Guideline

Mobile Laser Scanning Technical Guideline

December 2014
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### Definitions:

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<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td><strong>Breakline</strong></td>
<td>A Breakline is a barrier string which represents a crease in the topography. No triangles, created in the triangulation process, can have a side that cuts this barrier string.</td>
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<tr>
<td><strong>CORS</strong></td>
<td>Continuously Operating Reference Stations</td>
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<tr>
<td><strong>Clearly Defined Points</strong></td>
<td>A Clearly Defined Point is a distinct point on the ground that can be selected in the Pointcloud with reasonable certainty that the points on the ground are the same as the points in the Pointcloud.</td>
</tr>
<tr>
<td><strong>Data Mine</strong></td>
<td>The process of digitising information from the Project Pointcloud at a time after the capture of the Pointcloud, sometimes much later, when required by some other process than the one that caused the initial capture.</td>
</tr>
<tr>
<td><strong>DNRM</strong></td>
<td>Department of Natural Resources and Mines</td>
</tr>
<tr>
<td><strong>Geo-Referenced Imagery</strong></td>
<td>Imagery captured at the same time as the capture of the single Pointclouds and the principal point is encoded with the location.</td>
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<tr>
<td><strong>GNSS</strong></td>
<td>Global Navigation Satellite Systems</td>
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<tr>
<td><strong>GFM</strong></td>
<td>Ground and Feature Model - A model of the ground and the features on that ground made-up from coded Breaklines, spot heights, feature strings and feature points.</td>
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<tr>
<td><strong>IMU</strong></td>
<td>Inertial Measurement Unit</td>
</tr>
<tr>
<td><strong>MLS</strong></td>
<td>Mobile Laser Scanning - A moving platform that collects Pointclouds using Laser Scanner/s, GNSS instrument/s and other sensors which are combined and mounted on a constantly moving ground based vehicle. Excludes “stop and go” Terrestrial Laser Scanning.</td>
</tr>
<tr>
<td><strong>MLS Checklist</strong></td>
<td>MLS Technical Guideline Checklist</td>
</tr>
<tr>
<td><strong>MLS Contractor</strong></td>
<td>Mobile Laser Scanning Contractor</td>
</tr>
<tr>
<td><strong>MCPCC</strong></td>
<td>Minimally Constrained Project Pointcloud - This is aligning and combining of individual Pointclouds from multiple passes to a best fit location without the aid of ground targets. The MCPCC is generally aligned to the PRF using GNSS observations only and is represented as a singular Pointcloud with minimal feathering in position and height.</td>
</tr>
<tr>
<td><strong>Pointcloud</strong></td>
<td>Data collected by a Mobile Laser Scanner that has been adjusted for position from GNSS location and IMU corrections for each vehicle pass resulting in vertices with x, y, z coordinates and associated properties (eg intensity, RGB values). From a single pass only.</td>
</tr>
<tr>
<td><strong>PPC</strong></td>
<td>Project Pointcloud - The PPC is the MCPCC aligned to the PRF using targets. The PPC is represented as a singular point cloud with minimal feathering in position and height.</td>
</tr>
<tr>
<td><strong>Project Proposal</strong></td>
<td>Document detailing project scope and specifications that may be used as part of an Invitation to Offer or Request for Quote.</td>
</tr>
<tr>
<td><strong>PRF</strong></td>
<td>Project Reference Frame - The Project location as evidenced by the coordinates of the Project Reference Frame Marks.</td>
</tr>
<tr>
<td><strong>PRFM</strong></td>
<td>Project Reference Frame Mark - The Survey Control Marks that create the Project Reference Frame. These marks will be fit for purpose and provide a valid coordinate within the PRF.</td>
</tr>
<tr>
<td><strong>PU</strong></td>
<td>Positional Uncertainty – is the uncertainty of the horizontal and/or vertical coordinates of a survey control mark with respect to the defined datum and represents the combined uncertainty of the existing datum realisation and the new control survey.</td>
</tr>
<tr>
<td>SCDB</td>
<td>Survey Control Database - The SCDB is a computer record of the state’s geodetic survey control information.</td>
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<td>-------</td>
<td>---------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>SPRFM</td>
<td>Subsidiary Project Reference Frame Marks - Marks placed that are stable and have been positioned from PRFM's using GNSS, conventional traversing techniques and/or levelled with a digital level. These marks will be fit for purpose and provide a valid coordinate within the PRF. A detailed report on how these marks have been established is mandatory.</td>
</tr>
<tr>
<td>SU</td>
<td>Survey Uncertainty – is the uncertainty of the horizontal and/or vertical coordinates of a survey control mark relative to the survey in which it was observed and is free from the influence of any imprecision or inaccuracy in the underlying datum realisation.</td>
</tr>
<tr>
<td>TMR</td>
<td>Department of Transport and Main Roads Queensland</td>
</tr>
<tr>
<td>RU</td>
<td>Relative Uncertainty – is the uncertainty between the horizontal and/or vertical coordinates of any two survey control marks.</td>
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Introduction

The popularity of Mobile Laser Scanning (MLS) systems revolve around the rich, accurate and repeatable information that is captured during an MLS project. It is these characteristics which “add value” past the immediate needs of a project and delivers a wider corporate value than what is achievable with other types of survey techniques.

This document aims to bring consistent terminology and understanding to the MLS capture process for the Department of Transport and Main Roads Queensland (TMR) and industry. Although not a standard, this Technical Guideline attempts to standardise common terms and methods that are being adopted in industry.
1 MLS Technical Guideline Checklist

The MLS Technical Guideline Checklist (MLS Checklist) is an integral accompaniment to this Technical Guideline and also forms part of all Project Proposals. The MLS Checklist states technical aspects required by TMR and also provides the Offeror the opportunity to detail their method.

For each item where TMR has a technical requirement, it will be specified in the TMR column and the Offeror column will be greyed out. If the Offeror proposes an alternative, they will detail that method in the Offeror column. This offer will then be evaluated as non-conforming.

Where TMR does not specify a requirement, the TMR column will be greyed out and the Offeror shall detail their method in the Offeror column.

