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AP-R568-18

Scoping Study for a Location Referencing Model to Support the BIM Environment

Scoping Study for a Location Referencing Model to Support the BIM Environment

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Abstract

An extensive review of location reference literature and direct enquiry within Australian and New Zealand road authorities, is aggregated into a new theoretical framework for location, location reference methods (LRM) and location referencing systems (LRS). This virtual location framework establishes location as independent of any single physical representation of location and associated location reference method families. Three families of LRM are described; topological, geospatial and geometric. Common elements of each family are: points, lines, paths and areas.

This project proposes a new Primary Location Reference System designed to support and to depend upon existing secondary reference systems and families of LRMs. The new system is an open standard location referencing method for horizontal network infrastructure. It is designed to support an Austroads Building Information Management (BIM) environment.

In the new system, a National Hub for Location Referencing would store each location as an independent virtual object. The system would be designed to facilitate information exchange using an extended OpenLR™, the location reference method adopted by the European DATEX II standard.

Keywords

Location, virtual location, location reference methods, location reference systems, linear referencing, topological referencing, BIM, GIS

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About Austroads

Austroads is the peak organisation of Australasian road transport and traffic agencies.

Austroads' purpose is to support our member organisations to deliver an improved Australasian road transport network. To succeed in this task, we undertake leading-edge road and transport research which underpins our input to policy development and published guidance on the design, construction and management of the road network and its associated infrastructure.

Austroads provides a collective approach that delivers value for money, encourages shared knowledge and drives consistency for road users.

Austroads is governed by a Board consisting of senior executive representatives from each of its eleven member organisations:

- Roads and Maritime Services New South Wales
- Roads Corporation Victoria
- Queensland Department of Transport and Main Roads
- Main Roads Western Australia
- Department of Planning, Transport and Infrastructure South Australia
- Department of State Growth Tasmania
- Department of Infrastructure, Planning and Logistics Northern Territory
- Transport Canberra and City Services Directorate, Australian Capital Territory
- The Department of Infrastructure, Regional Development and Cities
- Australian Local Government Association
- New Zealand Transport Agency.

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Summary

This research project proposes a new Primary Location Reference System designed to support and to depend upon existing secondary reference systems and families of LRMs. The new system is an open standard location referencing method for horizontal network infrastructure and is designed to support an Austroads Building Information Management (BIM) environment. The proposal is informed by international location reference models and builds on earlier Austroads research.

This Report recommends development of a *National Hub* for storing virtual location references. This would be designed and created as a mechanism for sharing location reference information between different location reference systems and modelling environments. For information exchange, an extended OpenLR™, the location reference method adopted by the European DATEX II standard, is recommended.

The research conducted an extensive review of location reference literature and direct enquiry within Australian and New Zealand road authorities. From this a new theoretical framework for location, location reference methods (LRM) and location referencing systems (LRS) was developed. This virtual location framework establishes location as independent of any single physical representation of location and associated location reference method families. Three families of LRM are described, including topological, geospatial and geometric. Common elements of each family are: points, lines, paths and areas

Location is defined as a virtual object that is temporal, graphical and model-independent. The virtual location object can be a point, line, path or area, representing a physical place on a road network that may be identified in any given model by a suitable location reference. By this definition, a physical real world location is only one “view” of a location in the “real world” model, a view that is of equal importance to other model views, IFC-Alignment and LandInfra.

A Location Reference is one of many possible labels or codes derived from an associated location reference method that uniquely identifies a location.

A Location Reference Method is a model-specific methodology for assigning unique references to a location and can have either a static or a dynamic profile. More importantly, different types of business units can have business critical drivers for selecting specific types of location reference methods.

The new theoretical framework is based on an alternative grouping of LRM families that differs from previous publications. This new grouping introduces digital design (BIM) by redefining the Geometric family LRMs to include model geometry. The resulting groups are:

- Topological LRMs describe locations along discrete but interconnected networks of features. This family includes traditional Linear LRMs, as well as the emerging and more comprehensive network-based models used by ITS standards. The family is typified known points of connection, or interest (nodes), connected by road line segments (links) and distance travelled.
- Geospatial LRMs provide a way to describe locations on the Earth’s surface in real-world coordinates. This includes Geographic Information System LRMs (GIS) as well as coordinate-based mapping systems. The family is typified by road line segments (links), points of connection or interest (nodes), and real-world coordinates.
- Geometric LRMs are based on digital models that provide coordinate geometry within local model-coordinates. Typically, these include digital design (2D or 3D) and BIM models. Some model environments are stand-alone and, more recently, they may be geo-connected (placed in the real world).

Each of these newly defined families is a basic building block for multiple location references that have in common: points, lines, paths and areas. This commonality can form the basis for the extension to OpenLR™ the recommended data transfer specification for development of the National Hub for Location References, to be built adopting Semantic Web principals.

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Glossary of Terms

Alignment: A non-branching, continuous, single location constructed with polylines starting from a known geo-referenced point. An alignment may be horizontal, horizontal plus vertical, horizontal plus vertical with generated 3D, or 3D.

Alignment system: Two or more alignments grouped into an alignment system, where two different alignments can be related to each other.

Area: A three-dimensional (2 + time) object primitive

Dynamic Referencing: Dynamic location references (dynamic profile) where the location reference is generated on-the-fly based on geographic properties in a digital map database. The location reference methods used by senders or receivers may be unknown.

