LG TRRIP

Local Government Transport Road Research and Innovation Program

An initiative by: WALGA, The Government of Western Australia, Main Roads Western Australia, NTRO

Road Data Collection Technologies for Local Government

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About LG TRRIP

The Local Government Transport and Roads Research and Innovation Program (LG TRRIP) is an initiative between Main Roads Western Australia and the Western Australian Local Government Association.

LG TRRIP has a strategic commitment to the delivery of collaborative research and development that positively contributes to the design, construction and maintenance of safe, sustainable transport infrastructure in Western Australia.

Summary

This report aims to address the challenges of road data collection experienced by local governments (LG) by providing information on the types and uses of road data collection technologies and to enable greater adoption of the technologies.

The types of road data are presented as asset inventory data, defect data and condition data. Guidelines from the Western Australian Local Government Association (WALGA), Main Roads WA, Austroads and the Institute of Public Works Engineering Australasia (IPWEA) have been referenced. Due to the range of guidance available on the different data types, the report provides only a summary of the data types with sufficient detail to identify the technologies that can be used for data collection.

The most important uses of road data are presented from an LG perspective. The uses include renewal planning, specified and recovery funding, asset registers, road asset register validation, asset valuations, network performance and gifted assets.

With the uses and types of road data as a basis, a range of established and new road data collection technologies are identified and described. The technologies include, but are not limited to:

- automated visual condition assessment using computer vision
- inertial profilers
- lidar and laser-based technologies
- traffic speed deflectometers
- drones.

The summarised assessment of the technology capabilities is shown in Table 1.1. Note that this is a very generalised summary and results can vary significantly between suppliers and in different applications. A rating of ‘H’ indicates high capability or cost, ‘M’ indicates a moderate capability or cost and a rating of ‘L’ indicates a low capability or cost when compared against all the technologies.

Table 1.1: Summary of key technology types and their capabilities

Technology type	Potential range of road asset inventory that can be collected	Potential range of road defect data that can be collected	Typical level of accuracy of detection	Scale of cost
Computer vision	H	H	M	L
Inertial profilers	–	L	H	M
LiDAR and laser-based technologies – surface condition	–	L	H	H
LiDAR and laser-based technologies – road environment	L	M	H	H
Traffic speed deflectometers	–	L	H	H
Unmanned aerial vehicles	L	L	M	L

Following the explanation of the technologies, guidance has been provided on how LG can plan and specify the use of data collection technologies and services. The guidance is summarised in the process shown in Figure 1.1. This also provides a ready reference for readers in finding the relevant section of the report when planning for road data collection.

Figure 1.1: Process for planning road data collection

1. • confirm the needs and uses of data (with reference to Section 2.2)
2. • identify the type of data to be collected and whether this includes asset inventory data (Section 2.1.1), defect data (Section 2.1.2), and/or condition data (Section 2.1.3)
3. • identify the technologies that can provide the data (Section 3)
4. • specify the workplace health and safety requirements for the data collection (Section 4.2)
5. • confirm the range or extents of the data collection such as lengths of road, extents of verges and numbers of bridges, and identify the information to be provided to the contractor (Section 4.3)
6. • confirm what type of data is to be collected, identify the systems that will receive the data and required data formats (Section 4.4)
7. • consider contractual matters (Section 4.5)
8. • identify the level of data accuracy and how to validate and check the data (Section 4.6)
9. •arrange the data collection and then manage data storage in the asset register (Section 2.2.4) and report for the uses of data (Section 2.2).

The report provides the necessary technical information and guidance to enable LG to increase the use of current road data collection technologies.

Acknowledgements

NTRO acknowledges the information provided by LG practitioners on their experiences in road data collection.

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1 Introduction

Data collection to populate asset registers, log maintenance defects and assess asset condition is a commonly undertaken task, that often involves a high degree of manual effort. The typical methods can involve the manual identification, measurement and recording of data on portable devices with significant processing of data in the office. This more manual approach can suffer from subjectivity, poor data quality, inefficiency and can expose staff to safety risks. While there is an increasing use of semi-automated data collection equipment, the benefits are constrained by the ability of LG to specify the methods effectively and to gain the best insights from the data. In terms of outcomes, the methods currently used prevent LG from making optimal decisions about asset funding, lifecycle management, risk management and services to the community.

1.1 Scope

This technical report identifies the status of data collection technologies available in WA and Australia with relevance to the needs of LG and how LG can implement these technologies. When identifying the technologies, the scope included:

- technologies that were considered mature or available in WA
- technologies relevant to the data collection needs associated with asset data and condition
- a preference for technologies that automated data collection, with minimal manual effort.

The types of technologies are those used in the collection of road condition data and road asset data. This includes assets and their conditions such as:

- road surfaces, pavements, edges and shoulders
- the wider road environment including vegetation and signage
- bridges and large culverts.

With the focus being on road asset management, a range of technologies and applications were not included such as:

- traffic counting or monitoring
- road user attributes
- drainage data collection other than large culverts
- road safety assessment tools.

1.2 Objectives

The objectives of the report, in the context of LG management of road networks are to:

- enable improvements in data collection efficiency by LG
- improve safety in data collection
- improve access to higher quality data sources as provided by semi-automated technologies
- provide guidance for the adoption of different data collection technologies by LG
- ultimately, to reduce the data collection cost over the long term.

1.3 Background

Four key sources guided the scoping of the project and resulting report:

- *Road Visual Condition Assessment Manual* (WALGA 2016) (referred to hereafter as 'the Manual')
- *Automated Detection of Road Defects* (IPWEA 2023)

- a WA Road Research and Innovation Program (WARRIP) project with similar elements
- NTRO's experience in developing and delivering road condition survey services.

The Manual provides a comprehensive listing of common road and footpath defects, with ratings for extent and severity. Although the Manual was prepared in 2016 on the basis of manual inspections, the identification and rating methods are also being used with semi-automated detection technologies. This raises the need for guidance on the types of technologies that could inform the detection and rating of defects and on the need for the data types used for manual collection and semi-automated collection to align. Note that at the time of writing, the Manual was being updated to incorporate semi-automated data collection methods.

The Institute of Public Works Engineering Australasia (IPWEA) NSW Division assessed AI-based technologies for automating road defect detection and condition assessments in their report: *Automated Detection of Road Defects* (IPWEA 2023). The assessment involved surveying 295.8 km of roads within four local government areas. The roads included different road classes, urban and rural regions, and sealed and unsealed roads. The trial included 7 suppliers of different survey and support technologies and focused on defects such as potholes, edge breaks, wearing surface defects, pavement defects and pavement cracking. The report concluded that the technologies show promise in minimising manual tasks, with visual comparisons suggesting over 70% accuracy in defect identification. Ongoing development in the technologies are expected to enhance their capabilities and accuracy.

At the time of writing this report, a separate project was being conducted on a similar topic as part of the WA Road Research and Innovation Program (WARRIP). The project was to improve road defect data collection by Main Roads WA (Main Roads), with a key task being research on data collection technologies. While further details of the project are not available for public reporting, some information has been available to support the work for this report.

The National Transport Research Organisation (NTRO) operates a fleet of road condition surveying equipment. The fleet includes the technology types described in Sections 3.2 to 3.5. In addition to the experiences gained from the configuration of its fleet, NTRO has experience in scoping and reporting on the data collection services requested by a range of LGs, state and private road agencies. These experiences have helped refine the report.

2 Types and Uses of Road Data

Before introducing the technologies that can assist with road data collection, some clarification on why the data is needed and what types of data are needed is merited. To answer these questions, the types of data, grouped as asset inventory data, defect data and condition data, are described in Section 2.1. The uses of road data are described in Section 2.2.

Other types of data that may be associated with managing infrastructure assets include customer requests, user data such as traffic volumes, and financial data. However, as this report is focused on collecting asset defect and condition data, the other data types are not included in the report.

2.1 Types of Road Data

The *Austroads Road Asset Data Standard Version 4* (Austroads 2022) defines 14 groups of data types called function groups, that are needed for effective road management and investment. As this report is focused on data collection technologies for assets and their condition, only the function groups of inventory (the asset register) and condition (the condition of the assets) will be further detailed.

2.1.1 Asset Inventory Data

Inventory data that is common to most infrastructure assets includes:

- dimensions that may include length, width, depth and relative level
- quantity based on the type of measurement units such as per item, area or volume
- material details such as types and strength (of concrete, pavement)
- estimated useful life
- construction or installation date.

Table 2.1 shows the common road asset types in addition to the previous list. Further details on data requirements for different asset types can be found in *Austroads Road Asset Data Standard Version 4* (Austroads 2022), the *International infrastructure Management Manual* (IPWEA 2020) and practice notes, the A-spec digital data specifications (A-SPEC 2015) and the As Designed As Constructed (ADAC) standard (IPWEA QLD and NT 2024).

Table 2.1: Common road asset types and data types

Asset type	Common data types	Typical spatial data types
Road surface	Surface type (sealed or unsealed), layer thickness, material type (asphalt, bitumen, aggregate), technical specification of material type (e.g. AC7), number of lanes	Polygon or polyline
Road pavement	Layer thickness, technical parameters such as strength and compaction.	Polygon or polyline (centreline or road or lane)
Kerbing and edges	Kerb type (barrier, semi-mountable etc.), material strength, location (side of road)	Polyline
Road shoulder and verges	Type (table drain, swale, crossover, crossover culvert etc.), offsets from road edge or other feature, depths of the invert of drainage assets	Points for start and end inlets or outlets, polylines
Paths	Type (footpath, cycle lane, ramp, ancillary path), material strength or other technical measure.	Polyline
Street furniture	Manufacturer, model type, type of street furniture (bus shelter, benches, bins, bike stands, planter boxes etc.)	Point
Street lighting	Light type, luminaire type, wattage or lumens, pole type	Point

Asset type	Common data types	Typical spatial data types
Signage and line marking	Signage – type (regulatory, warning, parking, guide), sign text details, height, post material, panel materials, offset to road feature. Line marking - type (parking lines, centrelines), colour, design reflectivity	Signage – point Line marking for parking – polygon Line marking of road lines –line Line marking symbols e.g. arrows – point
Vegetation and street trees	Vegetation - type collectively or by species Trees - species, diameter at breast height (DBH), health rating, overall height, canopy spread, trunk offset to road feature	Polygon for vegetation area Point for individual trees or plants of interest
Bridges and large culverts	Bridges – componentisation as superstructure, substructure etc. or to individual detail such as deck, abutments, piers. Dimensions and material details specific to the type of component, design loading. Culverts – type (e.g. crown box, concrete pipe), loading class, flow direction, cross-sectional area headwall details	Bridges – Point or polyline (centreline) Culverts – Point or polyline Culvert headwall - point

Source: Adapted from Austroads (2022).

Bridges and large culverts are included in Table 2.1 as they were included in the scope of the report. The term 'large culverts' represents culverts with an individual span of at least 3 m, as defined by Main Roads (Main Roads WA 2013). Smaller culverts, groups of culverts and their data collection needs have not been assessed for the report.

In addition to the Austroads standard, two industry guides on the specification of asset inventory have been developed and are widely used across LG in Australia: A-Spec and ADAC.

A-Spec (A-SPEC 2015) is an asset specification framework designed to standardise the delivery of 'as-constructed' digital data for infrastructure assets in a GIS-ready format. A-Spec has data specifications for the asset types of buildings, drainage infrastructure, public open space and recreational assets, assets within the road reserve, sewerage and wastewater infrastructure, optical fibre and telecommunications assets and water supply infrastructure.

The ADAC (Asset Design and As Constructed) (IPWEA QLD and NT 2024) data specification was developed by IPWEA QLD and NT for transferring asset data between asset constructors and asset owners. The ADAC specifications include roads, water supply, sewer, stormwater, roads, open space and building assets.

Technologies for Collection of Asset Data

It is important to note that a large portion of the asset data presented in Section 2.1 cannot be collected by contemporary semi-automated data collection technologies. This is an important consideration when planning for asset data collection. Table 2.2 summarises the capabilities of current asset data collection technologies that are detailed in Section 3.

Table 2.2: Capabilities of technologies in collecting common road data

Asset inventory data type	Semi-automated data collection
Dimensions such as length, width, depth and relative level	LiDAR with feature detection can provide lengths, widths and depths of assets within the field of view.
Quantities	Potentially can be determined through post-processing of technologies that have feature detection capability or based on spatial attributes.
Material types and details	Generally there is no capability to discern the material type, although this can be inferred from the asset type.
Estimated useful life or design life	No capability.
Construction or installation date	No capability unless the inspection date coincides with an asset handover.

Asset inventory data type	Semi-automated data collection
Asset component types (e.g. type of kerb, type of sign)	Limited capability. Image feature detection may identify common sign types and can be trained to identify kerb types. Some types may be inferred by dimensions e.g. shared paths inferred by width. One UAV based system is capable of detecting bridge component types once trained. Vegetation type can be identified from some systems using satellite imagery.
Location, either relative to a road feature or geospatial	Strong capability for spatial location with accuracy of location subject to the accuracy specified for the data collection and having viable satellite or GIS communications. Location relative to a road feature such as a centreline is available for technology that accepts pre-loaded shapefiles.

2.1.2 Defect Data

Defects of road assets can be defined according to:

- their appearance and how they affect the asset
- their location relative to the asset
- their severity and extent
- aggregated severity and extent across a larger road section
- asset usage or function parameters such as road hierarchy or traffic volume
- assessed or inferred risk arising from the defect
- organisation response times for the repair of the defect
- cause of the defect
- treatment types or work resource types.

Only the first three attributes listed above are included in the range of data types that can be collected with current technologies in the scope of the report. The fourth attribute, aggregated extent, can be determined through post-processing of data (which may happen in the associated software application).

Severity refers to the magnitude or intensity of a defect while extent refers to the area or length affected by the defect. Severity is typically measured based on the physical dimensions of the defect while extent is typically measured as the percentage of the area affected.

Severity and extent measurements can be translated into a rating scale such as the commonly used 0 to 5 scale. As used in the Manual, a rating of 1 indicates no presence of the defect while a rating of 5 indicates a very high severity and extent of the defect, based on the assessment method being used. For system reporting, defects can also be rated ‘0’ to indicate it is not applicable. Note that this rating system can also be converted to a road condition rating by aggregating the individual scores into larger road segments, as is covered in the Manual.

Figure 2.1 with its attached table shows an example of the calculation of a condition index based on severity and extent for local surface defects as per the Manual.

Figure 2.1: Example of local surface defect measurement of extent and derivation of defect rating

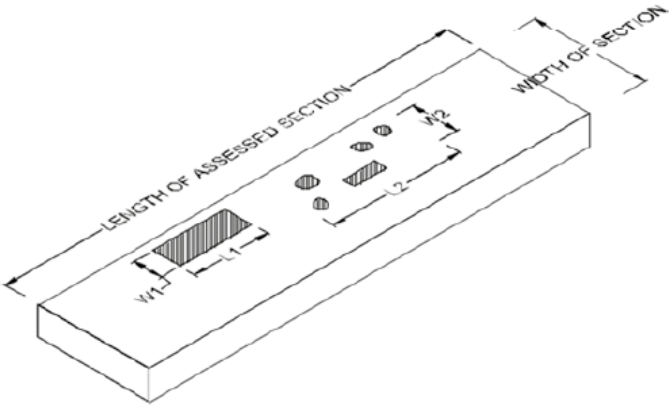


Figure 5.1: Measuring local surface defects extents

Table 5.1: Local surface defect measurements

	Rating
Not Applicable	0
No area affected	1
0% < area affected < 5%	2
5% < area affected < 10%	3
10% < area affected < 20%	4
20% < area affected	5

Source: WALGA (2016), p16, Fig. 5.1 and Table 5.1.

Table 2.3 shows the typical asset defect types being considered in this report, including road defects, roadside defects and bridge defects.