2 Project Reference Frame

TMR must be confident of re-establishing the Project Reference Frame (PRF) with a suitable precision. This may be for multiple purposes including design, construction or asset management. The practice of locating Project Reference Frame Marks (PRFM) accurately the first time will also minimise issues with future works not fitting with the MLS capture. In addition, TMR also has an obligation to help strengthen the State’s Survey and Mapping Infrastructure.

The coordinates of all PRFMs shall meet the following requirements:

<table>
<thead>
<tr>
<th>Project Datum</th>
<th>Geocentric Datum Australia (GDA94)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Projections</td>
<td>Map Grid Australia (MGA94), Zone 54, 55, or 56</td>
</tr>
<tr>
<td></td>
<td>Australian Height Datum (AHD71)</td>
</tr>
<tr>
<td></td>
<td>Ausgeoid09 Version 1.0</td>
</tr>
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</table>

All PRFMs shall meet or exceed the following for accuracy:

<table>
<thead>
<tr>
<th></th>
<th>SU and PU &lt; 60mm</th>
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<tr>
<td></td>
<td>(equivalent to superseded Class B, 2nd Order)</td>
</tr>
<tr>
<td></td>
<td>Survey Uncertainty (SU) and Positional Uncertainty (PU) as defined in Inter-Governmental Committee on Surveying and Mapping’s Special Publication 1 v2.1 (ICSM SP1 v2.1)</td>
</tr>
<tr>
<td></td>
<td>Height uncertainty between PRFMs shall conform to a minimally constrained Global Navigation Satellite Systems (GNSS) loop closure that meets 10mm + 1ppm of the loop distance for all marks.</td>
</tr>
<tr>
<td></td>
<td>If a digital level is being used, the misclosure will be as per TMR Surveying Standards December 2014 – Part 1 – Chapter 2 – Section 7.1.1 (ie 12√k)</td>
</tr>
</tbody>
</table>

At times, TMR will supply survey accurate coordinates of the PRFMs from recently completed GNSS, Total Station and/or Digitally Levelled control networks over the project area. Other times, TMR will require the MLS Contractor to accurately coordinate new PRFMs.

All marks used as PFRMs are to be registered with Department of Natural Resources and Mines (DNRM) as Permanent Marks. The coordination of new PRFMs will be derived via GNSS observation and static network adjustment. The base stations adopted as part of this adjustment will generally have a SU and PU of <30 mm (equivalent to superseded Class A, 1st Order) and be fixed by GNSS. Strong survey accurate connections to surrounding Continuously Operating Reference Stations...
(CORS) and AHD marks should also be a consideration when selecting datum points for an MLS survey.

All GNSS observations and network adjustment reports (ie both minimally and fully constrained) shall be submitted to TMR for approval. No PRFM coordinates shall be adopted or used until approved by TMR.

TMR has an obligation to help strengthen the State’s Survey and Mapping Infrastructure. TMR requires that any GNSS data recorded be supplied in either RINEX or TDEF format. Field observation sheets recording details of each setup shall also be supplied. TMR will ensure that this supplied information is passed onto the DNRM for use in strengthening the Survey Control DataBase (SCDB) network.

It is the MLS Contractor’s responsibility to complete a Form 6 accompanied by a sketch of the Permanent Mark for all new PRFMs placed. If required, TMR can supply Permanent Mark numbers upon request.

Short baselines between PRFM and the vehicle contribute to the best possible positional accuracy outcome (ref. CALTRANS Terrestrial Laser Scanning Specifications – Jan 2011 http://www.dot.ca.gov/hq/row/landsurveys/SurveysManual/15_Surveys.pdf). The options for spacing PRFMs along the road corridor are shown in the MLS Checklist.

It may not be practical in some instances to use the PFRMs supplied as base stations whilst collecting point cloud information. If this is the case, other Subsidiary Project Reference Frame Marks (SPRFM) can be used by the MLS contractor. Additional SPRFMs placed by the MLS Contractor shall be fit for purpose with a detailed description in the Survey Report of how this objective has been achieved.

The MLS contractor will ensure that any major differences observed in both the PRFMs and SPRFMs are brought to the attention of the TMR Project Manager immediately. No processing of data that could be impacted by any potential error in PRFM or SPRFM coordinates shall be undertaken until the differences are resolved to the satisfaction of the TMR Project Manager.

Note: Some points may be controlled horizontally using GNSS, some using conventional traverse. Similarly for heights, some points will be digitally levelled, others using trigonometric heighting or even GNSS. The information in the Survey Report will contain metadata detailing the method used in the location of all SPRFMs supplied and the resulting accuracy achieved.

3 Singular Pointcloud Requirements

This part refers only to the raw scanned data adjusted for position from GNSS location and Inertial Measurement Unit (IMU) corrections for each vehicle pass along a section of road or carriageway.

The Pointcloud from each pass will extend outside the kerbing to the closest limiting factor that will supply a return from the laser (e.g. noise barrier/retaining walls).
3.1 GNSS Concurrent Base Station Specification

The PRFMs/SPRFMs will be used to control the position of the Mobile Laser Scanner (MLS) by processing GNSS baselines using a number of base stations concurrently.

Note: If PRFM/SPRFMs base stations are occupied simultaneously, there is only a redundancy in the GNSS observation at the PRFM/SPRFMs, but generally NO redundancy at the vehicle. Therefore concurrent base station observations (ie 2 or more) only constitute a partially independent GNSS reading.

3.2 GNSS Baseline Specification

Short base lines between PFRM and the vehicle contribute to the best possible positional accuracy outcome (ref. CALTRANS Laser Scanning Specifications – Jan 2011).

The PRFMs/SPRFMs selected as GNSS base stations during Pointcloud capture must ensure that under normal circumstances, no processed baseline from the MLS vehicle exceeds the baseline length (if specified) in the Projects’ MLS Checklist.

For both the GNSS base station and vehicle, the GNSS measurement frequency should be set to one second epochs (or less) and all GNSS receivers shall be dual frequency.

3.3 GNSS Baseline Processing Specification

The method of processing GNSS baselines between the PRFM/SPRFMs base stations and the vehicle will be detailed in the Projects’ MLS Checklist.