Geospatial LRMs: These provide a way to describe locations on the Earth's surface in real-world coordinates. This includes Geographic Information System (GIS) LRMs as well as coordinate-based mapping systems. The family is typified by road line segments (links), known points of connection or interest (nodes), and real-world coordinates at nodes and also at regular intervals along links, or geographic polylines.

Geometric LRMs: These are based on digital models and provide coordinate geometry within local model-coordinates. Typically these include digital design, whether 2D or 3D, and BIM models. Some model environments are stand-alone and, more recently, they may be geo-connected (placed in the real world).

Line: A two-dimensional (1 + time) object primitive, also called a link and an alignment.

Linear Referencing Method: A group of methods within the topological family of location reference methods that specify a start position, a direction and a distance (also known as LRM).

Location: A virtual object that is *temporal, graphical and model-independent.* The virtual object can be a point, line, path or area, representing a physical place on a road network that may be identified in any given model by a suitable location reference.

Location Data: Information stored in a computer model that describes the virtual location object sufficiently to be able to encode and decode associated location references.

Location Reference (LR): One of many possible labels or codes that are derived from an associated location reference method that uniquely identifies a location.

Location Reference Method (LRM): A model-specific methodology for assigning unique references to a location.

Location Referencing System (LRS): Integrated systems by which location references are coded and decoded according to individual location referencing methods, and the rules for converting and exchanging location references between LRMs, as well as associated standards, definitions, UML models, databases and software.

Network: A description of a complex arrangement of interconnected links and nodes that form an identifiable system.

Node: A special case of a point that is also one end of a link.

Path: The concatenation of (several) shortest paths between two known points, each consisting of points and lines (involves routing and is synonymous with service).

Point: A one-dimensional (0 + time) object primitive, also called a period.

Positioning: provides coordinates with reference to the Earth.

Static Referencing: Pre-coded location references (pre-coded profile) use a unique identifier that is agreed upon in both sender and receiver system to select a location from a set of pre-coded locations.

Topological LRMs: These describe locations along discrete, but interconnected, networks of features. This family includes traditional Linear LRMs, as well as the emerging and more comprehensive network-based models used by ITS standards. The family is typified by known points of connection or interest (nodes), connected by road line segments (links) and distance travelled.

1. Introduction

This research project will investigate the state of national location reference models with a view to establishing the framework structure of an open standard referencing model for horizontal network infrastructure to support an Austroads Building Information Management (BIM) environment. Such a model will be informed by international location reference models, build on earlier Austroads research (including Report AP-T190-11) and identify impacts from location reference models on measuring and managing levels of service. This work is a sub-element of the overall Austroads road asset Data Standard project and it has linkages with other related sub-elements.

A significant feature of this research is the inclusion of direct contact and data collection before this Report was written. The Direct Enquiry collected a variety of perspectives on the terminology, practices and systems in use for all nine member road authorities. Over 50 individuals representing Asset Management, Traffic, Systems, Transport, Roads, Bridges, Cycle Paths, etc. provided explanations of the organizational practices that effects Asset Management.

1.1 Prior Work: Austroads Technical Report, AP-T190-11

The current Project builds upon previous Austroads research: *Harmonisation of Location Referencing for Road Related Data Collection* (Austroads, 2011). That report was produced when increasing use was being made of new data collection systems. These, predominantly geospatial systems, used emerging technologies such as rapid road condition survey and GPS positioning. The project specifically intended to explore the feasibility of adopting a universal method of referencing data collected in the field to achieve harmonisation. That report intended road authorities to more readily: share information, build linked networks, compare network data over time and reduce survey costs through improved data management.

That report concluded by acknowledging that it should be feasible to create a harmonised spatial referencing system that is fast, accurate and suitable for vehicle-based network surveys that could be readily transformed to any linear referencing system. That approach was intended to allow member authorities to benefit from continued growth and evolution in spatial technologies.

However, the recommendations for that harmonisation attempt conceded that the technology and associated specifications for spatial collection of linear data were not yet adequate to support an immediate shift. Several authorities have moved to accommodate the recommended transformation and to harmonise their linear and spatial referencing. However, that effort has been individual to each authority.

1.2 Project Objective

Direct Inquiry Findings

Asset Management Task Force members organised stakeholder consultations in each state, territory and New Zealand. The 54 participants provided details of location practices, processes and systems utilised in the past and present, including plans for the future. Although wide variety of perspectives were articulated, the major finding from this direct inquiry is the need for multiple location definitions to ensure optimum road network service performance.

Austroads Technical Report, AP-T190-11, was heavily constrained by its context. As a result, two important emerging technologies were not addressed. One was the increasing use of BIM (Building Information Modelling), a technology for the information-rich digital design of buildings and infrastructure. BIM is now impacting on road authorities (QTMR 2017The second was that of Intelligent Transport Systems (ITS) and associated developments in location referencing (TomTom 2012).

This study takes into account these two important technological advances. But, more importantly, a greater emphasis is placed on the primary requirement of defining location to enable implementation of the dynamic nature of the new technology for asset management. This research aims to construct a new theoretical framework for location, location reference methods and location referencing systems, with location being independent of any specific location reference method. This new theoretical framework will provide a mechanism for the introduction of the requirements of digital design in location referencing for asset management use.

1.3 Current Context and Directions in Location Referencing

There are two different use-types for location referencing. In this Report we have used the terms “static” and “dynamic” to differentiate these methods.

- **Static systems**: pre-coded location references (pre-coded profile). Location referencing using a unique identifier that is agreed upon in both sender and receiver systems to select a location from a set of pre-coded locations (ISO 17572).
- **Dynamic systems**: dynamic location references (dynamic profile). Location reference is generated on-the-fly based on geographic properties in a digital map database (ISO 17572). The location reference methods used by senders or receivers may be unknown.

