stepped rather than percentage MPE.

⁶ See OIML R 134-1 (2006), Automatic instruments for weighing road vehicles in motion and measuring axle loads (OIML)

Test Methods

LVS Accuracy testing requires the generation of suitable test measures. A **test load** is an artificially generated reference volume, known to a suitable level of uncertainty, loaded onto a truck or trailer.

Current Methods

The following is a summary of methods currently used for generating test loads. LoadScan Ltd has more detailed written procedures on file. These methods can be combined.

Solid Test Load (Reference Standard)

A solid block or hollow shell of known external volume, in the approximate shape of a typical measurable load, may be loaded onto the test vehicle and used as a test load.



Advantages

- A permanent reference standard analogous to test weights used for scales.
- Volume does not change significantly over time.
- Easy to transport and store.
- Fast and practical solution.

Disadvantages

- Only suitable for test volumes that are small compared to instrument capacity.
- Requires a very flat tray floor as it is rigid and does not adapt to contours of test vehicle.

Multiple Brim Measure Loading

A rectangular bin or other brim measure of known capacity can be loaded with suitable material, and this material transferred to the test vehicle one or more times to create a test load.



Advantages

- Uses real load materials and generates realistic load profiles
- May be able to use resources available at test site

Disadvantages

- It is very difficult to control or determine true test load volume because load material compaction may not be the same in truck/trailer bin as in measuring container.
- The uncertainty increases significantly with load size due to the unpredictable compaction or settlement level of the cumulative load. This means it is only suitable for a small number of repeated brim measure transfers.

Levelled and Measured Load

Where the dimensions of the tray on the test vehicle are known, a test load of known volume can be generated by loading the tray to a set level below the tray top-sides and computing the volume from the known dimensions of the tray and the measured level of the load. The load material needs to be compacted or "shaken-down" before leveling to avoid the volume changing over time as the load settles. Additional load material should be added by the brim measure loading method or a solid test load put on top to create a more realistic load profile.

**Advantages**

- Uses real load materials.
- May be able to use resources available at test site.
- Can test up to larger volumes by this method.

Disadvantages

- Time consuming and requires lots of resources
- Requires suitable test vehicle to be identified in advance and available for testing.
- Unless the vehicle tray profile is very regular and simple the uncertainty in manual dimensional measurements may be too high.

False Floor Measured Load

A false floor (flat or profiled) may be constructed for a truck tray or custom test trailer of known dimensions. A solid test load or a measure of load material (brim measure loading) may be placed on top of this to generate a more realistic load profile. This is essentially the same as the Levelled and Measured Load method, except that the levelled load is generated by a false floor and the floor itself may be profiled to represent a load instead of flat.



Advantages

- Better control of surface profile than leveled and measured load so volume uncertainty is lower.
- Can test up to larger volumes by this method.

Disadvantages

- Time consuming and requires lots of resources
- False floor must be custom-built for a particular test vehicle.
- Unless the vehicle tray profile is very regular and simple the uncertainty in manual dimensional measurements may be too high.

Practical Constraints on Test Load Generation

Only approved test loads or methods should be used. General requirements for test loads are:

- True volume (conventional true value) must be determined by a verifiable method to a suitable level of uncertainty.
- Must be made of materials that cannot be easily influenced by environmental conditions.
- Must not be subject to loss or increase in volume over time.
- The shape of the test measure should reflect the shape of the loads to be measured.

Meeting these requirements is challenging, especially for larger volumes. There are practical constraints on:

- Technical construction method
- Ability to determine true volume
- Availability of suitable resources at test sites
- Time
- Cost
- Size
- Transportation and storage

Because of practical limitations it is not feasible to repeatedly generate test loads with volume known to the required level of uncertainty up to the maximum used capacity of the LVS (130m³/170yd³) beyond initial one-time type approval testing. However, as previously noted, the statistical error variance in the physical distance measurements which volume computation is based on has no relationship to actual load volume or instrument range settings and cannot be adjusted (calibrated). An LVS instrument is either working within its accuracy capabilities across its full range or it is faulty.

Confirmation of acceptable error at lower volumes is adequate to confirm the LVS is functioning correctly within its accuracy capabilities across its usable range.

In New Zealand, where the LVS has had type approval since 1999, the trade measurement authorities recognized this fact and the difficulties of attempting to create suitable test loads at high volumes. A certified solid test load (reference standard) with a volume of 2.10 m³ is used for all verification/certification testing. Approved maximum capacity is currently 85 m³ in New Zealand. This is adequate for the local market, but type approval testing has been successfully conducted up to 100 m³.