3.4 MLS Variables

Generally speaking, environmental factors; colouring; shadowing; Pointcloud density and Pointcloud patterns all affect the quality of the final Pointcloud. Due to the wide variety of MLS hardware manufacturers and suppliers, the ability to customise hardware configurations and the methods used to collect information, it is becoming increasingly difficult to generate specifications that cover all aspects of all systems. It is the intention of this guideline to allow each MLS Contractor to supply sufficient information about their hardware and methods so that TMR can make an informed decision about their suitability. The resulting Pointcloud needs to be of sufficient quality so that identification of features at the desired accuracy can be achieved.

Environmental factors, colouring, shadowing, pattern and density will all need to form part of the MLS Contractors submission. This information should be submitted under the following headings:

- Environmental factors
- Pointcloud colourisation
- A methodology to eliminate shadowing as much as possible.
- Density and pattern diagrams (these diagrams can be theoretical)

Supply diagrams showing the Pointcloud density and pattern (at 80 km/h) in the direction of travel on a one metre square surface that is:

1. Horizontal and directly under the scanner head at the approximate height of the road.
2. Horizontal and at 5 m directly above the scanner head.
3. Horizontal and at 15 m left and right of the scanner head at the approximate height of the road surface.
4. Vertical at 15 m left and right of the scanner head at the same height as the scanner head and parallel to the direction of travel.

5. Vertical at 15 m left and right of the scanner head at the same height as the scanner head and perpendicular to the direction of travel.

Note 1: Multiple scans can achieve a higher overall density of points, but if there are any issues with aligning multiple Pointcloud scans together, the definition of features can become a problem if the point density is not high enough in each individual scan. Therefore all density diagrams above shall be prepared for a single Pointcloud pass only.

Note 2: If multiple scanning configurations are proposed for a project, then multiple diagrams representing each configuration will be required.

Note 3: Supplying a single Pointcloud (LAS file) so that TMR can do the assessment of density and pattern is an option with prior agreement from TMR. Details such as configuration name and vehicle speed will need to be supplied.

3.4.1 Environmental Factors

Different hardware will respond to different environmental conditions in different ways. For example, wet surfaces affect the ability of laser systems to get a return pulse. Rain, standing water and even a heavy dew will all have an effect on the quality of the Pointcloud captured. The MLS contractor shall identify the environmental conditions (heat, rain, dust, etc) that cause degradation to the Pointcloud for
their particular MLS system. A suitable methodology shall be presented with each project that mitigates each of these factors.

3.4.2 Colouring

Pointclouds can be coloured using a number of different techniques. The most common is to colour the Pointcloud using an intensity value derived from the strength of the return signal to the laser scanner. Providing TMR with the range of these values adds more understanding of the resulting Pointcloud, especially in relation to future Data Mining activities. Factors such as normalisation of the intensity value to correct for distance from the scanner are not well communicated at present.

Similarly, Pointclouds can be coloured with Red Green Blue (RGB) values. There are numerous methods currently available to undertake such a process. But the results from each process differ greatly.

TMR is looking to better understand how this information is currently being created and use this knowledge to provide greater value to our clients.

3.4.3 Shadowing

Shadowing due to blocking of the emitted laser rays means that some of the features in the capture area will be obscured. This can occur from sources such as; vegetation cover, steep side slopes, pedestrians and other traffic on the carriageway. For example, if there is a problem with parked vehicles in urban areas then consideration should be given to scanning at night when parked vehicles may be absent or completing additional passes to rectify these issues.

With rotating multi-sensor lasers, the shadowing is reduced by the forward motion of the MLS vehicle combined with the rotation of the multi-sensors giving multiple intersections of the scan lines. If oscillating single-sensor lasers are used in combination on a MLS vehicle, the alignment of the side scanners may be such that the scanning is performed oblique to the direction of travel of the MLS vehicle. Opposing scans will still pick-up points behind obstructions even if one scan is obstructed.

While some MLS systems have fixed alignment of the component lasers, all endeavours must be made to eliminate the effects of shadowing by adopting a suitable operational methodology in capture. This method shall be explained in detail in the MLS Contractors proposal.

3.4.4 Density

For Pointcloud density, some systems are capable of collecting over a million points per second whilst others only a fraction of this. Vehicle speed will also be a major factor affecting the final point density. TMR require the density of the Pointcloud to be sufficient so that points, lines and surfaces meet the accuracy requirements specified.
3.4.5 Pattern

Point cloud patterns vary widely with each having certain advantages/disadvantages. A few examples are provided below:

*Figure 3.4.5a - Oblique scans from rotating single-sensor scanner*

*Figure 3.4.5b - Rotating multi-sensor laser*

*Figure 3.4.5c - Several Oscillating single-sensor Lasers*
4 Multiple Pass Requirements

TMRs normal survey practice requires redundancies to achieve confident statistical results. To give a level of redundancy when capturing Pointclouds, a minimum of three passes shall be run on the pavement. Multiple passes over a period of time also allows the GNSS constellation to change significantly thus reducing the effects of multipathing. Multiple passes also minimise the effects of shadowing.

On dual carriageway roads, if the scans from each carriageway do not fully overlap, each carriageway shall be scanned a minimum of (three) times. Similarly, if the scan of each lane does not fully overlap the adjoining lane, then each lane shall be scanned a minimum of three times.

Horizontal or vertical steps in the delivered point cloud are unacceptable. These steps may occur where the project contains roads that are intersecting, or runs have been stopped or started on a road. At these locations, common control points must be applied to ensure a consistent and comprehensive point cloud is delivered.

In a situation where the current project intersects with an older MLS project that must be matched into, the Project Proposal will provide relevant details and data required to ensure a seamless match of both sets of data. This may include specifying the required overlap of data if any. Sufficient survey control from the older project, which may be include PRFM and/or SPRFM marks which shall be used for control, will be provided by TMR to the MLS Contractor.

If there are multi-lanes in any direction then the most appropriate lane(s) for reducing multipathing and shadowing; whilst also providing maximum coverage should be considered.