There are two primary approaches to managing location data. These are generally nominated in discussions colloquially with each authority as “the way we work”. The methods are:

- Linear referencing: A location reference is formed by a local method for measuring along road lines, from fixed known points, in a given direction. It may include other information such as offsets.
- Geospatial referencing: A location reference is formed from X-Y coordinate information and managed by a GIS application.

Direct Inquiry Findings

Interestingly, in Australia and New Zealand at the time of our review, only one jurisdiction claimed to use solely linear methods and one claimed sole use of GIS methods. All others used a hybrid of the two methods. Interestingly, an equal number said they were moving from GIS to linear methods or were moving from linear to GIS. It was concluded that such descriptors indicated the importance of business drivers and their relationship to legacy models or systems.

1.3.1 Static Location Referencing Systems

Direct Inquiry Findings

Australian and New Zealand road authorities presently use static asset management systems. These generally include examples of a wide range of heritage linear referencing methods and some mixture of spatial referencing capability.

It may be argued that the choice of systems adopted have been driven by historic software procurement, whether commercial products or bespoke applications influenced by international trends in location referencing. Of note are static standards for both linear referencing (AS/NZS ISO 19148) and geospatial referencing (AS/NZS ISO 19133) and asset management location referencing tend to lie within these influences.

Various US state departments of transport and selected software companies have cooperated and influenced the development of these local location referencing methods in the early part of the 21st Century. This effort has influenced ISO 19148 for linear referencing and ISO19133 for geographic referencing. These standards underpin existing and proposed software applications within road asset management. Global support for these standards has been helped by European interest driven by a need to harmonise data under the European *Digital Competence Framework 2.0.*

1.3.2 Emerging Dynamic Systems

However, the asset management systems are not the only type of systems used within road authorities that require location referencing. The domain of Intelligent Transportation Systems (ITS) similarly makes use of location reference methods.

This research project was influenced by asset management governance within Austroads, and so little feedback was obtained from ITS staff within road authorities. However, discussions about future needs referred to the desirability of engaging in ITS related activities. Currently there is little in the way of sharing of data across the two domains.

Direct Inquiry Findings

ITS representatives attended workshops at NT & VIC. Discussions about ITS arose in discussions about the future needs of asset management in most jurisdictions.

The ITS standards appear more heavily influenced by European research and by European-based companies. ITS standards are ISO17572 (part 2 is static and part 3 is dynamic) and CEN 16157 DATEX II (both static and dynamic).

Unlike asset management, ITS requires support for dynamic systems because users may be mobile and their local system may be unknown. The importance of having dynamic systems means that new models for data exchange have been developed.

- TPEG™: ISO 17572 relies on TPEG (a proprietary protocol controlled by TISA)
- OpenLR™: DATEX II relies on OpenLR (an open protocol developed by Tom Tom).

There appears to be little awareness of the potential of dynamic systems within road asset management. However, a close reading of ITS objectives will highlight several key areas of potential cooperation with asset management. These include: Journey time information; and Information on temporary diversions/roadworks.

Direct Inquiry Findings

One of the policy objectives of all Australian and New Zealand road authorities is public provision of information and management of levels of service. There is a clear imperative for adopting ITS functionality in the management of road assets.

2. A New Theoretical Framework for Location

This Section constructs a new theoretical framework for location, location reference methods and location referencing systems by reviewing past literature and standards to identify one underlying mechanism for using location in a referencing system. This new framework redefines location and the way referencing operates in the emerging digital environments.

2.1 Location in Roads and Horizontal Infrastructure

The multiplicity of meaning and use for 'location' meant that an extensive literature review was necessary. Appendix B provides a bibliography of all documents reviewed. They are categorised by content to indicate the breadth of the search, as well as the wide-ranging topic areas that consider location.

It is assumed that all categories have some relevance to the meaning of location as it is applied within road networks indicating complexity rather than simplicity. The best way to illustrate the complexity of the concept of location is to choose an historical sample of documents that provide a comparison of meaning, context and application. Thus, 16 documents, comprising academic or industry papers, international standards and consultant reports, provide a chronological framework for the discussion of the importance of location definitions and emerging technologies that impact on road asset management.

2.1.1 Literature Review

A critical review of the literature, indicates a consistent hierarchy for framing location management:

1. A Location may be given a Location Reference (LR)
2. The LR is determined according to a Location Reference Method (LRM)
3. LR and LRM together may be considered as defining a Location Referencing System (LRS). But, more importantly, an LRS may have multiple LRMs.

A seminal paper, *Integrating Traffic Management Data Via An Enterprise LRS* by Tom Reis (2000) influenced two important local studies: HTC 2001 series for Transit New Zealand and 2005 VicRoads RoadsOne Project series. These studies consistently reported (VicRoads 2005a):

> *"…there is consensus that multiple location reference methods (LRMs) are required to support all road location requirements, and that no single LRM can satisfy all requirements"*

Importantly, different jurisdictions will have, for historic reasons, different LRS and thus, it is unlikely that harmonisation of LRMs is possible and certainly cannot be agreed to, based on the US attempt (Scarponcini 2002; NCHRP, 2001). This means that a LRM from an organization may not be understood in a context outside that organization. Indeed, even an LRM from one functional area of an organization may not be understood by other functional areas.

To provide the chronological overview of the evolution of these key terms the documents listed in tables 2.1, 2.2, 2.3 and 2.4 offer definitions used in this Report:

T Ries, 2000, *Integrating Traffic Management Data Via An Enterprise LRS*. In Proceedings of the North American Travel Monitoring Exhibition and Conference.