Table 2.3: Defect types

Defect category	Defect types
Road surface	Sealed surfaces - localised surface defects (such as shoving, corrugations, depressions), patches, potholes, non-structural cracking, surface deficiencies (delamination, flushing, polishing, ravelling, stripping) Unsealed surfaces – potholes, localised rutting, localised corrugations, dust extent, surface texture
Road pavement	Structural cracking, rutting, pavement undulations
Road shoulder	Edge breaks, edge drop offs, unsealed shoulder defects (rural roads only), kerb defects (urban roads only), table drain defects, excess vegetation, loss of shoulder material
Road verge	Excessive vegetation growth, tree damage, erosion effects
Litter and debris	Lloose gravel, roadkill or hazardous tree branches/trees
Signage and line marking	Missing or illegible signs, damaged or ineffective sign, faded or missing line marking
Street furniture	Varies depending on the materials and use, level of safety hazard.
Street lighting	Light failure or damage, pole corrosion, damage or displacement.
Vegetation and tree	Growth in clear space of road, sign or path, pest infestation, fallen limbs, dead trees.
Bridges	Depends on the material and location – concrete spalling, concrete or steel cracking, steel corrosion, deformation or displacement, joint defects, loss of section, rotting of timber, pests, vegetation on structure or obstructing waterway, erosion, impact damage, graffiti etc.

Source: Expanded from WALGA (2016).

Technologies for the Collection of Defect Data

The current data collection technologies have strong capabilities in detecting defects, and this forms the majority of the technology reporting. There is a large range of different technologies and capabilities in detecting different types of defects as detailed in Section 3. In Section 3.8, Figure 3.12 shows the combinations of technologies being used by locally available suppliers.

2.1.3 Condition Data

The detection of defects is a key input into the derivation of asset condition for road assets. In the Manual, ‘condition’ refers to the current state or performance of the road pavement and related assets based on observed characteristics, primarily visual surface defects.

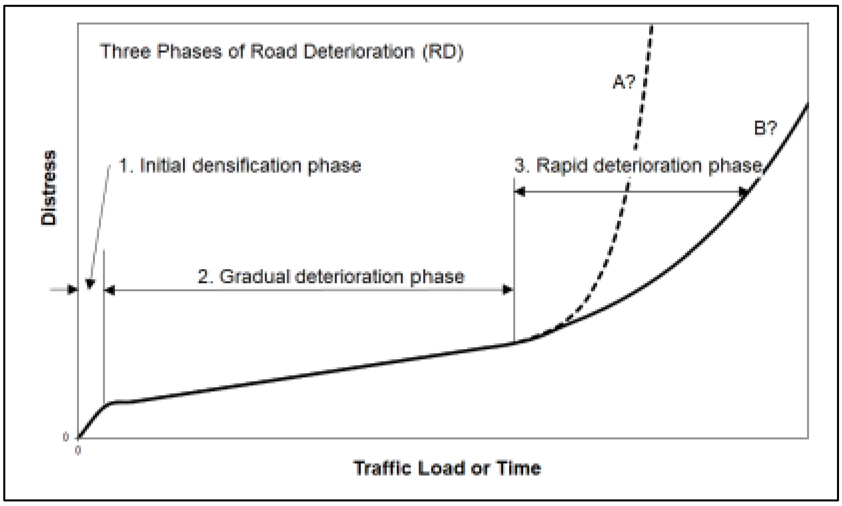
Accurate, up-to-date data on asset condition is often seen as critical for asset managers to develop plans that minimise whole-of-life cycle costs and maintain target levels of service. The visual condition assessment described in the Manual provides a record of how the network is performing at the time of the inspection and enables identification of potential sites for a more detailed assessment which assists in scoping maintenance and capital works.

As described in Section 2.1.2, the Manual provides a system for assigning a rating to each type of defect where 1 represents no or limited severity of the defect, and 5 represents a very high severity and extent of the defect. Defects that relate to a similar type of asset can be aggregated to produce a composite condition index. The common composite condition indexes are called the Pavement Condition Index (PCI) (also called structural condition index), Surface Condition Index (SCI), and Drainage Condition Index (DCI). The formulation of these composite indices uses the advanced maximum method, which is designed to emphasise the parameter that is in the worst condition within a particular section. If sufficient defect data is available, the composite indexes can be used as a direct replacement for the overall condition index of the asset.

Modelling Condition

If sufficient technical measures of defects are available, it may be possible to model the change in condition of the asset, also referred to as deterioration modelling. Austroads has 4 road deterioration models for cracking, strength (deflection), rutting and roughness that can be used in predicting future road condition and assessing maintenance needs (Martin & Choummanivong 2018). Figure 2.2 shows the 3 general phases of road deterioration identified by Martin and Choummanivong (2018) which are initial densification, gradual deterioration and rapid deterioration. The initial densification phase occurs within the first 12 months after construction with traffic loading and has been shown to lead to roughness and rutting. The gradual deterioration phase is where most in-service pavements operate and during this phase, deterioration proceeds at a constant, low rate. Predictive modelling is usually based on this phase to forecast the future condition of a road pavement and determine required maintenance measures. The rapid deterioration phase is the final phase and is characterised by a deterioration rate that is 2 to 3 times higher than the gradual deterioration rate. Thus, during this final phase it is difficult to undertake predictive modelling as the pavement approaches ultimate failure.

Figure 2.2: Three phases of road deterioration



Source: Martin and Choummanivong (2018).

The modelling of deterioration can be undertaken in spreadsheets. However it is more common to use a pavement management system (PMS) that has the deterioration models built in.

Simple Visual Condition Assessment

In the absence of suitable details for a composite index, for example if rutting and roughness have not been determined as an input to PCI, then the composite index may not be a reliable measure of overall condition. The alternative is to use a visual inspection method and generate a subjective measure of condition.

In addition to recording defects, the condition of assets can be determined with subjective information such as:

- visual appearance of the overall asset
- evidence of the asset supporting intended capacity and function, or having capacity exceeded (such as traffic congestion)
- community feedback, requests and complaints regarding asset performance
- exposure to risks such as safety incidences, natural events and impact to the environment.

In addition to the Manual, further information on the identification of defects and undertaking condition inspections is available from:

- Austroads' guides
  - *Guide to Pavement Technology Part 5: Pavement Evaluation*
  - *Guide to Pavement Technology Part 6: Unsealed Pavements*
  - *Guide to Pavement Technology Part 7: Pavement Maintenance*
  - *Guide to Bridge Technology Part 7: Maintenance and Management of Existing Bridges*
  - *Guide to Asset Management – Technical Information Part 15: Technical Supplements.*
- IPWEA's practice notes
  - *Practice Note 1: Footpaths & Cycleways*
  - *Practice Note 2: Kerb & Channel*
  - *Practice Note 5: Stormwater Drainage*
  - *Practice Note 9: Road Pavement (Visual Assessment Code) Suite*
  - *Practice Note 10.1: Parks Management: Inventories, Condition & Performance Assessment* (in relation to trees and vegetation)
  - *Practice Note 11: Street Lighting*.

- Main Roads WA's guidelines, specifically
  - *Detailed Visual Inspection Guidelines for Culverts (Level 2)*
  - *Routine Visual Bridge Inspection Guidelines (Level 1 Inspections) for Bridges*
  - *Detailed Visual Bridge Inspection Guidelines for Timber Bridges (Level 2 Inspections)*
  - *Detailed Visual Bridge Inspection Guidelines for Concrete and Steel Bridges (Level 2 Inspections).*

Technologies for the Collection of Condition Data

Where only a composite condition index is being used to determine overall asset condition, the defect detection technologies can provide the defect data inputs for subsequent processing of the data. Some technology suppliers provide this service through preset composite index formulae. Where such a service is provided, LG need to confirm that the composite index rating ranges and weightings are appropriate to their needs.

As the assessment of overall condition of assets can include subjective information (community feedback, capacity and risk), any data collection technology will only be able to provide an input to the condition.

Aside from the defects used in composite condition indexes and other forms of post-processing of data, overall asset condition cannot be collected by contemporary semi-automated data collection technologies.

2.2 Uses of Road Data

The highest priorities of needs for road data collection, as identified in an LG workshop survey during the preparation of the report, was to support renewal planning, condition reporting and funding applications. These types of data uses are detailed in subsequent sections.

Other uses of road data can include:

- planning maintenance and issuing work orders based on the identification of defects
- verifying asset extent and condition for public liability claims
- verifying current, replaced and new asset quantities and locations for various asset register reporting needs
- responding to requests or complaints from the community, covering a range of concerns such as heavy vehicle use, road safety, utility services activities and management of assets in the road reserve
- organisation reporting such as technical and community levels of service.

2.2.1 Renewal Planning

A common approach to scoping asset renewals is to:

1. assess the asset condition based on defects and evidence of decline in service of the asset
2. determine the intervention level and treatment needed for the asset
3. scope, plan, design, procure and manage the renewal of the asset.

This requires the following types of road data:

- asset inventory data with sufficient detail to identify the asset that is being scoped for renewal, as explained in Section 2.1.1
- defect data to identify the potential causes of decline in service and extent of renewal that may be needed, as explained in Section 2.1.2
- condition data as either a summarised representation of the decline in service or based on a composite index of defects, as explained in Section 2.1.3.

When the renewal work is completed, the change in asset inventory data will need to be recorded in the organisation's asset register.

2.2.2 Specified Funding

A range of funding opportunities for roads, bridges and associated infrastructure may be available to LG under different programs. These funding programs have specified requirements for asset and condition data, such as:

- direct grants, issued in accordance with the *Asset Preservation Model* (WA Local Government Grants Commission 2023)
  - road classification
  - seal length and width or gravel length
  - lengths of kerbing, paths and longitudinal drainage
  - bridge types and deck area
- *Guidelines for the Submission of Road Improvement Projects* (Main Roads WA 2023b)
  - routes identified as intersections and mid-block lengths
  - street lighting types and quantities
- *Commodity Routes Fund Application and Assessment Guidelines* (Main Roads WA 2023c)
  - start and end SLK for the nominated project
  - existing surface details and widths
  - road condition, geometric standard and drainage standard (all as 1-5 ratings)
- road and bridge condition data collection fund, administered by WALGA and Main Roads WA (Main Roads WA 2023a)
  - road condition data provided in an agreed format to Main Roads WA
- funding for remote aboriginal community access roads (Main Roads WA 2023a)
- bridges special project funding, requiring that LG have completed level 1 condition inspections of bridges under their maintenance responsibility (Main Roads WA 2023a).

Note that the Department of Infrastructure, Transport, Regional Development, Communications, Sport and the Arts' programs *Roads to Recovery Program* (2022), and the *Safer Local Roads and Infrastructure Program* (2024) available to LG, do not require specific asset inventory or condition data.

2.2.3 Recovery Funding

Local governments impacted by natural disasters may be able to apply for relief funding to repair or replace infrastructure through the Disaster Recovery Funding Arrangements Western Australia (DRFAWA). As part of the process, an Essential Public Asset Reconstruction (EPAR) submission is required (Department of Fire and Emergency Service 2025). This will include a damage assessment report, evidence of the pre–disaster condition and function and evidence of damage.

Specific data requirements for the EPAR submission include:

- the evidence of pre-disaster condition being no more than 4 years old
- geospatial data and satellite photos
- visual data through photographs or video
- asset register information
- inspection records.

The possibility of needing these specific data types for future submissions should be considered when planning for and collecting road data.

2.2.4 Asset Registers

Asset registers enable the storage and use of road data. Typically, in the form of digital databases accessed through computer software, they can contain descriptions of each asset, the asset condition, defects, spatial attributes, work records, inspection records, financial attributes and more. An accurate and complete asset register containing both inventory and condition data is necessary to develop renewal plans and complete asset valuations.

Inventory data is defined as the basic information about assets that includes the location, type and attributes of the asset. Location data may be linear such as chainage or straight-line kilometre (referred to as SLK), 2-dimensional coordinate referencing systems as used in GIS, or 3-dimensional systems such as used for digital twins and building information modelling (referred to as BIM).

The inventory data can include many asset types within the road corridor, such as bridges, major culverts, pavements, barriers, signs, lighting etc. The types of assets are described further in Section 2.1.1.

Assets may be separated into components and can have significantly different attributes, as are needed for operational and reporting needs. A common data type for all inventory data is the 'ID' field. This is a unique identifier for the asset, component or other record that enables data to be linked and reported.

Asset inventory data needs to be kept up-to-date. Omissions in asset registers can lead to problems such as:

- inability to accurately define scopes of works for asset renewals
- inability to prove the extent of assets to support funding
- inability to prove the extent of existing assets for recovery funding
- failure to comply with asset valuation standards.

Omissions in data records can arise when records from works are incomplete after an asset has been disposed, renewed, newly acquired or constructed. This can arise from:

- the original asset register not being complete
- maintenance activities being undertaken that include replacement of an item that was recorded as an asset, but the replacement has not been reported (such as a sign)
- renewal and upgrade works being completed, with incomplete reporting of the extent of assets disposed or replaced
- new asset acquisitions with incomplete reporting of the extent of assets acquired, including developer works that create gifted assets.

Further information on asset inventory data and asset registers is available in industry guidelines such as:

- Austroads' guides such as the *Guide to Asset Management – Processes Part 9: Asset Management Information System and Data* (Austroads 2018e)
- *International Infrastructure Management Manual* (IPWEA 2020) and IPWEA's practice notes covering roads, kerb and channel, footpaths and cycleways, stormwater drainage and condition and performance assessment.

The use of road data collection technologies should be undertaken with the aim of improving existing and future asset inventories.

2.2.5 Road Asset Register Validation

In the 2023/24 financial year, the WA Local Government Grants Commission allocated $130,658,557 in local road grants to LG in WA (Department of Local Government, Sport and Cultural Industries 2025). Of this, 93% was apportioned on the basis of the asset preservation need as defined in *The Asset Preservation Model*

(2023 Edition) (WALGGC 2023). The formula to apportion funds uses the **recorded road length** of each local government.

To determine the correct road length, the local government road network is recorded in the Main Roads WA's Integrated Road Information System (IRIS). Main Roads issue a request to LG in approximately October of each year, to verify the road network parameters. LG are then required to provide their road network data to a specification set out in the *IRIS Local Government Interface Requirements* (Main Roads WA 2012). The data required are:

- mapping grid of Australia zone
- road number and name
- road start and end point as the relevant intersecting road or road end
- road length per carriageway (i.e. lane)
- additional road segment and locational information.

As the road length is required by the interface requirements, and is used in the apportionment of grant funds, there is a significant benefit to LG to ensure their road asset register data is up-to-date.

2.2.6 Asset Valuations

The most important use of asset data from a regulatory perspective is to inform the asset valuation process and meet accounting standards. This requires that both inventory data and condition data are collected in a systematic method, to LG standards, with a rating system for condition.

The inventory data defines the quantity of the assets and when combined with the unit rates of replacement of the assets, produces the gross replacement cost for valuation purposes. The condition ratings are used to identify the asset's effective rate of consumption (in accounting terms). When assessed against the gross replacement cost this produces the outputs of the fair value and annualised depreciation for the assets.

Asset valuation processes are explained further in the *International Infrastructure Management Manual* (IPWEA 2020) and the *International Infrastructure Financial Management Manual* (IPWEA 2024).

2.2.7 Network Performance

The types of road data covered in this report can be used to inform measures of network performance including:

- determining required funding levels for renewals over 10 to 15 years
- asset performance based on overall condition, on composite condition indexes or on selected defect types
- deterioration modelling to determine useful lives and intervention levels
- predictive modelling that incorporates condition, deterioration modelling and funding to identify the service levels that can be achieved based on different funding levels
- technical and community levels of service associated with road asset inventory and condition.

More information on technical and community levels of service, deterioration modelling and predictive modelling can be found in IPWEA's *International Infrastructure Management Manual* (2020) and the Austroads guides:

- *Guide to Asset Management – Processes Part 4: Customer Needs, Expectations and Levels of Service* (Austroads 2018a)
- *Guide to Asset Management – Technical Information Part 12: Pavements* (Austroads 2018b)
- *Guide to Asset Management – Technical Information Part 15: Technical Supplements* (Austroads 2018c).