On MLS vehicles using multiple scanners to give the multiple aspect coverage in one pass by capturing two or more scans at the one time, these scans do not use independent GNSS constellations. In this case, a minimum of three independent passes are still generally required by TMR.

For some projects, it may be appropriate to minimise the number of passes to less than three but requires prior agreement with TMR. Extreme caution should be exercised and is NOT a recommended practice.

It is the responsibility of the MLS contractor to increase the number of passes or implement other strategies in poor GNSS environments. These areas should be reported to the project manager and noted in the survey report to explain what measures have been implemented to ensure the required accuracies have been met.
5 Imagery Capture

Geo-Referenced Imagery will be acquired over the project area at the same time as the capture of the Pointclouds as a record of the project area at the time of pointcloud capture. Image capture at a different time does not meet this requirement as site conditions may have changed (e.g., a workcrew with traffic control are digging up a section of road when the pointcloud is captured but have left the site when the images are captured). There may be times when an exception can be made with the prior agreement of TMR (e.g., pointclouds captured at night to minimise shadowing caused by vehicles).

When the MCPPC or PPC is made-up of multiple Pointclouds, only those passes that give a new image area are required to be imaged. For example, if a lane is run multiple times, only one of the passes needs to capture the imagery unless there is part of the project area that has not been captured previously.

The Imagery will cover the entire length and width of the project. Images shall be delivered on a per road basis and be appropriately named to differentiate individual TMR roads and side roads. The Imagery must also be indexed so that it can be cross-referenced to a coordinate. For example, camera number, frame number, coordinate, and file name or supplied with specific software with prior agreement from TMR.

Acceptance of imagery will be based on the completeness and quality of the images supplied. Images that are under or over exposed, blurry or not fit for purpose will be rejected and the MLS contractor will be asked to resupply. The MLS Contractor is responsible for ensuring all images are of acceptable quality. The contractor is encouraged to avoid early morning and late afternoon where under and over exposure of photos is likely to be an issue (8am to 4pm is usually ideal). Blurred or distorted images caused by water on the camera lens are also unacceptable.

Geo-Referenced Imagery captured may be used:

- to provide a visual aid at a particular location
- to assist with using the Ground and Feature Model for design and asset management purposes. (The multi-aspect imagery can be interrogated to assess the condition of the terrain and features in the Ground and Feature Model (GFM) and help in the interpretation of the model at particular locations)
- to assist with the “Data Mining” of the Minimally Constrained Project Pointcloud (MCPPC) or the Project Pointcloud (PPC) when future digitising is required. (Since “Data Mining” can occur sometime after the capture of the Pointclouds, the imagery will also assist with an estimation of the relevance of the data for any use)
- as a record of the project area at the time of capture
- for colourisation of the Pointcloud.

As different projects have different requirements for imagery, the Projects’ MLS Checklist may specify the distance between successive image capture locations.

Similarly, the MLS Checklist may specify the required resolution of each image captured.
Note 1: When tendering it may be a requirement for the tenderer to supply example imagery to show the coverage, format and quality that will be delivered.

Note 2: Colourisation of the Pointcloud using the imagery may affect the amount of imagery that needs to be collected. For example imagery may need to be collected on all passes at very short intervals for successful Pointcloud colourisation to occur.

Geo-Referenced Imagery shall be supplied in a file format agreeable to TMR and as outlined in the Project Proposal. To date the accepted file format for geo-referenced spherical imagery is .PGR. All other imagery shall be supplied geo-referenced in .JPG format with an index to allow cross-referencing to a coordinate. Panoramic JPG imagery is unacceptable.

An example setup for multi camera vehicle setups is shown in the diagram below. Cameras should be setup to ensure some overlap between the resultant images from Left & Front cameras; and Front and Right cameras.
6 Requirements for Combining Multiple Pointcloud Passes into a Minimally Constrained Project Pointcloud (MCPPC)

The Minimally Constrained Project Pointcloud (MCPPC) is to cover the entire carriageway in both directions and is to extend to the closest limiting factor that will supply a return from the laser (e.g. Noise Barrier).

In some instances when high accuracy information is not required at the time of Pointcloud capture, a GNSS only solution is the most appropriate capture technique. This may be the case where asset information is the primary objective of the MLS capture. A GNSS only solution will help minimise the initial cost of survey control, but still may have sufficient rigour around the collected data to post control it at a later date should a more accurate survey need arise.

6.1 Pointcloud Consistency

Variations in the raw individual Pointclouds, the MCPCC and the PPC representing the same features will give an indication of the consistency of the MLS system and calibration. The magnitude of the variation can be displayed in various forms to give an indication of the uncertainty that has been achieved.

6.2 Horizontal Survey Uncertainty

The MLS contractor will be required to place or locate check points throughout the project area to ensure that the MCPCC fits horizontally to the Project Reference Frame. The MLS contractor shall generate a report showing the compliance of the MCPCC to the Project Reference Frame. This will be done by tabulating the vector shift of each check point from the coordinates derived from the MCPCC and the coordinates of the check points as positioned using independent means.

Appendix A and F explain this process in more detail.

6.3 Horizontal Relative Uncertainty

The MLS contractor will be required to establish check sites throughout the project area to ensure that the MCPCC fits horizontally within itself. The MLS contractor shall generate tabulated reports showing this compliance. Within sliding windows of up to 200 m, the distances between Clearly Defined Points in the MCPCC must agree with independently measured distances between those same two points.

Appendix B and F explain this process in more detail.

6.4 Vertical – Longsections

A quality assurance string (QQ) shall be digitised from the MCPCC. This QQ longsection string is a defined feature that is also used for other purposes.

In the following road situations, this string shall be:

Two-way traffic - the linemarking separating opposing traffic (ie the centreline).

One-way traffic – the linemarking representing the right hand side of the right hand lane.

(A QQ string is required for each opposing carriageway for dual carriageways.)

(If the road is not line-marked then the centre of the pavement, defined as the mean of the edges of pavement, shall be used as the quality string).
This quality string shall be coded as QQ00. This is a quality assurance string named QQ with an identifier of 00 (zero zero). The project may include multiple separate QQ00 strings that cover single carriageways, dual carriageway situations and side roads.