HTC Infrastructure Management Ltd., 2001, Report for TNZ *Task 2100: Principles of Location*. Auckland, New Zealand.

NCHRP (National Cooperative Highway Research Program), 2001, Report 460, *Guidelines for the Implementation of Multimodal Transportation Location Referencing Systems.* Washington DC, USA.

P Scarponcini, 2002, *Generalized model for linear referencing in transportation*, GeoInformatica, vol, 6, pp. 35-55.

VicRoads, 2005, OneRoads Project, *Location Referencing System Glossary*, Melbourne.

AS/NZS ISO 19133, 2006, Geographic Information -- Location-Based Services: Tracking and Navigation.

TomTom, 2009, OpenLR™ Version 1.2 An Open Standard for Encoding, Transmitting and Decoding Location References in Digital Maps

Austroads, 2011, *Harmonisation of Location Referencing for Related Data Collection*, AP- T190-11, Sydney.

CEN/TS 16157, 2011, Intelligent Transport Systems -- DATEX II Data Exchange Specifications for Traffic Management and Information: Part 1: Context and Framework

CEN/TS 16157, 2011, Intelligent Transport Systems -- DATEX II Data Exchange Specifications for Traffic Management and Information: Part 2: Location Referencing

AS/NZS ISO 19148, 2012, Geographic information -- linear referencing.

INSPIRE (Infrastructure for Spatial Information in Europe), 2012, D2.10.1: Generic Network Model, Version 1.0rc2, Drafting Team "Data Specifications".

TomTom, 2012, OpenLR™ Version 1.2 Revision 2, An Open Standard for Encoding, Transmitting and Decoding Location References in Digital Maps

TomTom, 2012, OpenLR™ Version 1.5 Revision 2, An Open Standard for Encoding, Transmitting and Decoding Location References in Digital Maps

ISO 17572-2015, Intelligent Transport Systems (ITS) -- Location Referencing for Geographic Databases: Part 1: General Requirements and Conceptual Model.

ISO 17572-2015, Intelligent Transport Systems (ITS) -- Location Referencing for Geographic Databases: Part 2: Pre-Coded Location References (Pre-Coded Profile).

ISO 17572-2015, Intelligent Transport Systems (ITS) -- Location Referencing for Geographic Databases: Part 3: Dynamic Location References (Dynamic Profile).

In some cases, there was variation in definition between different parts of a standard. In this case, the better-developed definition is used. For this reason, this analysis does not distinguish between different parts of the standard cited.

In the following Sections, care must be taken when interpreting the three letter acronyms because **L** is often used (sometimes interchangeably) to mean both Location and Linear. Thus, LRM may be either a Linear or a Location Reference Method. Similarly, the acronym LRS may confuse the alternatives *Linear* and *Location* for a Referencing System. However, within this Report, linear referencing systems are considered a subset of location referencing systems and thus, the term is made explicit whenever linear is intended.

Earlier references, with the exception of the studies influenced by Reis, generally describe location for roads in terms of a linear reference; locations that lie along discrete road lines. Over time, this meaning has evolved into a broader location reference to include both the need for mapping and multiple types of location within a road network. This research builds upon earlier location definition models for asset management by incorporating recent data management and use trends in topological network models found in Intelligent Transport Systems (ITS).

2.2 Location Referencing

This section provides examples of the variety of the definitions for the hierarchy of location concepts used in relation to road assets: location, location reference, location reference method and location referencing system. One of the reasons for the diversity is because of specific organisation business drivers outlined in 2.2.5.

2.2.1 The Nature of Location

Location is variously defined, even within definitive references such as standards. A good starting point is with Austroads Technical Report, AP-T190-11, which defines location as "the point or position of interest on the road". This view aligns with a geospatial interest in location and suits the asset management perspective of location.

Table 2.1: Definitions of Location

Source	Year	Definition of Location
T. Ries	2000	
HTC,TNZ Task 2100 Glossary	2001	A specific point on a highway for which an identification of its linear position with respect to a known point is desired.
NCHRP Report 460 Glossary	2001	The numerical or other indicator of a point or object, sufficiently precise that the object or event can be found from the identification. A spatio-temporal expression that designates a unique place and time in space. The name given to a specific point on a highway. Identifiable part, of a physical place, that may be identified by position parameters. A position on the Earth's surface.
P Scarponcini	2002	
VicRoads RoadsOne Glossary	2005	(a) The numerical or other identification of a point or object, sufficiently precise that the object or event can be found from the identification. (b) A spatiotemporal expression that designates a unique place and time in space. (c) The name given to a specific point on a road for which an identification of its linear position with respect to a known point is desired. (d) Identifiable part, of a physical place, that may be identified by positional parameters. (e) A position on the Earth's surface.
AS/NZS ISO 19133	2006	Identifiable geographic place. *Note: 1: A location is represented by one of a set of data types that describe a position… including coordinates, a [linear], or an address*.
OpenLR™ V1.2	2009	A specification of the position on the earth surface of an object in a digital map. Locations are objects in a digital map, like points, paths and areas. (Version 1.2 concentrates on line locations (paths) in a digital map only). Path locations are the concatenation of several shortest paths and have a start and an end.
AP-T190-11	2011	The point or position of interest on the road.
DATEX II: CEN/TS 16157	2011	Identifiable geographic place. *Note 1: It is either on a network (as a point or linear location) or an area.*
AS/NZS ISO 19148	2012	Identifiable geographic place. *Note: 1: A location is represented by one of a set of data types that describe a position…including coordinates, a [linear], or an address*.