2.2.8 'Gifted' Assets Acquired from Development Work

Under the *Planning and Development Act 2005* (WA), and processes for managing conditions of development approval such as set out in the *Local Government Guidelines for Subdivisional Development* (IPWEA 2017), assets created by a developer may be handed over to the LG. The most common situation where this occurs is in a subdivision and the assets can include roads, drains, paths, parks and associated assets.

To manage how asset data is provided by developers for the gifted assets, LGs can include in their engineering approval processes that the asset data be provided in specified formats such as A-Spec or ADAC (as covered in Section 2.1.1). Developers will then typically provide the data in shapefiles with attribute tables.

In the context of this report, LG may need to verify the asset types and quantities. There may also be a need to validate the new condition of the assets. In these cases, the data collection can be planned and conducted as set out in Section 4.

3 Types of Technologies

3.1 Technology Capability

A table of technology characteristics and summary information is provided in Appendix A. Each technology is discussed in terms of:

- the detection basis of the underlying technology
- how the technology is used
- what outputs are provided to the LG
- what the technology is suitable for
- the advantages of the technology
- key limitations of the technology.

The summarised assessment of the technology capabilities are shown in Table 3.1. Note that this is a very generalised summary and results can vary significantly between suppliers and in different applications. A rating of 'H' indicates high capability with a large range of objects or high repeatability and accuracy in detection. A rating of 'M' indicates a moderate capability where the number of objects detectable is not as large as other technologies, or there are known limitations in accuracy. A rating of 'L' indicates a low capability when compared against all the technologies. Note that as some technology types are designed for a specific small range of defects, the 'L' is not representative of a problem in the technology itself.

Table 3.1: Summary of key technology types and their capabilities

Technology type	Potential range of road asset inventory that can be collected	Potential range of road defect data that can be collected	Typical level of accuracy of detection	Scale of cost
Computer vision	H	H	M	L
Inertial profilers	–	L	H	M
LiDAR and laser-based technologies – surface condition	–	L	H	H
LiDAR and laser-based technologies – road environment	L	M	H	H
Traffic speed deflectometers	–	L	H	H
Unmanned aerial vehicles	L	L	M	L

3.2 Automated Visual Condition Assessment (Computer Vision)

Computer vision is the recording of digital images and the analysis of the images using algorithms and machine learning processes to automatically identify features. The identification of features such as defects can occur 'live' as the digital image is acquired, presenting as an automated solution. An example is shown in Figure 3.1.

Figure 3.1: Automated visual condition assessment used in Gympie Regional Council

Source: Shepherd Services.

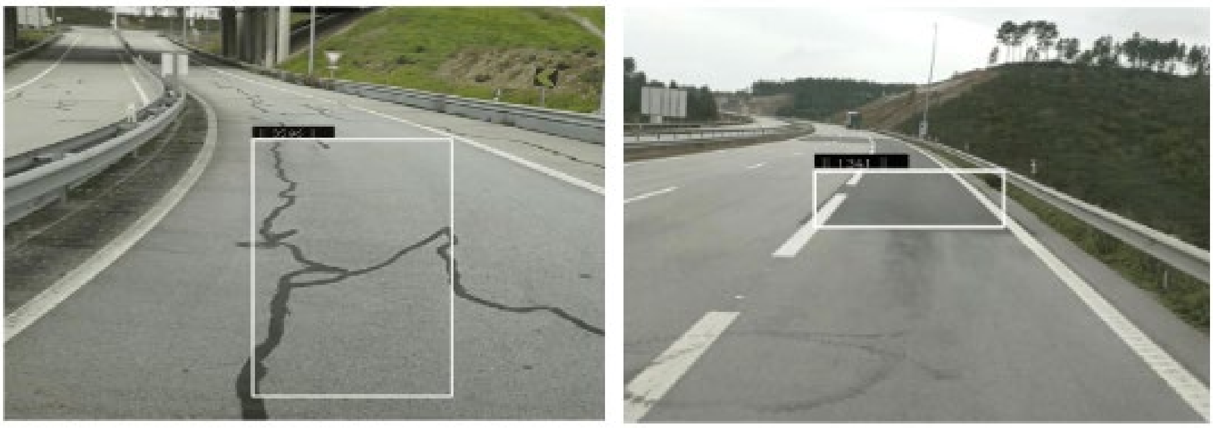
3.2.1 Scientific Principles

Automated visual condition assessment systems rely on computer vision, image processing, and machine learning. The underlying scientific principle is the analysis of digital images to detect and classify surface conditions such as cracks, potholes, rutting, and ravelling (Koch & Brilakis 2011). These systems emulate human visual interpretation using computational methods. They utilise high-resolution images to identify patterns and apply statistical modelling to interpret surface defects. It is important to note that this is a post-processing method and not a data collection method (Gopalakrishnan 2018, Maeda et al. 2018).

In the context of automated defect identification, two commonly used computer vision approaches are bounding box detection and semantic segmentation, each offering different levels of precision.

Bounding box detection can be likened to circling a crack with a marker as illustrated in Figure 3.2. The application draws a rectangular boundary around the detected defect, providing a coarse estimate of its location and existence. This method is computationally efficient and useful for object counting or presence detection but lacks accuracy in defining the defect's actual shape and extent.

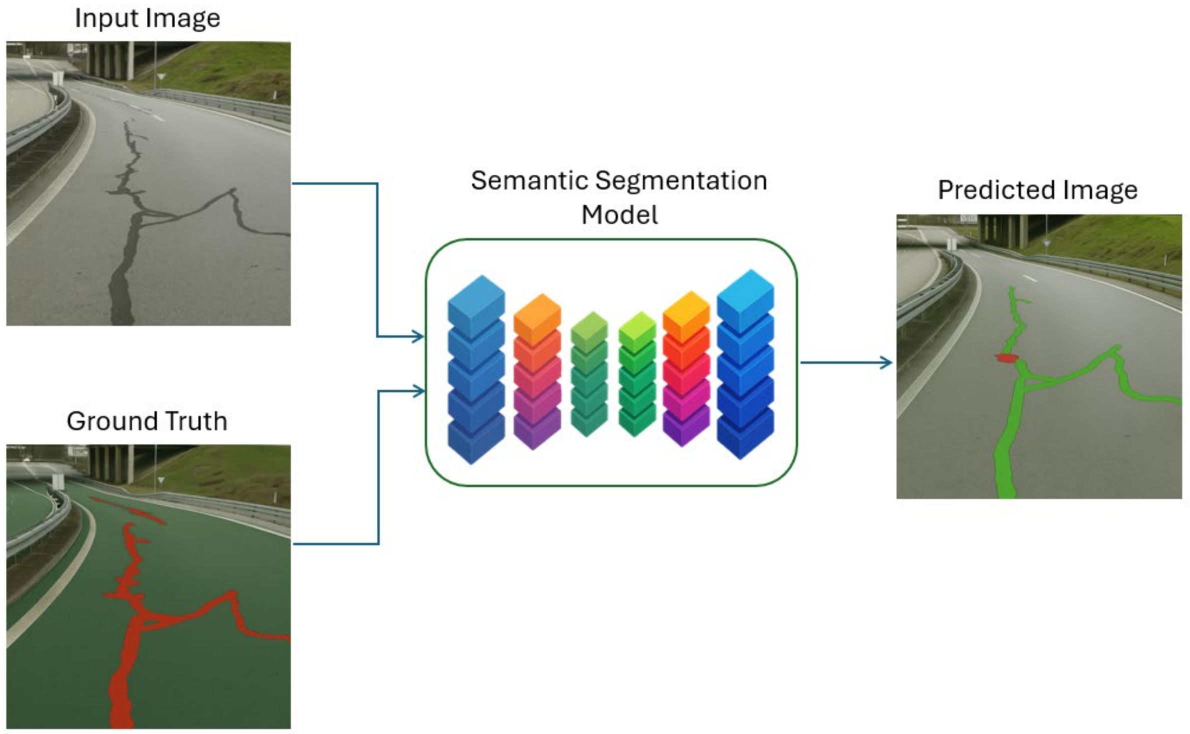
Figure 3.2: Defect detection using a bounding box



Source: Asimob.

Semantic segmentation, by contrast, resembles colouring the crack with a paintbrush as shown in Figure 3.3. It assigns a class label to each pixel in the image resulting in a detailed map of the defect. This level of precision is critical for quantifying severity, assessing area coverage and enabling more robust condition analysis.

Figure 3.3: Defect identification by a semantic segmentation



Source: Asimob.

3.2.2 Sensor Technology

High-definition cameras form the foundation of visual condition assessment. Cameras capture surface images under controlled lighting conditions to minimise shadows and glare and enhance defect visibility. Sensors typically include complementary metal-oxide-semiconductor (CMOS) or charge-coupled device (CCD) imaging arrays optimised for clarity and resolution. Controlled exposure, optical filters and specialised illumination ensure consistent image quality is produced that is suitable for automated analysis.

3.2.3 Data Processing

Captured imagery undergoes sophisticated processing using digital image analysis techniques. Initial image processing includes steps such as noise reduction, brightness and contrast adjustments, and segmentation where software isolates the areas of interest (e.g. cracks or potholes). Subsequent pattern recognition algorithms detect and quantify defects based on texture, size, shape and colour characteristics. Machine learning algorithms, particularly convolutional neural networks, further enhance defect recognition by classifying patterns accurately from extensive training datasets. These methods increase consistency and speed compared to manual inspection and processing.

Two principal methods of data processing are commonly utilised:

- cloud-based platforms and dashboards
- locally installed applications.

The choice between these approaches depends on factors including accessibility requirements, data security considerations, infrastructure availability, scalability needs and maintenance capabilities.

Cloud-based platforms are widely utilised in road-condition assessment technologies to manage, process and visualise collected data. These platforms provide secure remote access to inspection results through intuitive web-based dashboards. Users typically access such platforms via standard web browsers, enabling convenient interaction with data from various locations. Cloud solutions offer scalable computational resources, efficient data processing and centralised data storage, facilitating rapid analysis of large datasets without the need for local computing infrastructure.

The use of cloud-based platforms simplifies software maintenance and updates as the hosting provider typically manages these aspects centrally. Security measures, such as encryption and user authentication, ensure data protection and confidentiality. Web-based dashboards generally offer visual representations such as defect maps, graphs, condition ratings and comprehensive reports, which assist asset managers in interpreting the automated outputs. Effective data-management practices include protocols for data upload, storage management, secure access control and procedures for validating and correcting automated outputs.

Locally installed applications provide an alternative approach for processing and managing road-condition assessment data. Such applications are installed directly on desktop or server infrastructure maintained by the user organisation. These systems enable complete control over data storage and processing which may be preferred when handling sensitive or proprietary datasets. Locally installed software typically requires robust computing infrastructure, sufficient local data storage capacity and internal IT management support.

Advantages of locally installed applications include reduced dependence on internet connectivity, enhanced control over data security policies and the potential for integration with other locally managed asset-management or enterprise resource planning (ERP) systems. However, these advantages are balanced by the need for periodic maintenance, local software updates and IT resource commitments.

Local application interfaces commonly offer similar features to cloud platforms, including data visualisation, detailed defect categorisation and reporting tools. Illustrative images (clearly marked as examples rather than vendor-specific) within reports can demonstrate typical user-interface layouts, local data-processing workflows and output generation capabilities.

3.2.4 Limitations and Practical Considerations

Despite efficiency advantages, automated systems depend heavily on image quality with the following limitations:

- generally good accuracy measures however this can vary between suppliers and may require regular manual checking and validation
- reduced accuracy in adverse weather, inconsistent lighting and with variable surface textures
- difficulty in differentiating between minor blemishes and actual structural defects
- manual verification is often required to confirm automated findings.

However, machine learning and computer vision technologies are rapidly improving in accuracy and robustness. The research efforts in improving computer vision are focused on:

- data augmentation techniques
- domain adaptation strategies
- improving accuracy and precision of object detection
- integration of multi-sensor data.

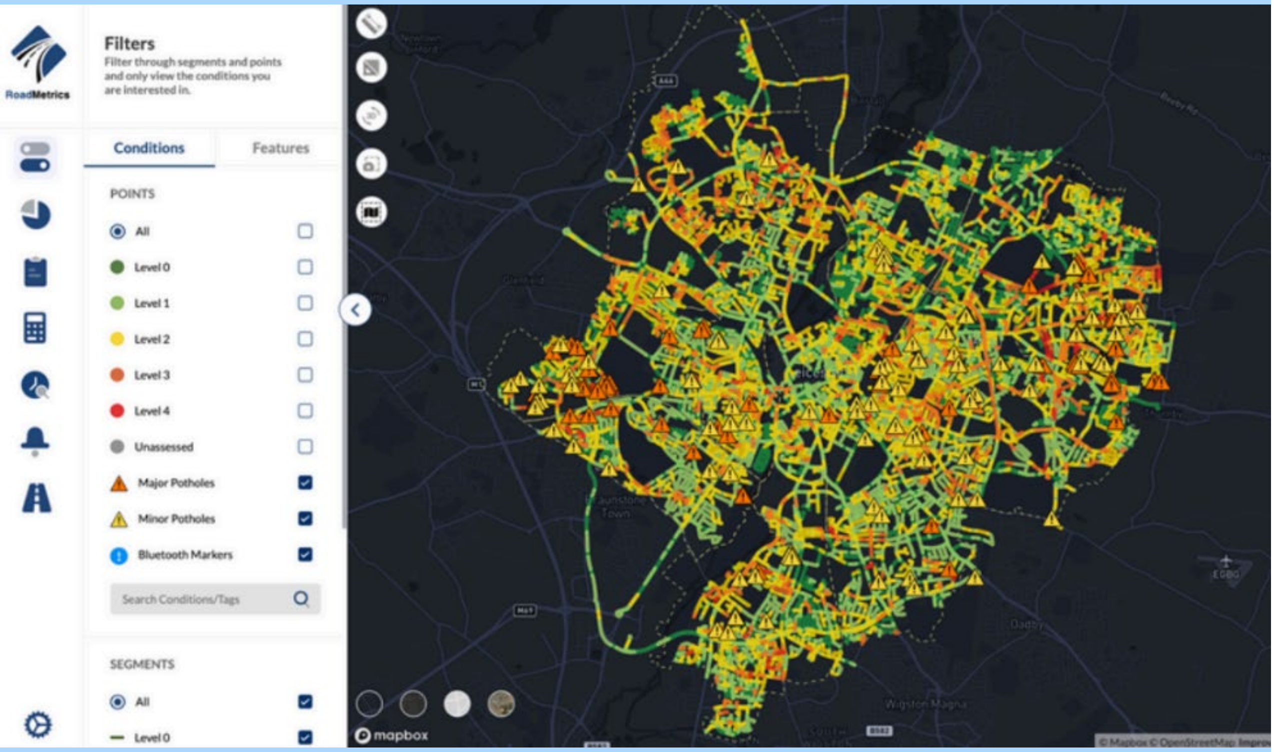
3.2.5 Case Studies of Automated Visual Condition Assessment

Cloud-based Applications

These case studies show examples where data is collected using a local device, transmitted to a cloud-based software application and then processed to identify defects.

Case study: Roadmetrics

Leicester City Council trialled a smartphone-based AI method developed by Roadmetrics for road condition assessments across their 850 km road network. The system involved mounting smartphones on standard vehicles, allowing flexible and affordable data collection without specialised fixtures. Captured data was analysed via AI algorithms compliant with PAS2161 (British Standards Institution 2024). The technology streamlined maintenance planning by automating defect identification, integrating results into their asset management system, reducing field visits and achieving considerable cost savings compared to traditional methods.