Longsection quality QQ strings are to have a valid height no more than 10 metres apart along the string and shall cover the entire length of the project including side roads. TMR requires a file containing QQ00 strings in 12da format.

In addition, TMR also requires files containing heights every 10 m taken from each individual raw Pointcloud on the horizontal position of the Quality String (QQ00) points. These strings are to be coded as QQ with the subsequent identifier number reflecting the raw Pointcloud pass numbers LAS 1.2 Classification as detailed in the table in Section 6.8.3.

E.g Raw Pointcloud Pass 1 (LAS 1.2 Classification: 21) would be coded QQ21 (two one), Pass 2 (LAS: 22) would be coded QQ22 (two two).

The project may include multiple individual strings with the same code (e.g Pass 1 for each section of the project). These QQ strings are to be provided in 12da format.

6.5 **Vertical Survey Uncertainty**

The MLS contractor will be required to place or locate check points throughout the project area to ensure that the MCPPC fits vertically to the Project Reference Frame. The MLS contractor shall generate reports showing this compliance. This will be done by tabulating the difference in height between the MCPPC, and an independently derived height for that same Clearly Defined Point.

Appendix C and F explain this process in more detail.

6.6 **Vertical Relative Uncertainty**

The MLS contractor will be required to establish check sites throughout the project area to ensure that the MCPPC fits vertically within itself. The MLS contractor shall generate reports showing this compliance. This will be done by tabulating, within sliding windows of up to 200 m, that the height differences between Clearly Defined Points in the MCPPC agree with independently measured height differences between those same two points.

Appendix D and F explain this process in more detail.

6.7 **Useful Range**

The useful range of different MLS systems will vary. Some systems have long range scanners that can easily measure more than 200 m from the scanner head, while others are significantly shorter range. The accuracy of the scanner at close, medium and long ranges also varies with distance due to angular and distance measuring accuracies. The quality of the IMU in the MLS system will also have an influence on how far from the scanner head a Pointcloud remains useful. Similarly the quality of the GNSS observations will impact on the useful range. Even though a Pointcloud may extend to 200 m from the scanner head, in most cases the part of the point cloud that meets the accuracy specified by the project will be considerably less than that distance.

Hence, TMR requires a statement that defines the useful range of the MCPPC making reference to the project uncertainties and the width covered. This statement will be based on calculations and the experience of the MLS contractor. Further it will be based on the GNSS, IMU and scanner accuracy specifications and procedures adopted.
For example, a useful range statement is provided by the MLS contractor stating “The MCPPC supplied meets or exceeds the accuracy requirements for this project between the edges of pavement.” In this example, it means that for any Clearly Defined Points collected during the project that fall between the edges of pavement, the resulting positions and heights of those points are within the project accuracy requirements specified.

Note: It is common practice that laser scanners measure in plane distances. The requirements for most TMR projects are that the MCPPC be delivered as MGA coordinates. Therefore, there is the potential for errors in the distance measured from the scanner head of up to 40 mm / 100 m due entirely to Point Scale Factor. It is important that this is considered when the MLS contractor makes their “useful range” statements, particularly in relation to the horizontal components.

6.8 Pointcloud (MCPPC) Cleansing, Thinning and Classification

6.8.1 Cleansing

During the capture of the Pointclouds, erroneous points may be captured from other sources that are moving, generally other road vehicles. Care should be taken to remove the influence of these erroneous points when aligning multiple Pointclouds together and later when defining the road surface and other features in the GFM. The final Pointcloud can be cleansed of these points for final delivery.

If the decision is taken to cleanse the MCPPC of erroneous data, care must be exercised to ensure that valid features in the apparently erroneous data are not deleted. It is recommended that data is not deleted, but pushed to other files or classified in such a way so that it can be separated from the clean data. Care should be taken as removal of non-erroneous data during a cleansing process may result in the MLS contractor having to re-supply datasets.

6.8.2 Thinning

When multiple Pointclouds are joined to give an excessively dense MCPPC, it may be that some thinning process is used on the MCPPC to bring the density back to more manageable sizes. For example, thinning the MCPPC on the pavement surface.

If a thinning process is used, care must be taken that ground points remain in the MCPPC and the resultant density of the MCPPC will be greater than that of a single Pointcloud pass.

6.8.3 Classification

Once individual point clouds are combined and delivered as an MCPPC, it becomes difficult to differentiate between individual Pointcloud passes. Therefore, each individual Pointcloud in the MCPPC is to be classified or identified in such a way so it can be differentiated from the other individual Pointclouds.

Each individual Pointcloud inside the delivered LAS file will be named as shown in the table below. In version 1.2 of the LAS file format, classification levels 13 to 31 are empty and are user definable. The following table outlines a classification regime:
<table>
<thead>
<tr>
<th>Individual Pointcloud Pass</th>
<th>LAS 1.2 Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21</td>
</tr>
<tr>
<td>2</td>
<td>22</td>
</tr>
<tr>
<td>3</td>
<td>23</td>
</tr>
<tr>
<td>Etc</td>
<td></td>
</tr>
</tbody>
</table>

### 6.8.4 Gridding

To be developed

### 6.9 Cloud to Cloud Matching

To be developed: matching multiple clouds to one another in Horizontal and Vertical to get a best fit result.

### 7 Adjusting Pointclouds to the Project Reference Frame (PRF) using Ground Control Targets to create a Project Pointcloud (PPC)

For applications where high accuracy is required, the MLS contractor will generally require ground control targets (e.g. a point, a series of points, a target, linemarking, etc) to meet the accuracy required. These targets will be used to align the MCPPC to the PRF to create the PPC.

The major source of error in an MLS project is expected to be in the vertical component. The captured data must be aligned vertically to the local PRF so that when the information is used, it can be used confidently knowing that the local topography and PPC are coincident. That is the existing ground, the PPC and the digital GFM must be consistent with the PRF.

Appendix E explains the targeting process in more detail.