In regions where required maximum capacity is significantly higher, a 2.10 m³ test load may not be considered as adequate for testing LVS performance across the full range as a matter of principle.

For such cases we suggest a requirement to test to 25% of 'used capacity' where used capacity set per device for the particular application, within limits of type approval (up to 130 m³ / 170 yd³).

This is analogous to the 25% rule for scales with a capacity greater than 20,000 kg or 40,000 lb in the USA⁷.

Note also that the LVS is a portable instrument and that due to system validation checks accuracy is not significantly affected by site-specific installation. The LVS has been approved as a portable instrument in New Zealand since 2000.

The LVS does not require re-verification each time it is installed on a new site.

Alternative Standardized Method

Due to the practical limitations discussed, solid test load is the preferred method for accuracy testing. It is also the most familiar to trade measurement authorities as it involves the use of a permanent reference standard that can be verified, does not change significantly over time and can be stored and transported relatively easily, as for example test weights used to test truck scales.

However, large solid volumes designed to simulate a load on any test vehicle are impractical. Such test loads do not mold to the internal shape of the test bin like a real load and large size is impractical for transport, handling and storage.

LoadScan Ltd has developing a self-contained portable test system that does not require a separate test vehicle. The test vehicle is a large collapsible rectangular bin that is trailer mounted to simulate a truck or trailer body and has a moveable false floor. Combined with solid test loads this method is practical for testing up to medium volumes. The current design can test up to about 35 m³ (48 yd³).

We propose the following accuracy testing regime:

Type Approval Testing

Test to maximum capacity with a suitable number of intermediate steps as required by testing authorities.

Initial Verification (Acceptance)

Where used capacity is less than or equal to 30 m³ or 40 yd³ (depending on configuration):

- Test at zero and as close as possible to used capacity with intermediate tests as close as possible to minimum capacity and 50% of used capacity.

Where used capacity is greater than 30 m³ or 40 yd³ (depending on configuration):

- Test at zero and a maximum test volume at least the greater of 30 m³ / 40 yd³ or 25% of used capacity with intermediate tests as close as possible to minimum capacity and 50% of maximum test volume.

Testing to be conducted with self-contained test system as discussed above. Initial verification can be conducted at any suitable location and the instrument then moved from site to site as required without additional accuracy testing on each site.

Alternatively, if acceptable to trade measurement authorities, use same method as for In-Service Inspection (below). This is the approved regime in New Zealand and the most practicable.

In-Service Inspection (Maintenance)

Test at zero and at a test volume of at least 2 m³ or 3 yd³ (depending on system configuration) with solid test load(s) using any suitable test vehicle available on site.

⁷ See NIST Handbook 44 (2012), section 2.20, Scales, p2-31, Table 4, *Minimum Test Weights and Test Loads* (USA)

Suitability for Use

The LVS has proven to have a high degree of suitability for use within its application areas, especially where volumetric truck measure is the standard traded quantity.

Primary Application Areas

Civil Construction

- Bulk civil construction materials are specified and traded in volumetric quantities (m^3/yd^3)
- Portable measurement device on job sites (move from job to job)
- Monitor incoming construction materials such as rock aggregates, sand and soil
- Monitor outgoing materials such as excavated clay, soil etc

The LVS is well established in the civil construction industry in New Zealand. Some regional/city councils are requiring LVS units to be operated on their infrastructure jobs. Some construction companies are also requiring that their suppliers (quarries) must use an LVS if they wish to supply to their jobs.



Quarrying

- Mainly supply to the construction industry which works in volumetric quantities
- Measure outgoing product such as rock aggregates or sand
- Measure incoming "cleanfill" for land reclamation



Mining

- Often problematic measuring weight due to size of vehicles and environment - LVS is a non-contact, in-motion, low maintenance solution
- Measure unprocessed ore or coal, over-burden and construction materials used on site
- Monitor carry-back (haul-back) where load material stuck in "empty" vehicle trays



Mulch/Landscaping Products

- Bulk landscaping products are specified and traded in volumetric quantities ($m^3/yard^3$)
- Measure outgoing processed product
- Measure incoming raw ingredient supplies



Forestry

- Measure woodchip for pulp production (pulp/paper mills)
- Measure woodchip, sawdust or bark for burner fuel or sale to landscape product manufacturers
- Measure construction materials for forestry road building and maintenance



Waste/Recycling

- Landfill reclamation or capping material
- Bulk recycled materials in crushed, shredded or similar form
- Disaster Debris cleanup



Traditional Measurement Methods

Traditional methods for determining volumetric truck measure are often inaccurate but are widely practised.