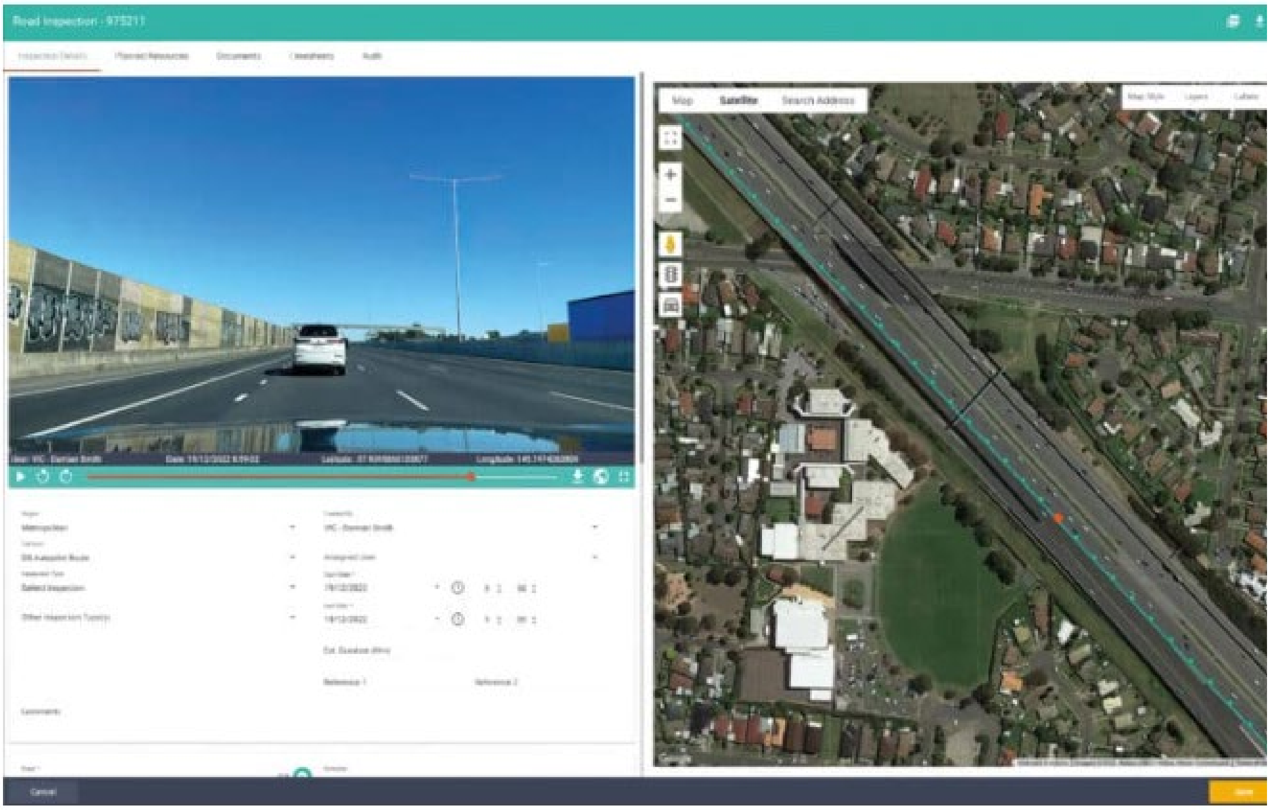


Source: RoadMetrics (2024).

Case study: Asset Vision

Moyne Shire Council, a long-term Asset Vision user since 2013, adopted AutoPilot in 2023, utilizing it for efficient road defect detection and to produce photographic evidence for storm event claims under the Disaster Recovery Funding Arrangements (DRFA). This application reduced the need for onsite inspections thereby improving operational safety and efficiency.

Ventia Australia also implemented Asset Vision for asset management across multiple large-scale transport sector contracts, including the Western Roads Upgrade (Victoria), the Road Asset Management Contract (Queensland), Brisbane Airport, and Port of Brisbane. Ventia's use of AutoPilot involves mounting smartphones inside inspection vehicles to capture road surface images and associated spatial data. This data is processed using Asset Vision's AI algorithms to automatically identify pavement defects. The processed information integrates into Ventia's wider asset management environment, including synchronisation with SAP for work orders, optimised scheduling, and ESRI for environmental compliance verification (Roads & Infrastructure 2022).



Source: O'Keane (2023).

Case study: Retina Visions

Retina Visions provides an AI-driven road condition assessment solution that uses high-definition cameras, including Google Pixel devices, mounted on vehicles to capture continuous video or photographic imagery of the pavement surface. The captured data is processed using advanced computer vision algorithms and artificial intelligence models trained on large datasets. The system automatically identifies and classifies surface distresses such as cracks, potholes and surface degradation. Processed outputs are delivered via cloud-based dashboards enabling efficient review, visual documentation and integration with asset management workflows.

The Road Vision Pro system has been operationally deployed by over 30 users across Australia, At Brisbane Airport Corporation (BAC), it has supported asset condition monitoring in a complex, high-traffic environment. Additionally, the latest generation of Road Vision Pro (RVP) cameras is currently in use or undergoing trials with a wide range of government and private sector clients. These include Transport for NSW (TfNSW), Queensland Department of Transport and Main Roads (TMR), and several local councils such as Moreton Bay, Noosa, Gladstone, Cardinia, Cumberland, Ryde, Cowra and Bayside, among others. Contractors such as Fulton Hogan and Downer are also trialling the system, supporting its continued validation in varied operational contexts.

Source: Information provided by Retina Visions in response to supplier questionnaire.

Case study: Crowdsourced and AI-analysed Road Condition Survey of the City of Lempäälä (Finland)

This project utilised the Carchupa App to crowdsource video data collection over a 250 km road network. The project used virtual coins and objects placed along the road network. The app incentivised users with virtual coins to systematically cover the entire network. Videos were analysed using Vaisala's RoadAI, a cloud-based AI system that detects and classifies over 20 types of pavement defects (e.g. cracks, potholes) with severity levels. The AI processed geo-referenced videos in near real-time, providing results on the same day via a map-based web interface. Data was exported to GIS formats and integrated into the municipality's road asset management system for maintenance planning. The survey was completed in four hours using ten surveyors driving at an average speed of 63 km/h.

Users earned money by recording GPS-tagged videos while driving over these markers: Coins (€0.05), Blueberries (€0.25), Cherries (€0.50), Lemons (€1.00), Strawberries (€2.00). This gamified incentive system proved to be a low-cost, rapid method for large-scale road monitoring.

Source: PIARC (2023).

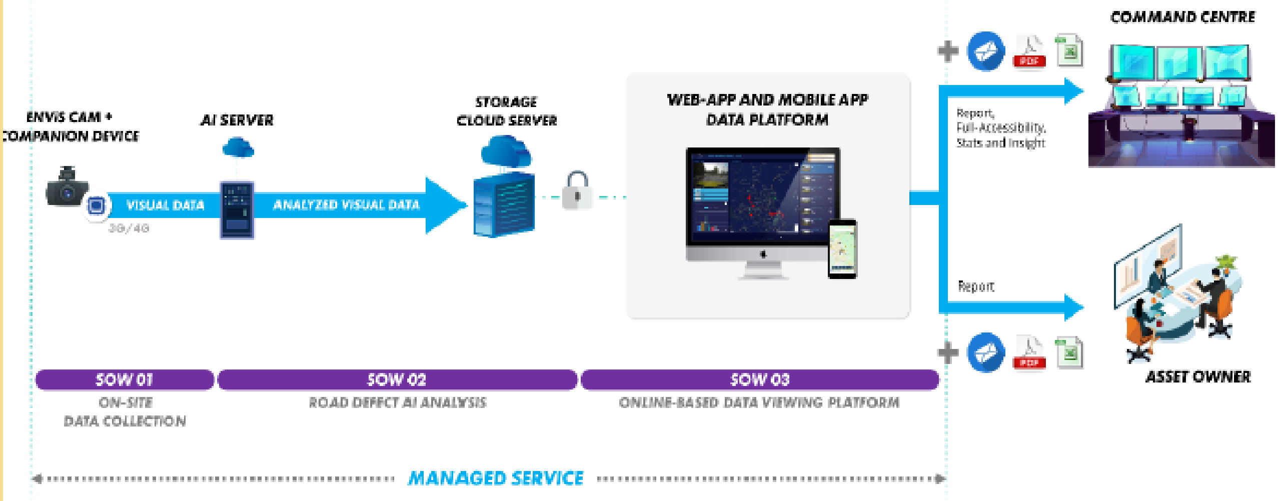
Case study: Digital Winter (Sweden)

The Swedish Transport Administration (STA) implemented a cloud-based system to monitor winter road conditions using floating car data (FCD) from vehicles including Volvo and Volkswagen. The data, combined with weather forecasts, was processed in real-time to optimise salt spreading operations. The system provided a dashboard for contractors to view friction data and maintenance recommendations, improving winter road safety and reducing environmental impact.

Source: PIARC (2023).

Case study: AI-powered Data Science Solutions for Road Anomalies Analytics (Malaysia)

The ENVIS Cam system collected data over 200 km of federal roads using vehicle-mounted cameras and a companion device for cellular data transmission. The cloud-based AI server processed images to detect potholes, cracks, and other defects, achieving 57% higher detection rates than manual inspections. Results were visualised on an online platform, with defects categorised by district and kilometre marker (e.g. 16 potholes at KM425 in Klang). The system provided near real-time updates enabling rapid maintenance responses.



Source: PIARC (2023).

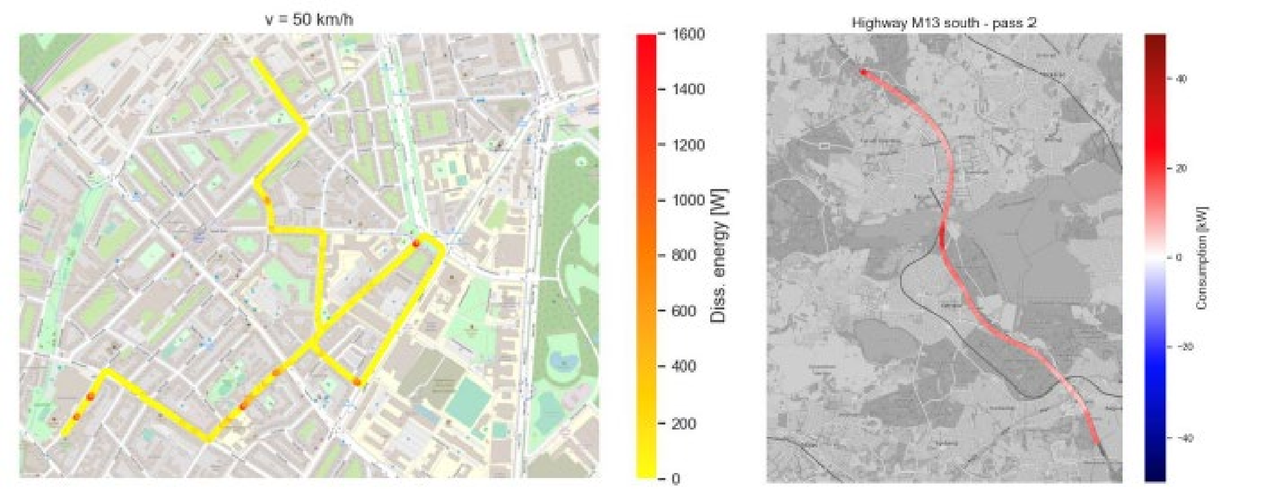
Case study: LiRA Project – Data-Driven Pavement Assessment Using Connected Vehicles (Denmark)

The LiRA project funded by Innovation Fund Denmark is a collaboration between the Danish Road Directorate, GreenMobility, DTU Civil Engineering and Sweco. It explores the use of sensor data from connected vehicles to assess road condition in real time and support infrastructure management.

A fleet of approximately 400 electric Renault Zoe vehicles operated by GreenMobility was outfitted with data logging devices connected to the CAN bus, capturing over 50 key vehicle parameters at 100 Hz- including acceleration, wheel torque, steering angle, tire pressure and motor data. These signals were used to infer road condition indicators such as ride comfort (IRI, profile unevenness), safety (friction), durability (damage indices) and environmental performance (energy expenditure).

The project included a controlled study across 350 km of Danish roads combining standard road condition surveys (e.g. profilometer, ARAN9000, CPX trailer) with the vehicle-based data to train machine learning and physical models. A cloud-enabled data pipeline was developed to manage ingestion, cleaning, interpolation and storage, facilitating model development and visualisation. Predictive models - such as random forests and deep neural networks - were then used to estimate condition parameters such as IRI and energy consumption based on the sensor data.

The resulting system enables integration with existing asset management platforms and provides live visualisations of road condition mapped by segment and defect type.



Source: PIARC (2023).

Locally Installed Applications

These case studies show examples where data is collected using a local device and processed using on-board software to identify defects. Data is then transmitted to either a cloud-based hosting service or directly to the customer's network.

Case study: AI for the Road Condition Diagnosis (Estonia)

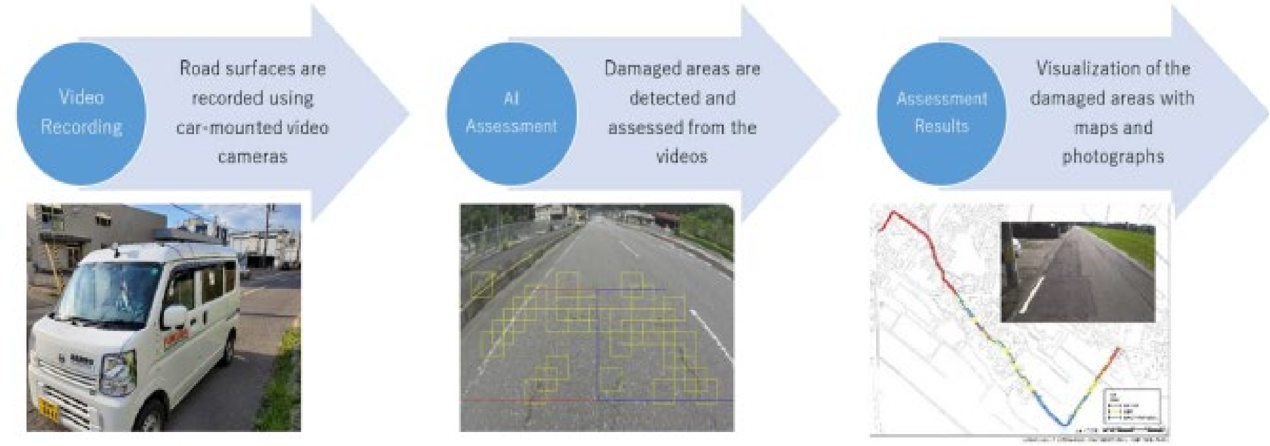
EyeVi Ltd. developed a locally installed AI system for pavement defect detection using high-speed digital cameras mounted on survey vehicles. The system processed 4096x4096-pixel ortho-frames through a multi-stage AI pipeline:

- road segmentation network: eliminated non-road areas.
- defect detection network: Identified cracks and potholes at pixel-level accuracy.
  The AI was trained on 27,617 images (9 km of roads) and achieved 91% correlation with human inspectors. The system was three times faster than manual inspections but required significant local computational resources for image processing.

Source: PIARC (2023).