Source	Year	Definition of Location
INSPIRE Generic Network Model	2012	Location is not used. Rather the model is for elements of a network
OpenLR™ V1.5r2	2012	Locations are [map-independent] objects in a digital map, like points, paths and areas. OpenLR™ can handle locations which are bound to a road network but also locations which can be everywhere on earth (not bound to the road network).
AS/NZ ISO 17572	2015	Simple or compound geographic object to be referenced by a location reference. *Note: A location is a part of the road network that is intended to be identified. The sender system aims to refer to it. The receiver system aims to find it in its map database.*

Note: In all definition tables, an empty cell indicates that no definition was provided or could be inferred.

Within relevant standards, there has been a shift in definition from a physical place or point of interest, toward a view of location as a geographic object. This change in thinking has been driven in part by the need to communicate location between different systems (such as hand-held devices or large corporate databases) both statically and dynamically, and by the desire to map features by location. There is a corresponding shift towards envisioning locations in terms of networks (for example INSPIRE).

These shifts are important, as it provides a framework for redefining location from the “point of interest” definition in AP-T190-11.

For the purposes of this Report a new, context independent, definition is created:

Location: ***a virtual object that is temporal, graphical and model-independent. The virtual object can be a point, line, path or area, representing a physical place on a road network that may be identified in any given model by a suitable location reference*****.**

This new definition establishes that a location:

- is independent of the modelling or mapping environment
- exists in time, it has a creation and may have a destruction time
- is geographical in nature with a time dimension and 0 to 3 geographical dimensions
- may be a point, line, path or area
- belongs to, or is associated with, a network (rather than being discrete)
- may be identified using a location reference (pointer to location object) in accordance with a location reference method applicable to the model view
- can be identified by multiple location references, each coded by a given location reference method.

By this definition, a physical real world location is only one “view” of a location in the “real world” model. This view is equally as important as any other model view depending on the context. The key is being able to find the location regardless of the model being used (such as finding a location in the real world).

A location may be a point, line, path or area. A path is a concept drawn from OpenLR™, which differentiates between a line and a path, so it is necessary to expand on these terms:

Point***: a one-dimensional (0 + time) object primitive, also called a period*** *(ISO 19148)***.**

Line***: a two-dimensional (1 + time) object primitive, also called a link.***

Path***: the concatenation of (several) shortest paths between two known points each consisting of points and lines (involves routing and is synonymous with service).*** *The optimal path is also called a route (ISO 19133:2005).*

Area*: a three-dimensional (2 + time) object primitive.*

Note that point has a special case, called a node, where the point lies at one end of one or more links.

Node*: A special case of a point that is also at one end of a link.*

These are primitive virtual objects that are independent of the model being used and therefore the location reference method. For example, these objects may be found in multiple LRMs, a good example being links and nodes that are lines and points respectively. Links and Nodes (or equivalent objects) feature in many LRMs and across LRM families. While a path may be considered as being made up of several other primitives (namely multiple points and multiple lines), it nevertheless forms an element which is different from such components, and is essential for ITS and Service requirements. ISO 17572-1 (p11) allows for a set of two or more links to be considered a location.

The nature of these primitives should not be confused with their attributes, which may include geometric and geographic properties in accordance with a particular model view. Thus, a point may have a two or three-dimensional coordinate, and lines may consist of polylines (in two or three dimensions) as applicable in a specific model view. The assembly of data that describes a location is stored in the location database. Indeed, location data is whatever data is required for coding or decoding a location reference for a location primitive, by any and multiple associated location reference methods. Therefore, typically location data will require multiple attribute sets.

Location Data: *Information stored in a computer model that describes the virtual location object sufficiently to be able to encode and decode associated location references.*

2.2.2 Location Reference (LR)

A location reference is often described as an address. This common language term is an effective way of describing how a location reference works. Another way is to consider a location reference as a pointer.

Table 2.2: Definitions of Location Reference (LR)

Source	Year	Definition of Location Reference (LR)
T. Ries.	2000	
HTC,TNZ Task 2100 Glossary	2001	Process of identifying locations on the network by specifying a start position, direction and distance.
NCHRP Report 460 Glossary	2001	
P. Scarponcini	2002	
VicRoads RoadsOne Glossary	2005	
AS/NZS ISO 19133	2006	Measured distance from a reference point along a route (feature).
OpenLR™ V1.2	2009	Location Code, created according to a specific set of rules, used to reference a location. The two location reference points describing the start and the end of the location reference path are mandatory components in any OpenLR™ Location Reference. Between these two LRPs may exist several additional LRPs.
AP-T190-11	2011	
DATEX II: CEN/TS 16157	2011	Data set assigned to a location. *Note 1: A reference shall define unambiguously and exactly one location in the location referencing system to identify the location.* *Note 2: Can be either static or dynamic.*
AS/NZS ISO 19148	2012	Specification of a location relative to a linear element as a measurement along (and typically offset from) a linear element.
INSPIRE Generic Network Model	2012	The term is not used, but there is emphasis on referencing network elements rather than geometry

Source	Year	Definition of Location Reference (LR)
OpenLR^{TM} V1.5r2	2012	Location Code, created according to a specific set of rules used to reference a location. The idea is to describe a location with an ordered set of location reference points (LRPs). This set of LRPs uniquely describes the location in a digital map and is called the location reference. A location is described fully by the concatenation of (several) shortest paths.
ISO 17572	2015	Label that is assigned to a location. A location reference is a unique identification of a geographic object. *Note 1: within a single LRM, one reference shall define unambiguously and exactly one location.*

In most of the literature, the location reference is considered a code, or a label, which is assigned to a location. A location reference only has meaning if it is constructed according to a specific set of rules. This then enables the physical location to be found according to that set of rules. However, ISO 17572 raises the issue of uniqueness. Logically, a location reference should uniquely indicate a location. However, in the following section it is demonstrated that multiple location reference methods may exist concurrently. Therefore, a location reference should uniquely identify a location, but it should not be a unique reference.