Converting from Weight to Volume

Measuring and trading by weight and applying conversion factors to determine volume is often very inaccurate. The most obvious problem is that weight to volume ratio varies greatly, depending on the moisture content of the load material.

- Product can become wet because of rain, ground moisture or from deliberate wetting of stockpiles or truck loads to prevent dust. This practice which often occurs in quarries, works in the suppliers favour when measuring weight.
- If the material is wet when loaded, it can weigh considerably more at the point of loading than at the point of unloading because water run-off occurs in transit. Generally trading by weight is based on weight at the point of loading.
- Weight-to-volume conversion factors are typically computed on a dry day in carefully controlled conditions and do not necessarily reflect the weight-to-volume ratio of supplied materials.

Counting Bucket Loads

There are well recognized issues with counting loader bucket scoops as a method of determining volumetric truck measure.

- In practice operators do not load each bucket consistently to the same level. In fact the loader operator cannot generally see the scoop very well and certainly it is not practical to get out and strike-off (level) every scoop. This varies from loader to loader and from operator to operator.
- How the bucket is pushed into the stock-pile significantly affects the effective volume when transferred to truck/trailer. For example, pushing the bucket hard into the bottom of the stockpile produces a more compacted load than loosely scooping off the side of the stock-pile.
- Due to the self-compaction/settlement of heaped material under its own weight, multiple bucket loads may not equate to resultant cumulative heaped volumes in truck bins or in stockpiles generated from truck loads. This issue extends to differences in cumulative heaped volumes generated by small bucket loads or generated by large bucket loads because of material self-compaction within a single scoop.



Manual Surveying

Manual survey methods include:

- Level and measure (manual survey of levelled load in truck bin using tape measure)
- Survey single load on the ground after unloading
- Survey stockpile or 'cut and fill' volume (multiple loads)
- Unload truck load into a container of measured capacity.

These practices are widely used on a 'random check' basis but are very time consuming. A common complaint about the 'level and measure' process is that it requires re-shaping and walking on the load which effectively changes the load volume. Disputes also commonly arise over load settlement in transit. This is the change in volume of a load due to the product "bedding down" or "fluffing up" as a result of vibration, braking and bumps during transport. Often the differences between what the supplier claims was in a truck (in cubic metres or cubic yards) and what the buyer claims, is quite significant. Unloading a truck onto the ground and then re-loading it with the same material and manually surveying the load (level and measure) at the buyer end is one way to check if the supplier's claimed volume is accurate. This method results in a load that should be very close in volume to the original loaded volume at the point-of-loading, before travel influences.

It should also be noted that volumes computed from 'cut and fill' surveys or by surveying large stockpiles generated from multiple truck loads over a period of time may not result in quantities that match the cumulative total of all the truck loads as the surveyed material may be closer to "solid measure" (compacted) than "loose measure" which is the measured and traded quantity.

Counting Truck Loads

A truck or trailer capacity may be determined by manual measurement, but in practice trucks and trailers are not loaded exactly to capacity every time. They may be at less than capacity or loads may be heaped above the sides to greater than struck capacity. Loader/excavator operators often cannot see inside the truck bins as they are lower than the bin sides. It is also difficult to load into the bin corners with a loader or excavator. And in fact, in many cases trucks would be over-loaded if filled to capacity.

Accuracy Limitations in Volumetric Load Determination

Traditional methods of determining truck load volume are often not very reliable. However, this is only partly due to limitations of the measurement methods. The true volume of a given quantity of bulk loose solid material is not a constant value. Volume fluctuates slightly as a result of natural changes in product density due to changing compaction levels, moisture content and environmental conditions. For this reason it is simply not possible to determine a meaningful volume to the same level of accuracy as some other measures, such as weight. This is not covered by legislation or type approval processes, but trade measurement officers involved in testing and enforcement in the field will be familiar with these issues.

Measuring truck load volume to a degree of uncertainty significantly smaller than the magnitude of natural volume fluctuations does not generally provide more meaningful measurement.

Industry understands the limitations in volume determination. It is for example, common practise when trading by truck load or multiple bucket count to round to the nearest cubic metre or yard where a higher resolution measure is not meaningful.

One response to this problem is to trade by weight because this can be determined more accurately. But as discussed above, there are problems with trading by weight where volume is the quantity of interest.