Case study: Road Surface Inspection System Using AI (Japan)

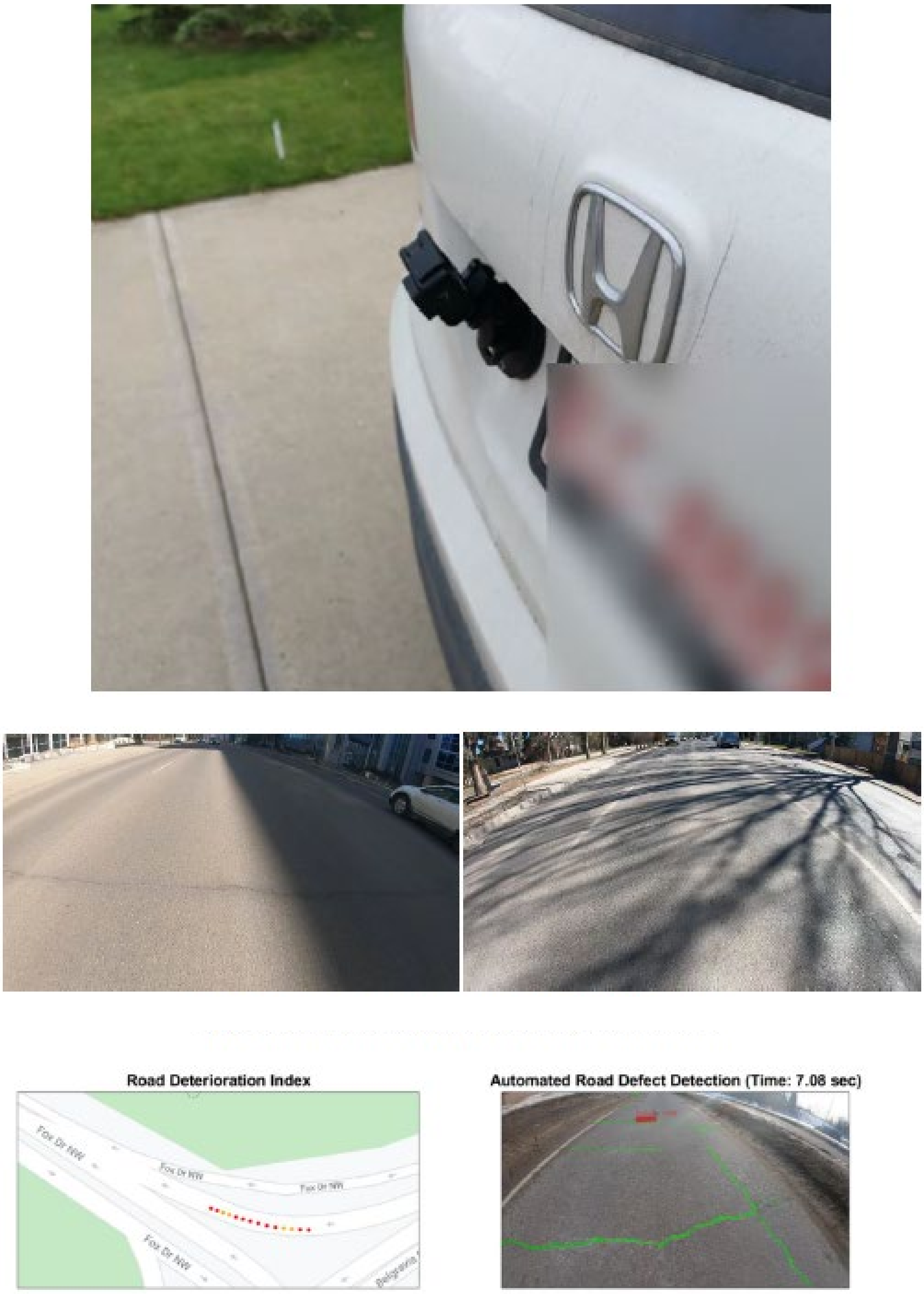
Fukuda Road Construction Co. Ltd. deployed a locally installed system using car-mounted cameras (e.g. GoPro) to record road surfaces at 24 fps. AI models analysed videos offline to detect cracks and ruts, classifying severity (e.g. 20-40% crack coverage). The system used GPS modules (u-blox) for positioning and produced 2 m-pitch reports. Training involved 16,000 km of road data with results stored locally for integration into pavement management systems.



Source: PIARC (2023).

Case study: Cost-effective Solution for Pavement Crack Inspection (Canada)

A GoPro HERO camera mounted on a vehicle collected images at 40-80 km/h. The EdmCrack600 dataset (600 images) trained a local deep learning model to segment cracks and calculate a road deterioration index. The system operated offline, with GPS-tagged results mapped locally. The proof-of-concept demonstrated feasibility for crowdsourcing but required further development for real-time processing.



Source: PIARC (2023).

3.3 Inertial Profilers

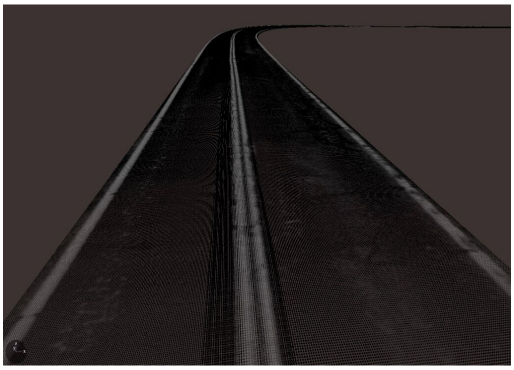
The systems described in this section are motion-based profilers that measure pavement roughness using vehicle dynamics rather than direct surface scanning. They rely on inertial sensors to capture the relative movement between the vehicle and the pavement while driving at normal speeds. These are distinct from laser-based surface scanning systems, which are discussed in Section 3.4.

3.3.1 Scientific Principles

Inertial profilers measure pavement surface roughness by applying fundamental principles from dynamics and motion analysis. They employ inertial reference methods utilising accelerometers and displacement sensors to precisely quantify vertical movements of the vehicle body relative to the pavement surface as it travels at normal traffic speeds. Figure 3.4 shows an example inertial profiler and the point cloud output.

Figure 3.4: Initial profiler and sample output (a) Inertial profiler from SSI, (b) Point cloud of a highway section

(a)



(b)

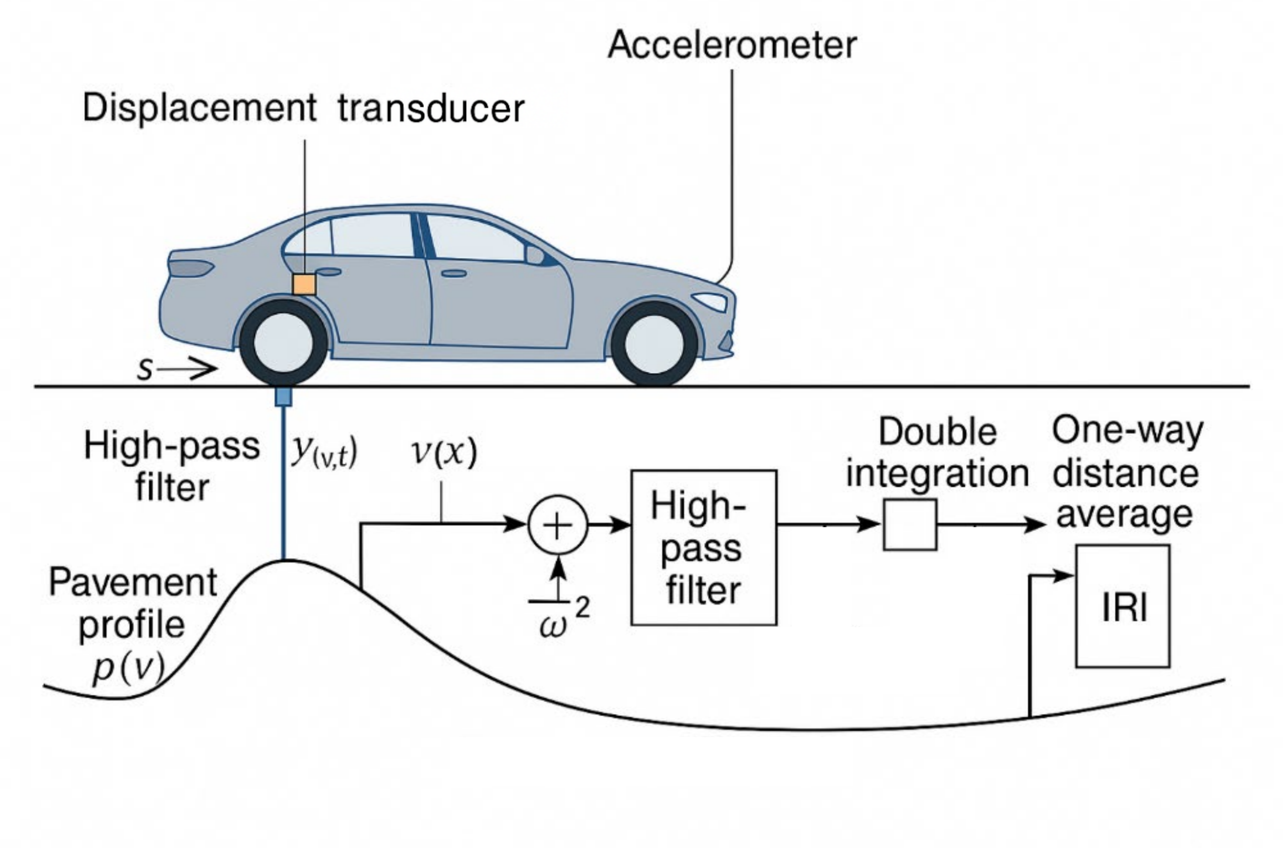
Source: SSI.

3.3.2 Sensor Technology

Inertial profilers typically include high-sensitivity accelerometers and laser-based height sensors. Accelerometers measure vehicle body motion while lasers measure the distance from the profiler to the pavement surface with extreme precision. Combined sensor data captures the pavement profile accurately at normal travel speeds (ASTM 2018).

The measurement of roughness by inertial profiler is provided by (Gillespie, Sayers & Segel 1980) and is shown diagrammatically in Figure 3.5.

Figure 3.5: Roughness measurement by LiDAR quarter car model as per ASTM E1926



Source: Conceptual illustration of International Roughness Index (IRI) calculation using an inertial profiler. Image generated using OpenAI's DALL·E based on Quarter Car Model for roughness measurement (Gillespie, Sayers & Segel 1980).

Note: s is the travel distance along the road

y(v,t) is the vertical displacement of vehicle body at position v and time t

ω2 is the suspension stiffness term in the quarter car model.

3.3.3 Data Processing

Data from accelerometers and laser sensors are integrated using algorithms based on inertial referencing. Sensor fusion techniques, typically through Kalman filtering, process these data streams to isolate pavement-induced vibrations from vehicle motions. The result is a precise longitudinal pavement profile used to compute standard roughness indices, such as the International Roughness Index (IRI), enabling standardised condition reporting.

3.3.4 Limitations and Practical Considerations

The accuracy of inertial profilers is affected by external factors such as:

- vehicle speed fluctuations
- suspension characteristics
- tire dynamics.

Profiler accuracy relies on calibration and sensor alignment.

Consistent operational practices and regular maintenance are critical for reliable performance.

3.3.5 Application Example

Inertial profilers are widely adopted for network-level pavement surveys.

3.4 LiDAR and Laser-based Technologies

3.4.1 Scientific Principles

LiDAR (Light Detection and Ranging) operates on the principle of measuring distances using laser pulses and accurate time-of-flight calculations. It provides detailed three-dimensional spatial data on surfaces or structures. LiDAR systems calculate distance by precisely timing the interval between laser pulse emission and its reflected return (Di Benedetto et al. 2023, Ristorcelli & Sarcinelli 2018).

3.4.2 Sensor Technology

LiDAR systems include laser emitters, detectors and precise timing electronics. Lasers produce short pulses of infrared or near-infrared light which reflect from surfaces and return to the sensor. The precision of the internal clock and detectors determines measurement accuracy. Modern LiDAR sensors frequently incorporate rotating or oscillating mirror mechanisms to achieve complete spatial coverage (Aero AI Drones 2025, Carter et al. 2012,Lohani & Ghosh 2017).

3.4.3 Data Processing

Collected LiDAR data, represented as point clouds, are processed into detailed three-dimensional models. Point-cloud processing involves noise filtering, surface reconstruction and spatial data interpolation techniques. Algorithms extract meaningful features from raw data, facilitating structural analysis, digital terrain modelling and detailed asset inspections.

3.4.4 Limitations and Practical Considerations

LiDAR data accuracy is influenced by several external and system-related factors, including:

- atmospheric conditions such as fog, dust and rain which can scatter or absorb laser pulses
- wet pavement surfaces which cause reflections, refractions or absorption of the laser signal leading to inaccurate or missing data
- surface reflectivity with highly reflective or dark surfaces affecting return signal strength and accuracy
- sensor calibration which must be regularly maintained to ensure measurement precision
- complex post-processing software required to clean, align and interpret point cloud data.

Skilled interpretation is essential to extract meaningful, actionable insights from raw LiDAR outputs.

Surveys are ideally conducted in dry, clear conditions to minimise environmental interferences.

3.4.5 Application Example

LiDAR is frequently employed in infrastructure inspections, surveying terrain or modelling complex structures such as bridges or tunnels. An example of the coloured LiDAR point cloud generated using mobile LiDAR and imagery is shown in Figure 3.6. LiDAR is now also used for detailed feature surveys to support road design.

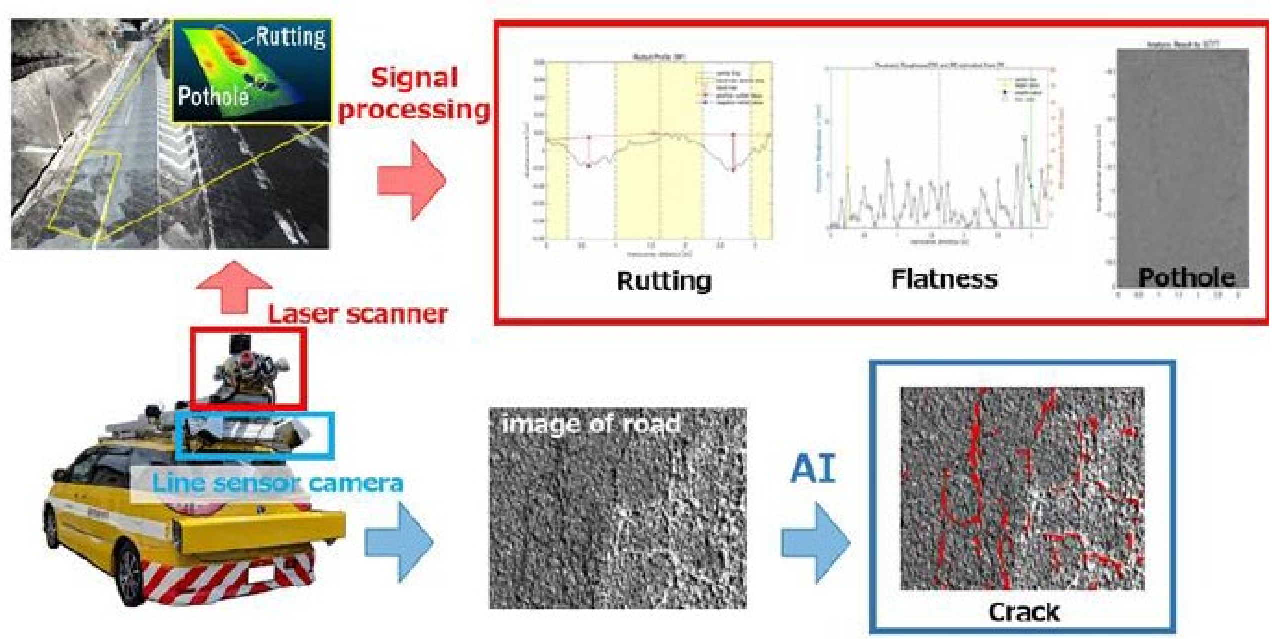
Figure 3.6: Coloured LiDAR Point Cloud, generated through mobile LiDAR and 360-degree imaging

Source: Anditi Pty Ltd (2025).

3.4.6 Case Study

Case study: Pavement Evaluation Method Using 3D Point Cloud Data (Japan)

The 3D point cloud pavement evaluation system utilised a mobile mapping system with 70 mm laser scanline intervals to capture precise road surface data. This LiDAR-based approach generated elevation meshes that automatically detected rutting exceeding 25 mm and flatness variations with just 0.16 mm average deviation from profilometer measurements. The system's local processing algorithms classified defects according to Japan's pavement standards and integrated results into GIS platforms for maintenance cost estimation, demonstrating how high-resolution LiDAR can replace manual inspections for critical measurements such as rut depth and surface deformation.