If the MLS contractor deems that additional targets are required to meet accuracy requirements in areas of poor GNSS reception, it will be the responsibility of the MLS contractor to place these extra marks.

Generally, the PPC is to cover the entire carriageway in both directions and is to extend to the closest limiting factor that will supply a return to the laser (e.g. Noise Barrier).

#### 7.1 PPC Consistency

Variations in the PPC representing the same features will give an indication of the consistency of the MLS system and calibration. The magnitude of the variation can be displayed in various forms to give an indication of the accuracy that has been achieved.

**Horizontal Survey Uncertainty**

Refer to Part 6.2 and replace all references to MCPPC with PPC

**Horizontal Relative Uncertainty**

Refer to Part 6.3 and replace all references to MCPPC with PPC

**Vertical - Longsections**

Refer to Part 6.4 and replace all references to MCPPC with PPC

**Vertical Survey Uncertainty**

Refer to Part 6.5 and replace all references to MCPPC with PPC
Vertical Relative Uncertainty

Refer to Part 6.6 and replace all references to MCPPC with PPC

Useful Range

Refer to Part 6.7 and replace all references to MCPPC with PPC

Project Pointcloud Cleansing, Thinning and Classification

Refer to Part 6.8 and replace all references to MCPPC with PPC

8 Ground and Feature Model Requirements

8.1 Background

The PPC (or MCPPC if no PPC exists) will be used as the source to digitise a Ground and Feature Model (GFM). This GFM may be used to model the road surface, the general formation shape and any observed road furniture.


All points and strings shall be coded as per the TMR Surveying Standards December 2014, Schedule 1, with particular attention paid to the situational examples provided.

8.2 General

If points are digitised from a PPC (or MCPPC) into a GFM, the horizontal and vertical positions of those points are deemed to meet the Horizontal and Vertical Locational and Relational Uncertainties of the project. This assumption is made based on the close relationship between the extracted information (GFM) and the data source (PPC or MCPPC). It also ensures that meticulous digitising and accurate extraction algorithms are being used in the GFM generation process.

If, the MLS contractor:

- proposes to use lower accuracy algorithms
- is working with a point cloud with a low point density or Pointcloud patterns not suited to the extraction task, and/or
- proposes to speed up GFM creation by relaxing care and attention when digitising

then, the accuracy loss between the PPC (or MCPPC) and GFM must be quantified. To do this, a new set of uncertainties will be supplied to reflect the accuracy loss between PPC (or MCPPC) and GFM. These values are to be supplied in addition to the uncertainties of the PPC (or MCPPC).

Note: If there are areas where the contractor has not achieved the uncertainties specified in the brief, the MLS contractor shall identify these areas in the Survey Report so that a negotiation can occur around final payment.

To better understand the likely quality of the digitising processes used by individual MLS Contractors, TMR requires an outline the methods that will be used to create the GFM. The Projects’ MLS Checklist will be used to provide TMR a summary of the proposed processes.

For 95% of any check points chosen on a non breakline detail feature in the MCPP, the perpendicular distance between it and the line segment representing it in the GFM must be less than 100 mm.
e.g. linemarking

8.3 **Terrain**

Generally, the extents of the GFM extraction area that will be supplied as part of a Survey Brief will be larger than what would be practicable to obtain from the PPC (or MCPPC if there is no PPC). Extraction of the terrain surface off the pavement is generally required within the extraction extents particularly where the grass is mowed or where the operator has confidence that the ground surface is being represented (ie when there is no grass on the terrain surface). If there are trees or high grass that provides a false representation of the terrain, these areas do not require terrain extraction, but should be identified in the survey report and by uniquely identified closed Boundary (BY) polygons in the digital GFM created.

Special note shall be taken in relation to stringing conventions to ensure the creation of a valid Triangular Irregular Network (TIN) to define the road terrain surface.

Note: Only codes in the SURVEY DTM model are used for producing the TIN.

Points digitised on the pavement and kerb/barriers have a defined extraction interval (vide Section 8.4 & 8.6) that will ensure that the TIN created will be representative of the surface, ie, there will be minimal interpolation if the default parameters are adopted.

For 95% of all differences between a terrains point interpolated height, as determined from the TIN, and its independently levelled value, must not be greater than that shown in the GFM TIN Interpolated Accuracy requirements in the Projects’ MLS Checklist.

8.4 **Pavement Extraction**

A control line (QQ00) will have already been digitised as part of the vertical long-section check performed. All QQ00 are to be duplicated as RC00 but with a longitudinal point every (y) metres. This control line will be the reference for the pavement definition. The pavement shall be represented by a series of longitudinal Breaklines. These Breaklines are to be coded as RC (Road Crown) and are to be created parallel to the control line (RC00) every (x) metres across the pavement to within 300 mm of the edge of pavement (EP string) or kerb lip (KL string). All these Breaklines are to have a valid height every (y) metres along the string within the extraction extents. (x) and (y) will be detailed in the Projects’ MLS Checklist.
8.5 Linemarking Strings

The linemarking on the pavement within the extraction extents shall be digitised. QQ00 strings may be duplicated as an appropriately coded linemarking string.

Note: Linemarking is not used to create the TIN. It is only to show where the linemarking exists on the road. As such it is only needed to be located at changes in type of line, changes in direction and with points close enough to give a reasonable approximation of curves. The points on linemarking strings will not need to be located every (y) metres, only enough to indicate their true horizontal position (vide diagram in 8.2).

8.6 Barrier Device Strings

Any Barrier devices within the extraction extents such as Median Kerbs, Kerb and Channel, Concrete Barriers, Guardrails, Fences along the median, Wire Rope Barriers, etc… shall be digitised.

The kerb and channel within the extraction extents shall be digitised as KL (Kerb Lip), KI (Kerb Invert) and KT (Kerb Top) strings.

All these Breaklines are to have a valid height at least every five metres along the string. It is recommended that manual digitising is performed to ensure compliance with horizontal, vertical & GFM TIN interpolated accuracies.

The TMR Surveying Standards December 2014, Schedule 1 has situational examples on how to locate this information.