An accurate measure of weight is often less meaningful than a less accurate measure of volume where volume is the quantity of interest

Key Advantages of the LVS

For trade by volumetric truck measure the best solution is a fair determination of the load volume as it sits in the truck at the time of measurement. This is what the LVS provides. Some key advantages of the LVS are:

- Avoids need to estimate by:
 - Converting from weight
 - Counting bucket scoops or truck loads
 - Manually measuring or guessing
- Fast, fully automated measurement
- Non-contact, so measuring the load does not interfere with the load volume.
- Measures actual load in truck or trailer bin regardless of theoretical bin capacity
- Equity of trade for seller and buyer

Our experience is that the LVS is accepted as providing a fair measure for all and acts to prevent many disputes that otherwise occur. Truck measure is a happy median between individual bucket loads and stockpiles and as such is equally equitable to seller and buyer. It is also our experience that suppliers such as quarries that use the LVS system may lose the small advantage of selling by more easily manipulated methods but their customers are happier.

The LVS is also a portable device, making it suitable for installation on construction sites and other short-term applications.

The ability of the LVS to automatically detect unsuitable measurement conditions, combined with the fact that no re-calibration is necessary makes the LVS very suitable for portable use and installation on different sites by trained operators without any special legal metrological qualifications.

Limitations and Potential Objections

Limitations of the LVS

- Limited to open-top trucks/trailers/bins
- Measurement of bulk loose solid materials only
- Measurement accuracy is limited
- The LVS is a visual inspection system. It is unable to operate in conditions of "visual pollution" and reports an error condition in cases of:
 - extreme dust
 - dense fog
 - dense clouds of steam rising from load material

Potential Objections to Trade Use of the LVS

Objection

Why should the LVS be approved for trade use when weighing instruments of similar measurement accuracy have been rejected?

Response

The following points should be considered:

- The LVS is not a weighing instrument. It should be compared to existing alternatives, not a different class of instrument.
- The LVS is not a general purpose measurement instrument. Unlike axle-weighers for example, which also have a lower accuracy classification, it cannot measure any type of product of any value. It is limited to measurement of bulk loose solids in open bin truck and trailer units. The application areas where volume is of interest for this type of load is mainly limited to relatively low value product.
- Volume measurement inherently has a higher uncertainty due to natural volume fluctuations. Measuring instantaneous volume to a higher degree of accuracy than the inherent uncertainty is not beneficial.
- The LVS provides a significant improvement in accuracy, consistency and convenience over current standard practices
- The accuracy is well within that demanded by industry itself (the buyers and sellers) for the types of transactions that LVS is used for.
- Accurate measurement of weight and conversion to volume from known bulk density does not provide a solution.

Objection

The LVS is not suitable for high value products due to accuracy limitation.

Response

The natural limitations of the device and industry requirements largely limit application to lower value products. Generally "high value" products that could be measured with the LVS are bulk dry powders with a high level of consistency in bulk density and so are suitable for measurement by weight and are traded by weight as standard.

Where considered necessary, trade measurement authorities can limit use. At a minimum the following suitability for use applies:

- a) Earth, sand, gravel and other similar excavated or mined materials
- b) Mulch, compost and other similar specialty mixes and primary raw constituent materials
- c) Woodchip, sawdust, bark and similar materials
- d) Unprocessed ore, coal or mining waste
- e) Bulk recycled materials in crushed, shredded or similar form
- f) Lumpy, irregular mixed materials only where traded as waste or debris

Objection

The LVS is only suitable for a limited range of vehicle types and material (product) types. Weight measurement does not have these limitations.

Response

True. The LVS is only suitable for measurement of bulk loose solids in open bin truck and trailer units. It is not intended as a general replacement for weight measurement. In fact it is often used in conjunction with weight measurement. It meets specific requirements of the industries where it is applied.

Objection

The LVS measures surface profile so voids (empty spaces) inside load are included in the measured volume.

Response

- In general the LVS is only intended for the measurements of bulk particulate materials with relatively small particle size so large voids do not occur.
- If the material is used in the same form it is measured in then it will have the same volumetric properties, including voids, in use.
- If the material is crushed/ground or otherwise modified after measurement then it becomes a different product with different properties.
- In special cases such as measurement of debris the material may be lumpy and contain significant voids, but the volume of interest includes the voids.

Objection

Some traders will believe they can make more money selling by the bucket count or weighing wet material so it is not in their interest to adopt this technology.

Response

Firstly, it is the trader's choice to use the LVS or not. Secondly, the point of measurement is the point of payment so the measurement needs to be as equitable as possible (fair to buyer and seller). Of course rates (i.e. cost per cubic metre or yard) also need to reflect the condition of the traded material at the point of measurement.