Source: PIARC (2023).

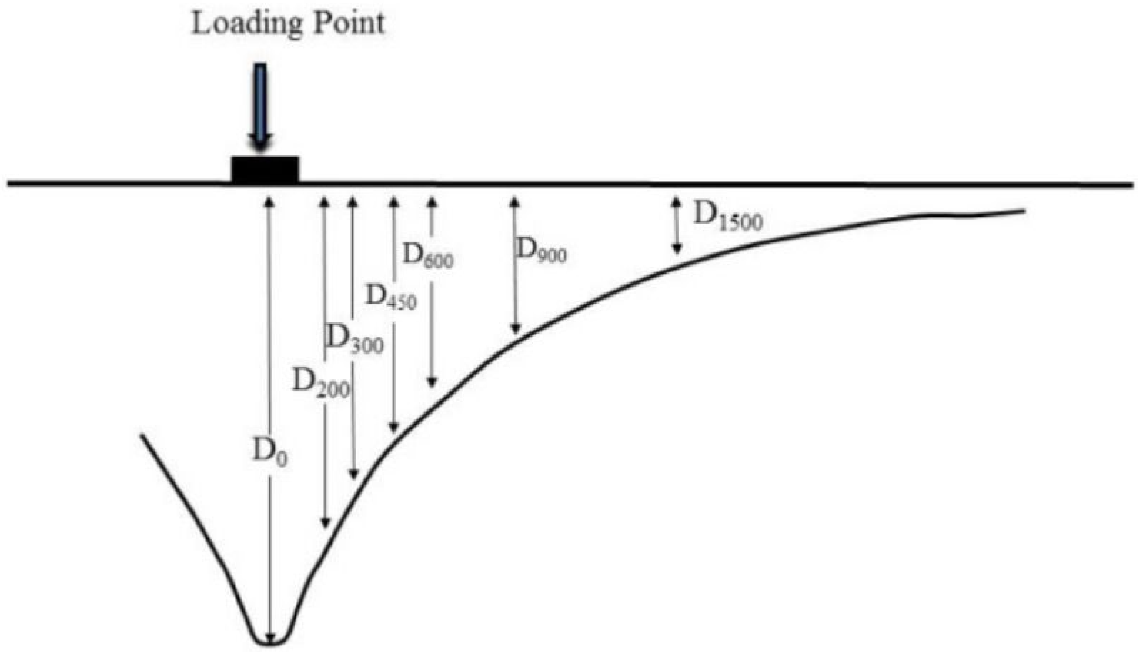
3.5 Traffic Speed Deflectometers

3.5.1 Scientific Principles

Traffic speed deflectometers (TSD) quantify pavement structural response by measuring surface deflection at traffic speeds. These devices use structural engineering principles, particularly pavement deflection theory and elastic deformation behaviour, under applied loads. As the TSD travels, it imposes dynamic loading conditions on the pavement and measures the resulting surface movements. The deflection is calculated using the vehicle speed, loading and surface movements.

TSD surveys generally produce a deflection bowl as shown in Figure 3.7, similar to that produced by the falling weight deflectometer (FWD) surveys, at 10 m intervals. The curvature (difference between the measurements of D_0 and D_{200}) provides a stiffness indicator of the upper pavement layer whilst the lower layer index (difference between D_{600} and D_{900} provides the strength indicator of the base or subgrade. The iPAVE (a specialised pavement assessment vehicle used by NTRO) can provide a deflection bowl curvature of (D_0-D_{1500}) (Chai 2016, Zofka & Sudyka 2015).

Figure 3.7: Deflection bowl and structural indicators



Note: The 'D' indicates the deflection at the distance in millimetres from the loading point. So D_0 is the deflection at the loading point, while D_{1500} is the deflection at 1,500 mm from the loading point.

Source: NTRO.

3.5.2 Sensor Technology

TSD systems utilise Doppler lasers aimed precisely at multiple points on the pavement surface. These lasers measure vertical surface velocity changes caused by pavement deflection under wheel loading. The Doppler effect – a shift in frequency of reflected laser beams based on relative movement - is fundamental to obtaining accurate velocity measurements (Duschlbauer & Lee 2021, NTRO 2025).

3.5.3 Data Processing

Raw velocity data collected by Doppler lasers is processed into deflection profiles using computational methods that integrate measured velocities over time. The deflection profiles provide valuable insights into structural pavement health. Data analysis often involves advanced statistical and numerical methods to interpret pavement strength and to identify structural deficiencies accurately.

3.5.4 Limitations and Practical Considerations

Accurate deflection measurement with TSD requires:

- careful calibration
- tightly controlled operating conditions
- environmental factors, such as temperature fluctuations, which do not significantly affect pavement response
- speed variations and pavement surface conditions which do not compromise data accuracy and repeatability
- use of standardised testing protocols to ensure consistency and comparability
- mounting on large, stable vehicles to maintain proper sensor geometry and minimise vibrations.

3.5.5 Application Example

TSDs are increasingly used for pavement structural assessments on highways due to their ability to efficiently survey extensive road segments without traffic disruption. The iPAVE from NTRO shown in

Figure 3.8 features the third generation of the TSD equipped with 11 sensors including 8 Doppler lasers positioned in front of the vertical axis of the test load rear axle at different offsets. Three sensors are also mounted behind the rear axle. A final sensor positioned at a wider offset serves as the reference sensor.

Figure 3.8: NTRO's iPAVE vehicle

Source: NTRO.

3.6 Unmanned Aerial Vehicles

3.6.1 Scientific Principles

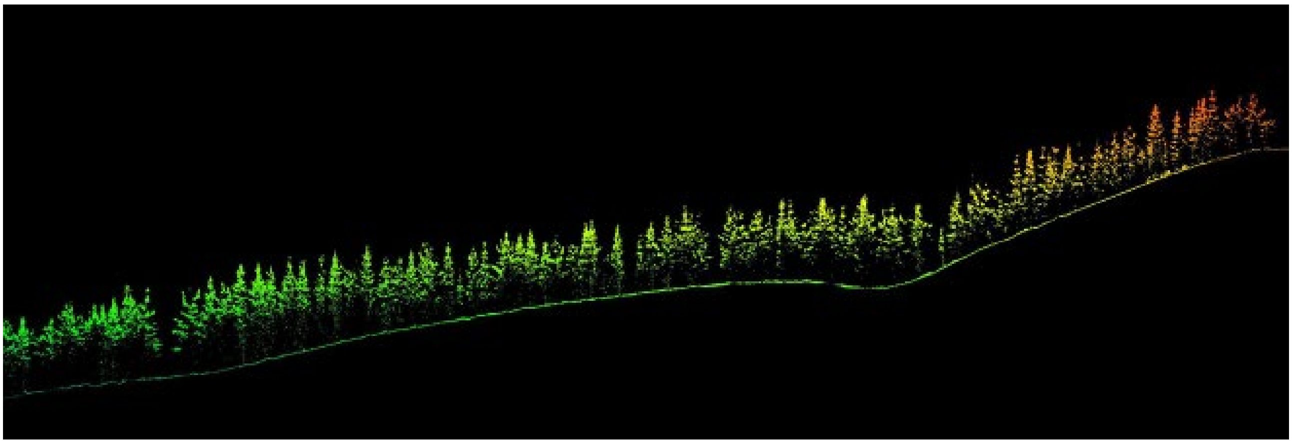
Unmanned aerial vehicles (UAVs), can also be referred to as drones, although not all drones are UAVs. They operate as mini-helicopters with multiple propellers to provide stability in flight. Their inclusion as data collection technologies comes from the ability to attach cameras, LiDAR and other types of sensors to the

UAV. An example of a UAV is provided in Figure 3.9 with an example of a LiDAR output from a UAV in Figure 3.10.

Figure 3.9: Typical UAV used in surveys

Source: Provided by AUAV, used with permission.

Figure 3.10: Identification of vegetation from aerial imagery



Source: Provided by AUAV, used with permission.

3.6.2 Sensor Technology

Modern drones typically carry advanced sensors tailored for specific inspection or data-collection tasks. Optical sensors or high-resolution cameras are frequently used to perform visual inspections. These sensors employ fundamental optical principles: lenses gather reflected visible light, focusing it onto electronic imaging sensors such as CCD or CMOS arrays (refer to Section 3.4.2 for explanations). The captured images contain detailed visual information that is essential for asset inspection.

Some drones incorporate LiDAR sensors. LiDAR systems emit laser pulses toward surfaces below and measure the precise time taken for these pulses to reflect back. This timing data allows the system to accurately calculate distances, creating highly detailed three-dimensional maps or models. LiDAR effectiveness hinges on precise timing measurements and careful calibration of laser pulses.

Thermal sensors are another specialised technology found on certain drones. These sensors measure infrared radiation emitted by objects, converting this radiation into temperature-related data. Thermal imaging relies upon established physical laws, primarily Planck's law and Wien's displacement law to detect subtle variations in temperature, which can highlight structural defects or material anomalies invisible to standard cameras.

3.6.3 Data Processing

After drones complete data collection, the raw imagery and sensor data typically undergo significant post-processing. For visual data, photogrammetry techniques are used to convert overlapping images into accurate three-dimensional reconstructions. Photogrammetry involves identifying shared reference points across multiple images using feature-detection algorithms such as SIFT (Scale-Invariant Feature Transform) and SURF (Speeded-Up Robust Features). These algorithms detect and match unique image features, enabling triangulation and precise spatial modelling.

Georeferencing of drone-collected data further enhances accuracy. This involves combining data from onboard global navigation satellite systems (GNSS), inertial measurement units (IMUs) and ground control reference points. Accurate geospatial positioning relies on precise calculations, including trilateration from satellite signals and data fusion algorithms such as Kalman filtering, ensuring high spatial accuracy.

Advanced drone inspection methods sometimes leverage machine learning techniques to automate defect identification. Convolutional neural networks (CNNs) are particularly effective at recognising visual patterns and anomalies from large image datasets, speeding up analysis and improving consistency. Training these models involves extensive annotated datasets and statistical optimisation techniques to enhance accuracy and reliability.

3.6.4 Limitations and Practical Considerations

The use of drones in Australia is governed by the Civil Aviation Safety Authority (CASA). In their website (Civil Aviation Safety Authority n.d.), CASA sets a number of rules regarding using drones including:

- keeping the drone at least 30 m away from other people
- never flying over another person
- not flying a drone in a way that creates a hazard to another aircraft, person or property
- keeping the drone within visual line-of-sight
- if over 250 g weight, not flying a drone within 5.5 km of a controlled airport
- having a licence or accreditation if flying the drone for work.

Some local authorities in WA have additional rules regarding drones. The ‘Local Drone Rules Map’ (Department of Infrastructure, Transport, Regional Development, Communications, Sport and the Arts 2021) can be referenced to identify if there are rules that affect the drone operator.

Main Roads WA (2020) do not require approval if wanting to fly a drone to capture imagery of their assets, advising that operators must however comply with CASA rules.

Practical limitations of using drones include:

- environmental conditions such as strong wind, rain, or poor visibility degrading flight stability and reducing sensor accuracy
- limited battery life, reducing inspection flights to less than one hour per charge.

Additionally, the detail and resolution of drone-captured data vary based on flight altitude and sensor specifications. Higher-altitude flights cover larger areas more quickly but at reduced spatial resolution. Operators must balance efficiency and accuracy depending on the specific inspection requirements.

3.6.5 Application Example

One common practical application is the inspection of bridge infrastructure. Manual bridge inspections can take significant time as they need to be undertaken with physical access on foot or by boat, and can require costly equipment, such as under-bridge inspection vehicles. These practices all create high safety risks. Drones equipped with high-resolution optical or LiDAR sensors can perform thorough inspections remotely, capturing extensive visual data quickly and safely. Engineers can subsequently review the drone-collected imagery to identify defects such as cracks, corrosion, or structural misalignments, greatly improving efficiency, reducing risk and minimising disruption to road users.

3.7 Other Technology Types

3.7.1 Satellite and Aerial Images

Satellite image detection technology can also play a role in road asset data collection, with the potential for large-scale, cost-effective monitoring of road infrastructure. Technological advances in computer vision and machine learning have allowed for the automatic extraction of road features such as lanes, kerbs and footpaths through the generation of asset geometry utilising sources such as Nearmaps.

These sources provide the data for the AI models to accurately and efficiently measure and characterise road asset data. This can offer significant benefits to road asset managers by reducing costs and improving safety by reducing the need for visual asset inspections. It is important to note that there are also challenges associated with using satellite image detection technology, such as the presence of vegetation coverage which can obstruct the assets analysed by the AI model. This is particularly problematic in areas with mature tree growth, where assets may be entirely hidden from aerial view. Additionally heavy shadows, variable surfaces or visual clutter may also be present which can impact the ability of the AI models to correctly identify and generate geometry for the asset.

Case study: SAR Imagery for Ancillary Pavement Assessment (USA)

The University of Colorado Boulder and the Minnesota Department of Transportation (MnDOT) are testing the use of Synthetic Aperture Radar (SAR) imagery to evaluate pavement condition on ancillary road elements such as ramps and frontage roads, which are not typically covered by vehicle-mounted survey systems. SAR data is being correlated with MnDOT's existing pavement condition datasets to train machine learning models that estimate surface condition directly from radar imagery. The objective is to enable year-round, weather-independent data collection, especially in winter conditions where frost-induced surface roughness limits the effectiveness of laser-based sensors. This system is intended to feed into MnDOT's Pavement Management System and support predictive modelling for low-coverage assets.

Source: PIARC (2023).

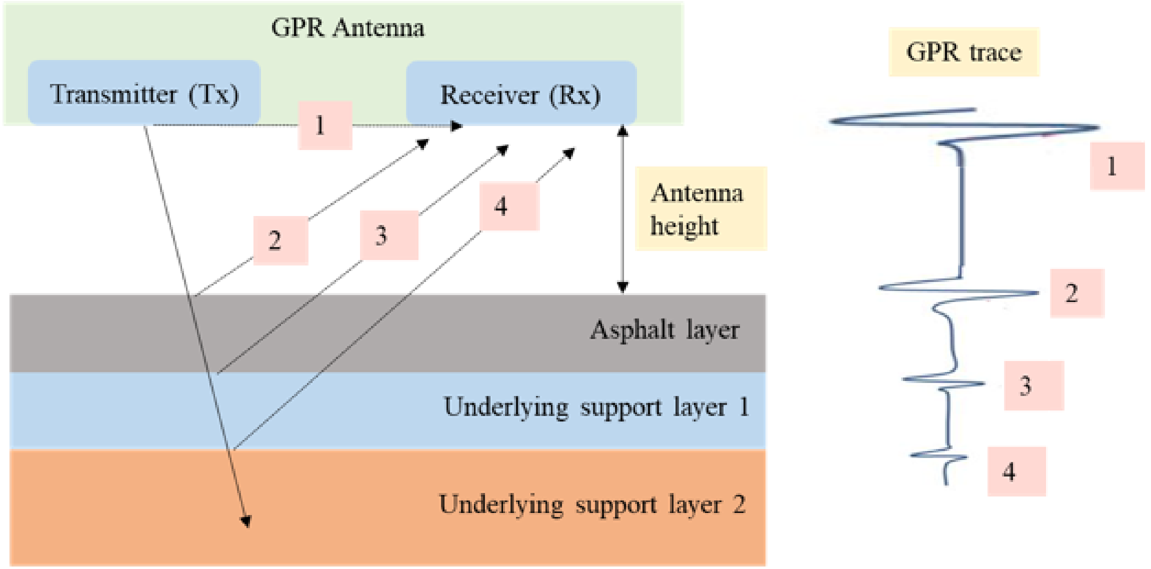
3.7.2 Ground Penetrating Radar (GPR)

GPR is being employed in pavement evaluation for its ability to non-destructively assess layer thicknesses and subsurface moisture conditions. GPR operates by emitting high-frequency electromagnetic pulses into the pavement structure and analysing the reflected signals from interfaces between materials with differing dielectric properties (Abdelsamei, Warda & Taha 2024). The time delay and amplitude of these reflections are used to determine layer boundaries and estimate material characteristics.