8.7 Road Signage

Any observable road signs within the extraction extents shall be digitised. Care should be taken in the imagery capture to ensure that both sides of signs that are double sided are captured. Comments that identify the type of sign or a summary of the words that appear on the sign shall be recorded on these points in the digital GFM. When delivered, the comment should be attached to the point feature or line string as vertex text.

8.8 Features and Services

Any identifiable features and services that can be confidently located within the extraction extents are to be located, e.g. Street Lights, Noise Barriers, Large Signs, Variable Message signs, Gantries, Pits, Gully Traps, Manholes, Edges of Concrete, etc.
8.9 **Structures**

Bridge overpasses shall have basic bridge strings extracted:

The purpose of extraction is to provide an envelope that represents the available width and height. The basic strings should consist of the following:

- A Soffit string (SF) at the entry and exit to each overpass
- Additional Soffit Strings (SF) if there is another soffit under the bridge that effects clearance
- Abutment Strings (HT and HB)
- Headstock Top and Bottom Strings (HT and HB)
- Pier Top and Bottom Strings (BE)
- Centre of Columns or Piles (PBPC and PBPP) [and a diameter if applicable]
- Any concrete protection or other feature that will limit clearance. i.e concrete barriers, stone pitching, rock cutting, etc.

9 **QA, Reporting and Delivery**

A number of reports shall be prepared that outline the results of the MLS operation. These should include but not limited to the following documentation:

a) MLS system reports – Component calibration, alignment and self tests.

b) PDOP value report during the collection of the Pointclouds (This report should relate to a position and run number rather than a time of capture).

c) Statement on how the IMU (and wheel encoder if fitted) observations are applied during times of degraded, lost, or obstructed GNSS signal reception.

d) If a multi-laser system is used, evidence of how the scans from each scanner join.

e) A 12D Model file of the long-section plots of (where appropriate) each individual Pointcloud, MCPPC and PPC taken along the quality string QQ00.

f) Reports on the horizontal and vertical compliance of the MCPPC, PPC and individual Pointclouds to the Project Reference Frame.

g) A Survey Report shall be prepared outlining the successful completion of the project and any problems that have been encountered along the way.

A statement describing how any new PRFMs/SPRFMs have been coordinated and levelled shall be outlined in the Survey Report. (eg. SPRFMs Numbered 1234-2345 have been located using GNSS techniques pursuant to meet or exceed SU and PU < 60 mm (equivalent to superseded Class B, 2nd Order) {vide SP1 v2.1} and levelled using a digital level from the adjacent PRFMs).

If there are areas where the contractor has not achieved the accuracy specified, the MLS contractor shall identify these areas in the Survey Report so that a negotiation can occur around final payment.

The Survey Report shall be signed by the person responsible for the survey. This person shall be a Surveyor as defined in the TMR Surveying Standards.

For a summary of the deliverables, file naming and formats required for successful delivery of Mobile Laser Scanning information, refer to Appendix G.
Appendix A – Horizontal Survey Uncertainty

For 95% of points, the length of the vector between:

a) The coordinates of a Clearly Defined Point in the MCPPC, PPC or GFM and,

b) The coordinates of that same Clearly Defined Point derived by independent means; must be less than \( (x) \) mm \((x)\) will be specified in the Projects’ MLS Checklist.

This process is provided as a means to check the absolute horizontal positioning during processing and can be used by independent auditors to check the supplied data for horizontal fit to the PRF.

For example if error allowance \( (x) = 30 \) mm

There is always a trade off between checking everything and not checking anything. For each project, this balance may be different and the MLS Checklist provides the flexibility to customise the distance between successive check point locations (in the context of this document, check points and check sites are defined in Appendix F).
Appendix B – Horizontal Relative Uncertainty

Within a sliding window of up to 200 m, 95% of all distance differences between Clearly Defined Points in the MCPPC, PPC or GFM must agree with independently measured distance differences between those same two points by (y) mm + (yy) ppm of the distance between the points as defined in the GFM section of the Projects’ MLS Checklist. Even over shorter distances the same formula can be used to check the information provided as the (yy) parts-per-million (ppm) over short distances becomes negligible and the formula effectively becomes (y) mm.

For example, the relative distance difference between two points in the PPC have been measured by total station and the difference in distance is compared using (y) mm + (yy) ppm of the distance between them.

If (y) = 10 mm and (yy) = 30 ppm

There is always a trade off between checking everything and not checking anything. For each project, this balance may be different and the MLS Checklist provides the flexibility to customise the distance between successive check site locations (in the context of this document, check points and check sites are defined in Appendix F).
Appendix C – Vertical Survey Uncertainty

For 95% of all points tested, the difference in height between the MCPPC, PPC or GFM and an independently derived height for that same Clearly Defined Point must be less than (z) millimetres. The MLS Checklist provides categories for Vertical Survey Uncertainties and Check Site Spacing’s.

There is always a trade off between checking everything and not checking anything. For each project, this balance may be different and the MLS Checklist provides the flexibility to customise the distance between successive check site locations (in the context of this document, check points and check sites are defined in Appendix F).
Appendix D – Vertical Relative Uncertainty

Within a sliding window of up to 200 m, 95% of all height differences between Clearly Defined Points in the MCPPC, PPC or GFM must agree with independently measured height differences between those same two points by (zz) mm + (zzz) ppm of the distance between the points. Over short distances the same formula can be used to check the information provided as the (zzz) parts-per-million (ppm) over that short distance becomes negligible and the formula essentially becomes (zz) mm.

For example, the relative height difference between two points in the MCPPC has been levelled by digital level and the difference is compared using (zz) mm + (zzz) ppm of the distance between them. If (zz) = 10 mm and (zzz) = 30 ppm.

The MLS Checklist provides categories for vertical relative uncertainties and Check Site Spacing.

There is always a trade off between checking everything and not checking anything. For each project, this balance may be different and the MLS Checklist provides the flexibility to customise the distance between successive check site locations (in the context of this document, check points and check sites are defined in Appendix F).
Appendix E – Ground Control Targeting

The target size, shape, placement regime and configuration are required as part of the MLS Contractors proposal. The spacing of these targets will depend on the MLS system components and methodology chosen by the MLS Contractor.