For the purposes of this Report, the following definition is adopted:

Location Reference*: One of many possible labels or codes that are derived from an associated location reference method that uniquely identifies a location.*

2.2.3 Location Reference Method (LRM)

The concept of a location reference is relatively meaningless without the concept of a location reference method. This provides the specific set of rules for both encoding and decoding the location reference.

Direct Inquiry Findings

In Australia and New Zealand, each road authority has one or more location reference methods. Indeed, it is common for different parts of an organisation to have a different LRM.

VicRoads stated: *"A variety of LRMs are valid in a road authority to facilitate the location workflow that locates road asset features and/or events in the field, records those locations in a database, and allows placement of real-world activity resulting from decision-making outcomes."*

Table 2.3: Definitions of Location Reference Method (LRM)

Source	Year	Definition of Location Reference Methods (LRM)
T. Ries	2000	A way of describing the location of an object or event relative to some known point in space.
HTC,TNZ Task 2100 Glossary	2001	The technique used to identify the specific point (location) or segment of road, either in the field or in the office.
NCHRP Report 460 Glossary	2001	A mechanism for finding and stating the location of an unknown point by referencing it to a known point.
P. Scarponcini	2002	A way to identify a specific location with respect to a known point.
VicRoads RoadsOne Glossary	2005	A mechanism (or technique) for finding and stating the location of an unknown point by referencing it to a known point.
AS/NZ ISO 19133	2006	[LRM defined as Linear Referencing Method]. The manner in which measurements are made (and optionally offset from) a curvilinear element.

Source	Year	Definition of Location Reference Methods (LRM)
INSPIRE Generic Network Model	2012	
OpenLR™ V1.2	2009	
AP-T190-11	2011	The method used to identify a specific point or event on the road by providing it with a unique address.
DATEX II: CEN/TS 16157	2011	Defined in context of definition of LRS: “complete system by which location references are generated, according to a location referencing method…”
AS/NZS ISO 19148	2012	Defined only Linear Referencing Method: Manner in which measurements are made along (and typically offset from) a linear element. *Note 1: A Linear Element is defined as a 1-dimensional object that serves as the axis along which linear referencing is performed).*
OpenLR™ V1.5r2	2012	OpenLR™ describes a method and a format for encoding, transmitting and decoding (map-independent) references of locations.
ISO 17572	2015	Methodology of assigning location references to locations

It is important to understand that any given LRM will be the result of both historic practice and business objectives. In many cases, the LRM will simply be an expedient solution to achieve desired outcomes with available technology.

For the purposes of this Report, the following definition is adopted:

Location Reference Method***: A model-specific methodology for assigning unique references to a location***

2.2.4 Location Reference Systems (LRS)

Management of location requires at least one location reference method for the coding and decoding of location. Accordingly, to use an LRM requires the development of a system of additional features such as standards, definitions, software, hardware, and databases to be able to code, store, retrieve and decode locations. Together these form a location reference system. In the definitions provided below, many standards relate a LRS to a single LRM, but the intention is that the LRS manages and integrates an organization’s formal location methods (e.g., maps, GPS, mileposts) (Ries, 2000).

Table 2.4: Definitions of Location Reference System (LRS)

Source	Year	Definition of Location Reference Systems (LRS)
T. Ries	2000	The management of location reference methods (includes field and office data and procedures).
HTC,TNZ Task 2100 Glossary	2001	The total set of procedures for determining and retaining a record of specific points along a highway. Includes the location referencing method(s) together with the procedures for storing, maintaining, and retrieving the information about points and segments on the road.
NCHRP Report 460 Glossary	2001	(a) Policies, records, objects, and procedures that relate the included location referencing methods in a way that the accuracy requirements for end users are met (b) A system of determining the position of an entity relative to other entities to some external frame of reference.
P. Scarponcini	2002	
VicRoads RoadsOne Glossary	2005	(a) Policies, records, objects, and procedures that relate the included location referencing methods in a way that the accuracy requirements for end users are met. (b) A system of determining the position of an entity relative to other entities or to some external frame of reference.

Source	Year	Definition of Location Reference Systems (LRS)
ISO 19133	2006	Positioning system that measures distance from a reference point along a route (feature). *Note: The system includes the complete set of procedures for determining and retaining a record of specific points along a linear feature such as the location reference method(s) together with procedures for storing, maintaining, and retrieving location information about points and segments on highways.*
INSPIRE Generic Network Model	2012	
OpenLR^{TM} V1.2	2009	
AP-T190-11: p2	2011	The location referencing system is the total set of procedures for determining and retaining a record of specific points or events over the whole road network. This includes the location referencing method(s) used together with other aspects of linear referencing such as storing and maintaining data in a logical manner so that it can be retrieved in the future.
DATEX II: CEN/TS 16157	2011	Complete system by which location references are generated, according to a location referencing method, and communicated, including standards, definitions, software, hardware, and databases.
AS/NZS ISO 19148	2012	UML Class Package for the Standard. The core package “Linear Referencing System” supplies classes and types to the definition of Linear Referencing Systems.
OpenLR^{TM} V1.5r2	2012	The communication chain of a machine-readable location can be described as encoding the location at the sender side, transfer of the code to the receiving system and decoding the code at the receiver side.
ISO 17572 (3)	2015	Complete system by which location references are generated, according to a location referencing method, and communicated, including standards, definitions, software, hardware, and databases.