Moisture presence significantly affects the dielectric constant of unbound layers, allowing GPR to infer areas of potential water ingress or saturation. Calibrated with ground-truth data (e.g. cores or FWD), GPR can provide spatially continuous profiles of pavement thickness and moisture-related anomalies (US Department of Transportation Federal Highway Administration n.d., Wang et al. 2024). Note that GPR does not directly identify defects. Instead, it detects subsurface discontinuities or anomalies that may correlate with deterioration.

Figure 3.11 shows how the GPR technology works, with the transmitter (Tx) sending the electromagnetic pulse into the surface and pavement materials and the receiver (Rx) receiving the different reflected signals from the different materials. The amplitude of the wavelength shown in the right of the figure is used to identify the material types.

Figure 3.11: How GPR technology works



1 – Direct coupling from the source
2 – GPR signal reflected at asphalt surface
3 – GPR signal reflected at asphalt-underlying support 1 interface
4 – GPR signal reflected at the interface between underlying supports 1 and 2

Source: Sivagnanasuntharam et al (2021)

3.7.3 Thermal Imaging and Infrared Surveys

Thermal imaging uses infrared sensors to detect temperature anomalies indicating potential issues such as moisture infiltration, delamination or compromised insulation. This method is particularly useful in identifying hidden defects in bridge decks and road surfaces.

3.7.4 Friction and Skid-resistance Measurement Systems

Specializsed measurement vehicles or trailers equipped with controlled tire-contact equipment directly measure surface friction and skid resistance. These systems ensure compliance with safety standards and guide timely interventions.

Case study: The Digital Mountain Pass - Norway

Norway's Digital Mountain Pass implemented roadside IoT sensors measuring friction and weather conditions, feeding data to LSTM neural networks that predicted road conditions 6 hours ahead for winter maintenance planning. The pan-European BD PAVE initiative aggregated heterogeneous data sources including 50+ CAN bus signals from connected vehicles to enhance pavement deterioration modelling across 11 member states. Denmark's LIRA project utilised 100 Hz CAN bus data from Renault Zoe electric vehicles, correlating acceleration and torque measurements with professional profilometer scans to develop real-time roughness prediction models. The Minnesota SAR satellite project explored using synthetic aperture radar to monitor ancillary road surfaces inaccessible to ground vehicles, with potential for tracking seasonal deterioration patterns such as frost heave across entire networks.

Source: PIARC (2023).

3.7.5 Manual Data Collection Technologies

Although not directly examined as part of this project, it is acknowledged that there is the continued use of manual data collection technologies by LG. These include mobile or tablet-based platforms such as DoForms and Fulcrum which enable structured field data capture through to customisable digital forms. Additionally, some organisations employ system-integrated forms such as those linked to Intramaps Roam, to facilitate linkages to spatial records and asset registers.

While these tools offer accessible, low-barrier entry points for recording field observations, they are inherently subject to limitations. Manual data collection is labour-intensive, can pose safety risks when inspectors are required to work close to live traffic or hazardous environments, and introduces variability due to differences in individual judgment and observational consistency. These factors raise concerns around efficiency, reproducibility and data reliability - particularly when used for large-scale or longitudinal assessments (Satterlee et al. 2013).

In contrast to automated or sensor-based solutions, manual approaches also lack scalability and may struggle to meet the growing demand for real-time condition monitoring and analytics. Nonetheless, understanding these legacy and hybrid methods provides essential context for evaluating current practices and opportunities for system modernisation (Ethan 2023).

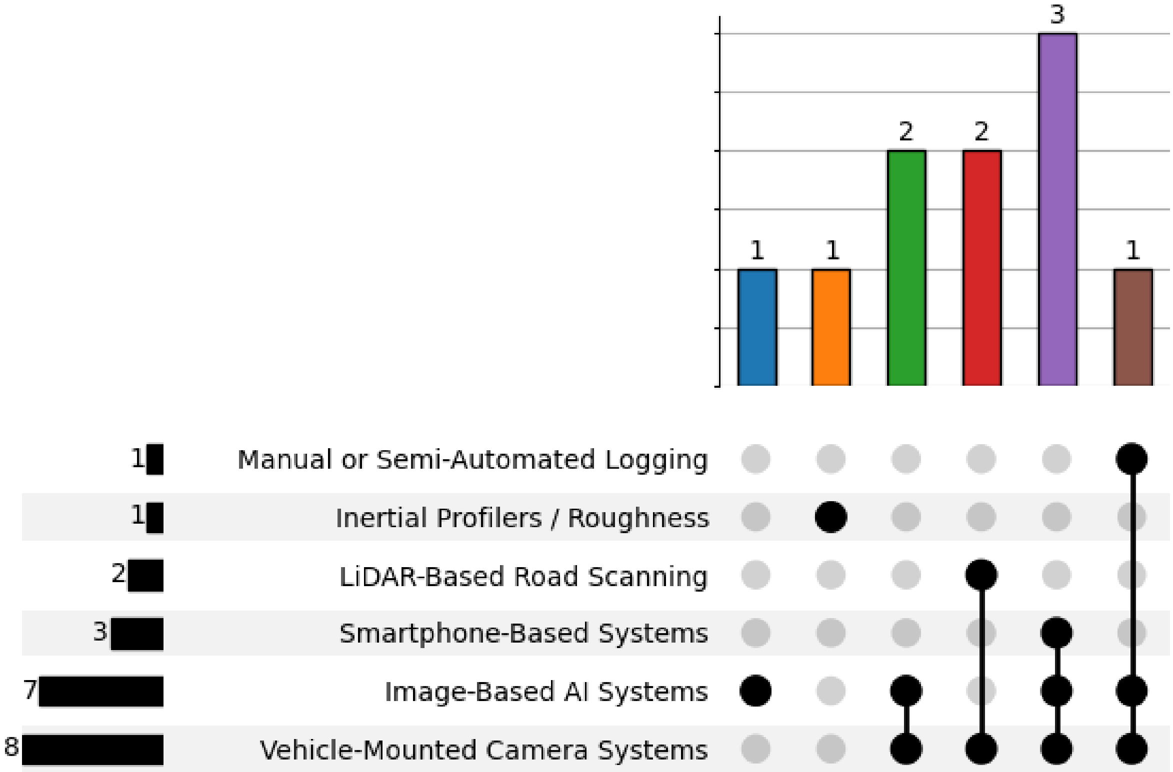
3.8 Combined Technologies Available

A market scan was undertaken to identify commercially available technologies for road defect detection. This involved compiling a list of known and emerging suppliers, reviewing publicly available material, and directly contacting vendors to request technical documentation, complete a structured questionnaire and clarify operational capabilities. Follow-up correspondence was conducted to resolve gaps in information and validate use cases. It should be noted that this did not involve open public notifications so there may be local suppliers not represented in the report.

The Figure 3.12 presents an UpSet plot illustrating the distribution of suppliers across various combinations of defect detection technologies. Each column in the matrix represents a unique combination of technologies, with the presence of a filled black dot in a row indicating that the corresponding technology is included in that combination. The rows represent individual technology categories as listed.

The vertical bars above the matrix show the number of suppliers using each combination of technologies. For instance, a bar height of 3 indicates that three suppliers utilise the set of technologies denoted by the filled dots below that column. On the left-hand side, horizontal bars show the total number of suppliers using each technology, regardless of what other technologies they use in combination. This enables quick identification of the most adopted individual technologies, as well as the most frequent multi-technology configurations.

Figure 3.12: Supplier technology combinations



Source: NTRO.

3.8.1 Case Studies of Combined Technologies

Case study: Shepherd - Pilbara and Gascoyne Regional Road Survey (Western Australia)

In this project, the RACAS® Midline system was deployed to conduct a condition survey across 7,903 km of sealed and unsealed roads within eight local government areas in the Pilbara and Gascoyne regions. The system, mounted on standard vehicles, captured forward-facing imagery, GPS data and surface roughness measurements at 10 m intervals. The collected data was analysed to identify road defects and generate condition scores based on the WALGA Road Visual Condition Assessment Manual. Outputs included georeferenced defect logs, image datasets and condition indices, all delivered offline via portable storage. The project provided local governments with comprehensive and consistent records of their remote road networks, enabling more informed maintenance planning and capital works forecasting.

Source: Shepherd Services email correspondence 28/03/2025.

Case study: Shepherd - South Burnett Regional Council - RACAS AI Proof of Concept (Queensland)

A proof-of-concept project was conducted in partnership with South Burnett Regional Council to evaluate the effectiveness of RACAS AI in detecting sealed road defects using image-based machine learning. The project involved the assembly of a steering committee, the development of training datasets using validated imagery, and systematic testing of the AI models against verified defects. The exercise helped council asset managers assess the operational accuracy, integration feasibility and value of AI-supported defect detection within their existing workflows. The results led to continued development partnerships with multiple councils, helping to shape RACAS AI into a more robust and field-ready product.

Source: Shepherd Services email correspondence 28/03/2025.

Case study: iPAVe Structural Condition Survey – New South Wales (Australia)

Since 2014, Transport for NSW (TfNSW) has partnered with NTRO to assess the structural health of its rural road network using the Intelligent Pavement Assessment Vehicle (iPAVe). The iPAVe replaces traditional falling weight deflectometer (FWD) testing by enabling pavement strength assessments at highway speeds (up to 80 km/h), eliminating the need for stop-start testing and associated traffic control.

The system integrates a heavy axle load and laser-based deflection measurement to capture continuous data along the left-hand wheel path. This allows for real-time deflection velocity profiling and the assessment of pavement bearing capacity during normal traffic operations. Annually, approximately 17,600 km of the rural network is surveyed, with structural data collected for half the network using iPAVe and the remaining half assessed functionally using a network survey vehicle (NSV), alternating each year.

In 2023, the iPAVe collected 10,000 km of structural data in just 35 days - 150 times faster than traditional methods - providing a comprehensive, high-resolution understanding of network condition. The data enabled TfNSW to identify structurally weak segments, optimise maintenance planning and prioritise capital works. The ability to collect both structural and functional data at traffic speeds has improved operational efficiency, data coverage and safety outcomes, while supporting strategic, data-driven investment decisions.

Source: TfNSW Network “ROADS_RTA_CLASSIFIED” adapted by NTRO, 2023.

4 Planning and Specifying for Data Collection

There is a range of industry guidance available for planning data collection. Aspects to consider before initiating data collection include:

- what it will be used for
- extent of detail needed for the data type, such as extent of cracking
- accuracy in the recording of the type of item such as distinguishing between road surface flushing and stripping
- spatial accuracy needed such as measuring a pothole's dimensions or the vertical height of a road crest
- data storage and management needs including data security and considerations of storage capacity for photo and video records
- in-house skills to manage the received data including processing defects to generate asset condition
- limitations of the data collection technologies
- ensuring that there is sufficient need for the data when balanced against the effort in collecting it
- cost of data collection
- whether the type of data needs to be collected again (such as defects) and how frequently.

For further information on planning road data collection, refer to:

- Guide to Asset Management – Processes Part 6: Defining and Understanding Asset Requirements (Austroads 2018d)
- *Guide to Asset Management – Technical Information Part 15: Technical Supplements* (Austroads 2018c)
- *Road Inspection Manual A Risk Based Approach to Managing Road Defects* (IPWEA NSW and ACT 2021).

4.1 Process for Planning Road Data Collection

Although the data collection technologies are advancing rapidly and the capability of receiving asset register systems are also improving, the data collection guidance remains largely the same. The key aspect to monitor with the more automated data collection technologies are:

- accuracy and completeness of the reference data before initiating data collection such as asset register shapefiles
- ensuring that the data received matches asset register formats for ease of upload or integration
- being prepared for the wider variety and type of data such as the many fields of deflection data from TSDs or extended defect definitions from image feature detection, which also increases data storage needs
- ensuring there is data validation and quality checks during data collection.

The process for planning road data collection is described in the context of LG sourcing a data collection service. The process can be adapted to suit the situation where LGs source the technology and use it with in-house staff. The process is shown in Figure 4.1.

Figure 4.1: Process for planning road data collection

1. confirm the needs and uses of data (with reference to Section 2.2)
2. identify the type of data to be collected and whether this includes asset inventory data (Section 2.1.1), defect data (Section 2.1.2) and/or condition data (Section 2.1.3)
3. identify the technologies that can provide the data (Section 3)
4. specify the workplace health and safety requirements for the data collection (Section 4.2)
5. confirm the range or extent of the data collection such as lengths of road, extents of verges and numbers of bridges, and identify the information to be provided to the contractor (Section 4.3)
6. confirm what type of data is to be collected, identify the systems that will receive the data and required data formats (Section 4.4)
7. consider contractual matters (Section 4.5)
8. identify the level of data accuracy and how to validate and check the data (Section 4.6)
9. arrange the data collection and then manage data storage in the asset register (Section 2.2.4) and report on the uses of data (Section 2.2).

Example specifications are provided below for procuring data collection services. Where example specifications are provided in the following sections, LG can use the examples and complete the information between the angled brackets ‘<’ and ‘>’.

4.2 Workplace Health and Safety and Temporary Traffic Management

As the data collection can occur in environments exposed to vehicular traffic and a range of field work hazards, the LG will need to define requirements other than what may be normally specified in tender or quotation requests. The following specification may be used:

The contractor and their subcontractors must comply with the *Work Health and Safety Act (WA) 2020*. In complying with this the contractor must:

1. Apply safety policies and procedures appropriate to the scope of work, including but not limited to:
   a. driving and vehicle safety and communication
   b. site hazard assessment and management when accessing any site on foot.
2. Ensure approved temporary traffic management is in place for any work in the road reserve, in accordance with the Main Roads WA *Traffic Management for Works on Roads Code of Practice* and Austroads' *Guide to Temporary Traffic Management* series.
3. Provide evidence of safe work method statements.
4. Have an emergency action plan including communication methods.
5. Provide evidence of insurances as per section <insert section number> requirements.

The contractor must provide a WHS plan stating how they will comply with the obligations. The consultant will be required to attend a safety induction with the <LG> prior to commencing work.

Where the consultant determines that a traffic management plan is required, this is to be submitted for assessment by the <LG> at least 14 days before commencing work.

4.3 Information to be Provided by the LG

The LG is advised to specify the information that will be provided to the contractor. As a minimum this should include:

- shapefiles of road centrelines
- template file (such as a spreadsheet) that defines the data field arrangements (field names) and data formats (e.g. numerical, integer, date) that are required.

Additional information that can be provided to assist in scoping the data collection includes:

- quantities of the assets
- spatial data files such as cadastres or other features to define roads and road reserves
- reference files such as development plans that show new road assets.

The list of quantities of assets should enable the contractor or LG to check that the data collection is for the correct extent and to manage the scope of data collection (including contract variations). In certain cases, such as where the true length of kerb is unknown, the quantity may need to be stated as an estimate.

For clarification, when requesting quotations, the contractor will need to know the template file format, some information on the extent of the data collection, such as a road network map and new assets, and quantities of the assets. More detailed data such as shapefiles can be provided by the LG once a contractor has been appointed.

4.4 Specify the Data to be Collected

The LG is advised to specify the required data types, fields and formats. The data types (asset type, defect type or condition type) can be selected from Section 2, however it is recommended to use the listed guidelines such as from WALGA, IPWEA, Austroads or M (see Sections 2.1.1, 2.1.2 and 2.1.3). The guidelines provide greater definition than the summarised lists in this report.