To accurately position targets, they will be located by independent means, coded as PGCP points (vide TMR Surveying Standards December 2014) using PRFM or SPRFM as datum. The PGCP points must be included in a 12D Model .12da file format. These targets will generally be objects that are permanent in nature and can be accurately identified and positioned from within the PPC and by conventional total station, GNSS and/or digital levelling.

In addition to the requirements for ground target spacing as listed in the table below, a ground control target must be placed adjacent to the start and end of the project. Additionally, a ground control target shall be placed at all intersections of state controlled (main) roads within the project area. This requirement will allow accurate matching of future MLS on adjacent main roads and extensions to existing MLS.

Note: To better understand the usefulness of these targets it requires an underlying understanding of the quality and accuracy of the PRFM and SPRFM. Thus the requirement to outline the methodology used in the location of all survey control points in the survey report.
Appendix F – Check Sites and Points

Horizontal - Survey and Relative Uncertainty Check Points and Sites

To check the horizontal survey and relative uncertainty, Clearly Defined Points will be located by independent means as PQAP points. These points will generally be objects that can be accurately identified and positioned from within a PPC (or MCPPC) and by conventional total station or GNSS reading. Some possible examples of objects that are Clearly Defined Points are:

- Corners of concrete (bridge abutments, culverts, etc)
- Centres of light poles or posts
- Ends of line marking strings
- Guardrail Posts
- Targets that have been specifically placed for this purpose.

In each case, a comment should be attached to the PQAP point that unambiguously describes the point located.

Sites will generally be spaced evenly throughout the project as defined in the MLS Checklist. At each site the MLS Contractor will locate a total of at least 10 points within each defined section. Each PQAP point will be at least 10 m from any other PQAP point.

These checks of Clearly Defined Points will be independently located and the methodology detailed in the Projects’ MLS Checklist.

Vertical - Survey and Relative Uncertainty Check Points and Sites

Height quality checks will take the form of QQ strings. The QQ strings will be a length of approximately 70 metres with valid points at approximately 10 metre intervals longitudinally along both carriageway edge-lines. At the approximate midway point of each longitudinal QQ string, a cross sectional QQ string will be located. These strings will have valid points:

- Sufficient to define the road surface where there is obvious rutting OR Equally spaced across each travel lane with at least two valid points in each lane, and
- On the linemarking.

The methodology, including Check point & Site spacing, used for capture of these QQ will be documented in the Projects’ MLS Checklist.

Note: To better understand the usefulness of all of these checks it requires an underlying understanding of the quality and accuracy of the PRFMs and SPRFMs. Thus the requirement to outline the methodology used in the location of all survey control points in the survey report.
Appendix G – Summary of Deliverables, File Naming and File Formats

Geo-Referenced Imagery

Geo-Referenced Imagery shall be supplied in a file format agreeable to TMR and as outlined in the Project Proposal. To date the accepted file format for geo-referenced spherical imagery is .PGR. All other imagery shall be supplied in .JPG format with an index to allow cross-referencing to a coordinate (as per Section 5 Imagery Capture).

Imagery shall be delivered on a per road basis with each individual road requiring a unique file identifier. All side roads shall be delivered as separate files with unique file identifiers. Imagery shall at least meet the maximum specified “Imagery photo-point capture intervals” in the MLS Checklist.

Long Sections

TMR requires separate files in 12da format containing the QQ00 from the:

- MCPPC (or PPC), and
- Individual Pointclouds.

Pointclouds (PPC OR MCPPC)

1 km Tiles:

Pointclouds should be blocked into individual one kilometre tiles based on the MGA coordinate system. Tiles are not to exceed 4GB in size or contain more than 100 million points. Where a 1 km tile exceeds these parameters, this tile must be blocked into smaller individual square grid tiles.

All tiles shall be supplied in LAS version 1.2 file format. The naming convention for these files is to be:

Road_Type_Date_Block where:

Road = the Road Section Number e.g. 12A
Type = the type of file
e.g.  PPC for Project Pointcloud
Date = the date of capture / production in year/month format
e.g. YYYYMM
Block = PPPPP_ZZ_EEE_NNNN where -:
PPPPP = the Projection used
ZZ = the projection Zone number (00 if N/A)
EEE = the three most significant numbers of the easting coordinates of the south-west corner of the data grid block,
NNNN = the four most significant numbers of the northing coordinates of the south-west corner of the data grid block.
e.g. 12A_PPC_201212_MGA94_56_560_6800
Note: The use of the underscore (_) to separate the fields of the file name demands that the field type information is in the correct field position. It also allows a variable field length so that the number of characters in each field can change as required but the field must exist.

Note: Where a one kilometre grid tile has been reduced to smaller tiles, the EEE and NNNN fields shall be lengthened to allow unique tile file identification.

*e.g. 12A_PPC_201212_MGA94_56_5605_68005*

### Layout File:

A layout file consisting of a one kilometre grid covering the area of interest is required in a format suitable to TMR such as a MapInfo .tab file or a 12D Model .12da file. It is to consist of the boundary of interest for the project superimposed on the grid with closed polygons of each grid block. This Layout file is to be named the Project name appended with Layout. That is: 

TMRGT1208_MLS_12A_Layout

### Ground and Feature Model

Ground and Feature Model shall be provided in 12D Model .12da file format. The file name should be as per the convention above but using GFM instead of PPC.

*eg. 12A_GFM_201301_MGA94_56_560_6800.*

Note: Do NOT block the GFM into 1 km tiles.

### Project Reference Frame

All observations, reductions and reports that relate to any new PFRM or SPRFMs shall be delivered to TMR. These should generally take the form of a 12D Model .12da file, an ASCII Text or PDF Files or similar as agreed by TMR.

TMR requires that any GNSS data recorded be supplied in either RINEX or TDEF format. Field observation sheets recording details of each setup shall also be supplied, generally in PDF format

### Quality Assurance

Quality Assurance is to be supplied in a file format agreeable to TMR and as outlined in the brief response.

### Survey Reporting

The Survey Report shall be supplied in a PDF file format or similar as agreed by TMR.