Again, there has been evolution in the meaning of the term ‘location reference system’. Early concepts favoured the inclusion of office and field processes along with procedures for locating, storing, maintaining, retrieving and analysing the information about points and segments on the road. Later concepts include software, particularly with reference to UML (Unified Modelling Language) package structures.

However, we already know that a jurisdiction is likely to require more than one LRM. It therefore makes no sense to limit the LRS to a single LRM. This is sensible when relating the use of different linear referencing systems within different departments that each have their own system. But, rarely are organizational systems utilised in complete isolation, particularly with the need to include geospatial features for public service mapping via the internet.

The reality is that the functioning of an LRS within any road management organisation necessarily requires multiple LRMs. For example, assets might be recorded against a linear reference while works instructions might issue a map and coordinates. As long as the system is able to handle the multiple methods and exchange information, then the LRS is integrated. Where interoperability of information is not possible, then discrete LRS may be maintained independently, both within jurisdictions and particularly between them.

The emerging Intelligent Transport Systems (ITS) standards have broadened the perspective of location referencing systems specifically to include both coding and decoding. Thus, a new definition of the LRS is required that adequately explains the average LRS complexity.

Location Referencing System*: Integrated system by which location references are coded and decoded according to individual location referencing methods, and the rules for converting and exchanging location references between LRMs, as well as associated standards, definitions, UML models, databases and software.*

Importantly, this definition accepts the notion of multiple LRMs, and identifies a degree of interoperability between the LRMs. Where no interoperability exists, discrete LRS can exist in parallel. In Australia and New Zealand, LRS formed by a single LRM are rare or non-existent. There are always alternative ways to code individual locations and some method for converting different coding between location references.

3. Families of Location Referencing Methods (LRMs)

The evolution of families of LRMs is linked to the evolution of asset management in road infrastructure outlined in this section. Each jurisdiction in any country has developed different approaches over time. However, across jurisdictions, the various methods have similar properties and these may be grouped into families formed from fundamentally different concepts.

VicRoads cite Ries, (2000) as the source for three groups of LRMs: geodetic, geometric, and linear.

- Geodetic (or Geographic) LRMs provide a way to describe locations on the Earth's surface.
- Geometric LRMs represent discrete features on the Earth as a map coordinate.
- Linear LRMs describe locations along discrete features.

Although Ries wrote about groups, his diagrams indicate that within each group are a number of sub-sets. In this Report, these sub-sets are referred to as families because of the close relationship between LRMs within the families and the differences from LRMs of other families.

Road network management functions require LRMs found in all three groups. However, while this is a useful start, it does not adequately deal with emerging trends in location referencing (as these were nascent at the time of the RoadsOne Project). The emerging technologies are:

- BIM (3D, information loaded, digital design)
- ITS (Intelligent Transport Systems)

Accordingly, this research updates the previous grouping of LRMs in favour of an alternative set of conceptual families:

- **Topological** LRMs describe locations along discrete but interconnected networks of features. This family includes traditional Linear LRMs, as well as the emerging and more comprehensive network-based models used by ITS standards. The family is typified known points of connection, or interest (nodes), connected by road line segments (links) and distance travelled.
- **Geospatial** LRMs provide a way to describe locations on the Earth's surface in real-world coordinates. This includes Geographic Information System LRMs as well as coordinate-based mapping systems. The family is typified by road line segments (links), known points of connection or interest (nodes), and real-world coordinates at nodes and also at regular intervals along links, or geographic polylines.
- **Geometric** LRMs are based on digital models that provide coordinate geometry within local model-coordinates. Typically, these include digital design (2D or 3D) and BIM models. Some model environments are stand-alone and, more recently, they may be geo-connected (placed in the real world).

The need to create an alternative set of LRMs highlights the difficulty of exchanging digital information between different LRM systems.