Where the data needs to conform to LG asset register requirements, the data field names and formats (integer or date etc.) need to be specified accordingly. It is recommended that the LG provide a template file such as a spreadsheet with headers to manage asset register data needs.

Both A-Spec and ADAC may help to define data format requirements. They can be used to specify the data type in terms of integer, numeric or text and the spatial formats such as points, lines and polygons.

Before requesting data in formats that meet any of the guidelines or data specifications, ensure that the data types described have been checked and represent the data needed. For example, vertical coordinates ('Z' value) may be described in the data specifications however this detail may not be needed by the LG.

It is noted that some contractors may be able to provide data linkage through an application programming interface (API), or provide the data directly through their proprietary platforms, however explanation of these processes is out of scope of this report.

The following specification may be used:

> The contractor is to collect data for the following data types as defined by <insert preferred guideline(s)>.
>
> <provide a list such as the types of defects, types of assets etc.>
>
> Provide data in Excel or csv file formats in accordance with the provided data template.
>
> Data provided for <types of assets or defects, delete this paragraph if not applicable> is to be provided in accordance with the <A-Spec or ADAC> digital data standards. <advise where the supplier can source the standards>.
>
> Data provided through an API must meet the requirements of <LG asset register name>: <specify asset register requirements or delete sentence if not applicable>

4.5 Data Accuracy, Validation and Checking

Accuracy

As covered in Section 3, there can be significant variation in the accuracy of data detection from the different technologies. Accuracy in object detection is defined in terms of:

- accuracy – the measured accuracy of dimensions and location of the feature (e.g. length or coordinates)
- precision –the proportion of features that are identified compared to actual occurrences of the feature
- false negative –that a feature is not recorded when one is present
- false positive –that a feature is recorded when one is not present.

The term 'object' here can represent an asset, a defect or a condition as is relevant to the data collection service.

As there is not yet an industry standard of minimum performance in object detection for road data, the recommended approach when specifying for data collection services is to request information from the contractor and then validate the performance during data collection.

Validation

There are two methods that can be used to validate the collected data:

1. establish a baseline data set to compare with the collected data
2. request a set of data early in the data collection to enable the data quality to be checked.

A baseline consists of a sample of previously collected data for the objects (assets, defects or condition). The data should be recorded to the best level of accuracy available to the LG and verified by detailed inspection and measurement. A representative sample size is needed that has sufficient occurrences of the object to test against a larger data collection set without the baseline itself taking an excessive amount of resources. It is not necessary for the LG to provide the baseline data to the contractor provided the relevant section or area of the baseline is specified as part of the validation requirements.

The alternative to a baseline is requesting a set of data early in the data collection and checking the quality against the required formats. This early data could consist of the first day or week of collection or first nominated percentage of length or by quantity of features. The LG will need to specify clearly how much of the early data is needed for checking and will need to plan for a quick validation of the data as delays in the data collection services can be expensive.

The following specification may be used:

Quality Control and Validation

The contractor is to provide the first <percentage by measure or quantity or timeframe> of data collected within 48 hours of collection to enable quality control checks.

The quality control will verify that the accuracy is as <specified / agreed> and data formats are correct.

Where any correction is required, the contractor is to:
1. recollect or correct the incorrect data and submit for further validation
2. amend data collection and reporting processes to ensure the quality of future data collection is complying and advise <LG> of the change in process being applied.

The acceptance by <LG> of the quality of the first data set is not an indication of acceptance of quality for any additional data set.

Checking

Once the validation process is complete, the LG will need to check on contractor progress in data collection, and then check the completed data collection. The final check will be against the required formats, as has occurred in the validation step.

The timing of these events during the data collection contract is discussed in Section 4.6.

4.6 Considerations for Procuring Data Collection Services

Contractual Matters

If the payment schedule or basis of payment is too controlled, the contractor may be exposed to significant risk as the payments can affect their cashflow. This can lead to adverse results with a reduction in service quality or outcomes. In a typical data collection project, a large part of the resource is utilised in the data collection which may not be paid until the full data collection is completed. If this takes several months, then the contractor may be exposed to additional costs. The payment schedule in Table 4.1 is suggested for adoption by LG to enable:

- the LG to manage progress of the data collection and deliverable milestones
- the contractor to manage cashflow while meeting the deliverable milestones.

Table 4.1: Payment schedule example and explanations

Task	Contractor deliverables	LG deliverables	Explanation
Inception meeting and initiation of the data collection project	Inception minutes SWMS and associated safety documentation by contractor. Request for information to LG	Attend the inception and confirm minutes. LG to provide specified information to enable the contractor to start the data collection.	Recognises a formal and necessary project management event has occurred and allows for start of cashflow for the contractor. Before the inception has occurred, the contractor will be actioning contracts, planning work and should have submitted safety documentation. Although the specification may advise that LG data is to be provided, the contractor should not wear the risk of a delay in this data.
Initial data collection for validation	Initial data set as specified for validation purposes.	Assess and validate within specified timeframe, for example 2 weeks.	Enables LG to ensure that all data requirements are being met and to validate the data.

Task	Contractor deliverables	LG deliverables	Explanation
			Note that due to data collection costs, it may not be feasible for a contractor to cease data collection while awaiting validation.
Proportion of data collection completed	Agreed proportion (as percentage or by measure) of data collection completed. Evidence through collection record, diary or similar. Payment claim.		Although data is not being provided in this task, the provision of regular payments enables the contractor to manage cashflow. The contractor must provide evidence of having undertaken the data collection (by tracking maps or similar).
Submission of data	Full data set submitted	Receive and check within specified timeframe, for example 2 weeks.	If the validation task is successful, the checks will ensure the data collection is complete. This task provides for processing and if required, correction of data by the contractor.
Finalise data and report.	Corrected data set (if required) and report of work completed.	Receive and check within specified timeframe, for example 2 weeks.	The report ensures that assumptions and site conditions have been recorded.

Where the cost of data collection is unknown or there are budget constraints, the LG may define separate portions or provisional items under the conditions of contract. However, these methods can cause an increase in price as the contractor will need to manage the risk inherent in the unknown scope of work. To avoid unnecessary risk, it is recommended for the LG to source indicative pricing prior to procuring services, and this can negate the need for these contract methods.

Specifying Preliminary Information

As part of contract or specification preliminaries, the LG is advised to:

- provide information addressing the objectives of the data collection and overall location
- if necessary, clarify how the supplier (of the service) is to differentiate between LG owned or managed assets and third-party assets.

Operational Considerations

The timing of the data collection needs to consider seasonal effects on the detection technology, as image and light-based technologies are affected by low angle sunlight and wet surfaces. This may require that the collection services are undertaken:

- during daylight hours but not in the early morning or evening
- when the asset surface is dry.

Where the technology consists of a device mounted within the vehicle, consideration is also needed for the internal temperature and its effect on the device.

5 Conclusion

The *Road Data Collection Technologies for Local Government* report has aimed to provide information for LG to understand and in turn adopt road data collection technologies to gain benefits that may include more efficient and safer data collection, and higher quality data.

Supported by industry guidance on uses of road data, the report focuses on uses that were considered important to LG from an industry workshop: renewal planning, condition reporting and funding applications. There is also sufficient industry guidance available on the types of road data in the scope of the report, for asset inventory, defects and condition. The report was therefore able to focus on the types of technologies used in road data collection and how the technologies function.

The technologies used for road data collection have dramatically improved in recent years, and there has the been an increasing number of suppliers. In particular the range of asset types and defect types that can be detected is rapidly increasing.

However all the technologies have limitations arising partly from the level of development of the respective technology, or in practical application. Despite the limitations, in many cases and applications the technologies will enable a better result (in terms of efficiency and safety) than the more manual methods of data collection.

As the technologies become more available, LG will need to develop their in-house skills and knowledge in data management and in systems (such as asset registers) to enable integration of the different data sets.

The final section of the report provides information on how LG can plan and specify for data collection services. This includes some insights into the type of information that must be provided by the LG and how to ensure data quality is controlled with validation and checking steps.

5.1 Future Work

While the report has attempted to describe and represent the status of current road data collection technologies, the capabilities of the industry are rapidly changing. The uses of the data are also increasing, as LGs develop capabilities to use larger and more complex data sets, and to manage the data in asset register systems and report through more advanced reporting tools such as Power BI.

The report presents an introductory view on the uses of data, data collection technologies and specifying data collection. It is anticipated that guidance will be needed soon on more advanced aspects of data use and methods for specifying data collection. Guidance will also be needed on managing the more advanced asset register systems and using advanced reporting tools in the process of data management.

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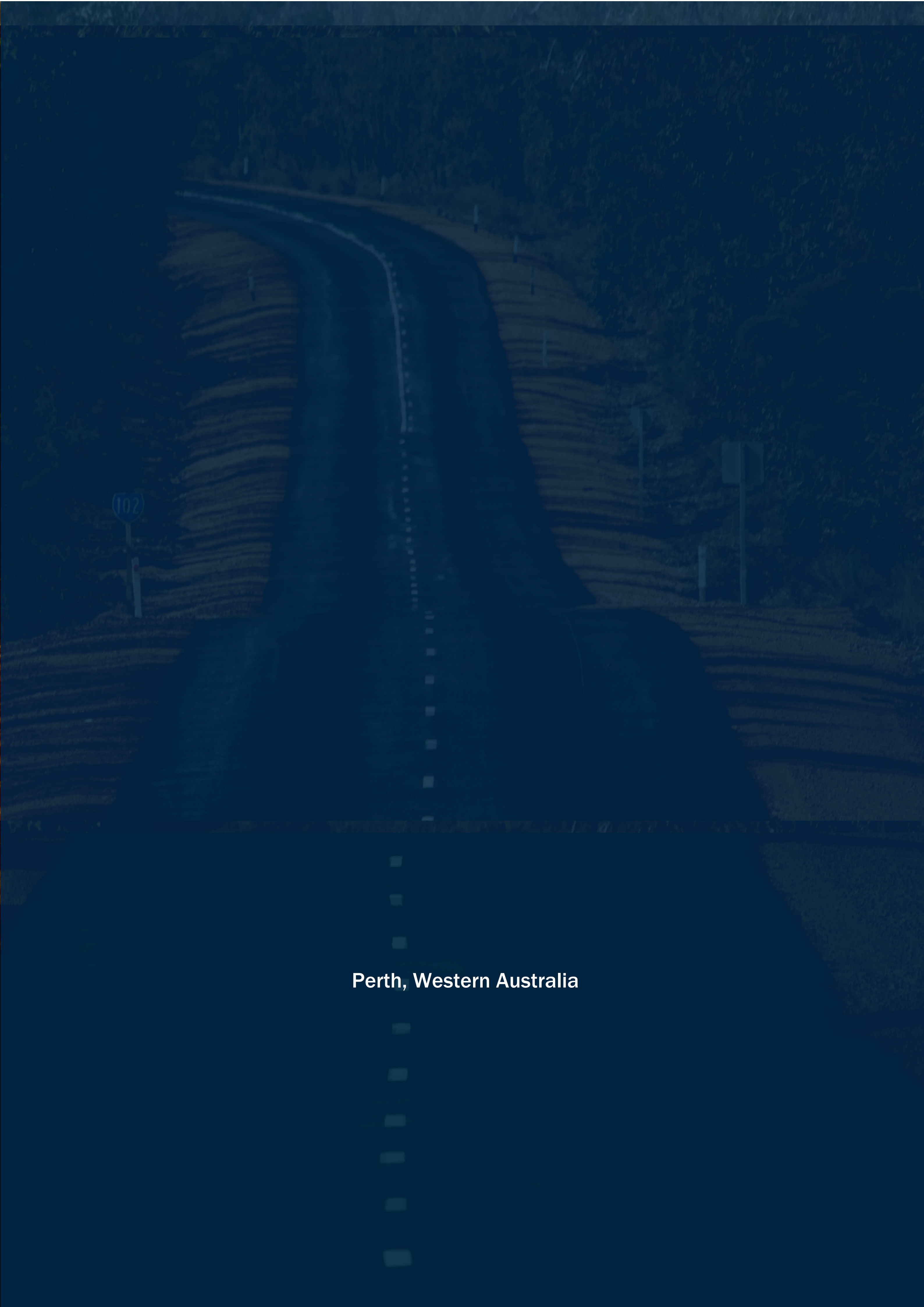
Appendix A Technology Characteristics

	Technology Type					
Characteristic	Computer vision	Inertial profilers	LiDAR and laser-based technologies - surface condition	LiDAR and laser-based technologies - road environment	Traffic speed deflectometers	Unmanned aerial vehicles
The underlying technology	Images from cameras are analysed to identify objects in the image and define their types and extents.	Accelerometers sense the inertial displacement of a vehicle relative to the road surface.	Lasers scan surfaces and the results are used to identify surface objects and can generate 3D representations of the road surface.	Lasers scan the road environment and can generate 3D representations of the road environment.	Doppler lasers measure minute deflections in the road surface that occur behind a loaded tire.	Images from cameras or other sensor outputs are analysed to identify objects in the image and define their types and extents.
How the technology is used	Typically dashcam or smartphone app takes the images at the vehicle's operating. Processing occurs either on-board or in the cloud.	Specialised equipment is mounted to vehicle axles and may include a laser unit to provide accurate measurements of the relative position of the road surface.	Specialised equipment is mounted to a vehicle and calibrated, with processing to produce desired outputs.	Specialised equipment is mounted to a vehicle and calibrated, with processing to produce desired outputs.	Specialised equipment mounted to a truck's axle and calibrated, with processing to derive the deflection measurements.	Small scale aerial vehicles (drones) mounted with cameras and other sensors, record the data. Post-processing after the data is downloaded.
Outputs provided to the LG	Images with objects identified and labelled with a unique ID. Includes GIS coordinates so the objects can be displayed on maps.	Roughness measurement of a road surface (sealed or unsealed) identified by chainage of the road.	High resolution cross-sectional surface profiles to identify cracking, roughness and rutting (among others) for set chainages of the road. Can be converted into 3D representations for improved definition of objects.	Point cloud to specified level of detail with objects identified, located and measured. Can be converted into 3D representations for improved definition of objects.	Data sets showing the deflection of the pavement in specified intervals by chainage of the road.	Image, LiDAR or thermal outputs as provided by the other technologies, depending on the setup of the drone.
Suitable for	Detecting common defects and asset types for sealed roads and sometimes unsealed roads.	Measuring surface roughness.	Technical measures of sealed surface condition especially cracking, roughness and rutting but can include edge break and deformations.	A range of asset and defect identification in the road environment, depending on the survey precision.	Determining pavement strength for sealed roads.	Survey of isolated or inaccessible components of bridges and culverts.
Advantages	Low cost setup and minimal installation. Consistent objective results (subject to accuracy of the technology).	Relatively lower cost to install than the LiDAR and Laser profilometers.	Very accurate and repeatable, able to scan at high speeds.	Very accurate (subject to specified accuracy) and repeatable, able to scan at high speeds.	Very accurate and repeatable, able to scan at moderate to high speeds (80 km/hr). Provides the only reliable way of testing pavement structural strength at speed.	Enables close-up recording of bridge and culvert components while staying remote from the drone.
Limitations	Weather and lighting effects such as shadows can limit effectiveness of the object detection. Unable to measure fine technical measures like rutting and roughness. Widely varying object detection capability between different suppliers.	Accuracy is affected by vehicle speed changes, suspension and tires. Needs to be calibrated.	Sensitive to dust and rain. High cost to acquire and the higher accuracy units require a dedicated vehicle. Specialised post-processing software is needed. Needs to be calibrated.	Sensitive to dust, rain and any objects that obscure line of sight of the target objects. High cost to install and requires a dedicated vehicle. Specialised post-processing software may be needed. Needs to be calibrated.	Highly specialised and expensive equipment, requiring a dedicated vehicle (although can be combined with other technologies). Needs to be calibrated.	Not suited to large scale network surveys. Object detection capabilities (of bridge defects and components) are currently limited. Essentially a manual task to pilot the drone and access data.



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