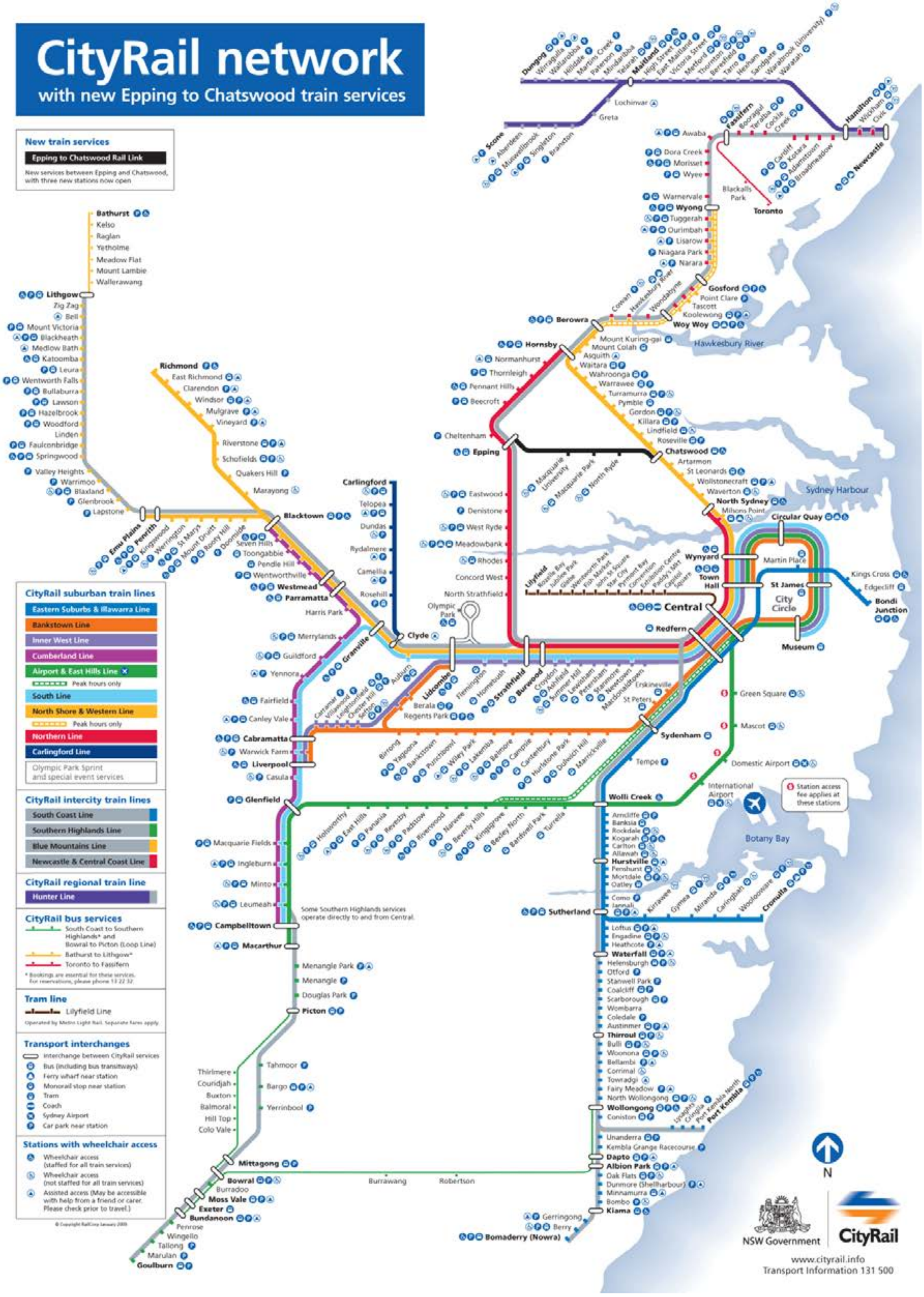
3.1 Topological (Logical Linear and Network Referencing)

Some topological location referencing methods are very common in road infrastructure asset management. They are a family of methods that, at the base level, describe "locations relative to a one-dimensional [excluding time] object as measured along (and optionally offset from) that object" (ISO 19148: 2012). They do not rely on any spatial coordinate information, but often include this to a varying extent, such as in attributes.

There are two groups of LRM within this family:

- Linear referencing (discrete linear elements)
- Network referencing (topologically connected – routable – network of linear elements)

Figure 3.1: Sydney Rail – topological map



Source: CityRail, Transport for New South Wales

These are topological in that there is no need to have the representation to scale or proportional. It is sufficient to describe locations in relative terms. Well-known examples of topological mapping are for public transport networks such as London Underground or Sydney Rail (Figure 3.1). The user is aware that there is no way to interpolate geospatial proximity from topological maps. However, it is always possible to plot a path from one network location to another through the network. Scarponcini (2002) describes a topological network as representing

> *"…allowable transportation paths through the set of roadways. They are comprised of nodes where turns can occur and links which represent the roadways which connect the nodes"*

The ability to plot a path is an important differentiator between these two groups. None of the LRMs used by road authorities for asset management, including the associated software systems, currently provides routing functionality. Yet, ITS standards do provide this function in traffic management systems and there are many private providers of such networks for navigation purposes.

This research considers that there is benefit for asset management in adopting ITS approaches, particularly with regard to networks and path calculation (sometimes known as routable systems).

ISO 17572-1 requires that an LRM should enable referencing of the relative spatial relationship of objects and not change topological relationships by its own action. For example, the order of points along a line should not get confused (this has significance when dealing with imprecise geospatial LRMs).

It is also possible to hybridise the topological LRM by including geospatial data as attributes (particularly with modern geospatial databases such as Oracle Geospatial).

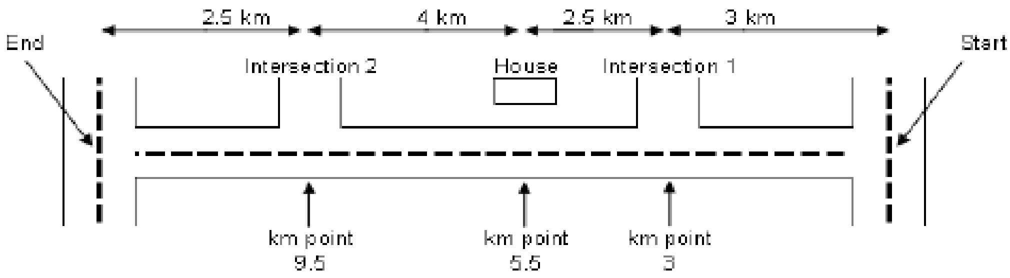
3.1.1 Linear Referencing

This description of linear referencing is from Austroads AP-T190-11 provides:

> *"Linear referencing is the most common referencing method used by road authorities for vehicle-based data collection. It is easy to understand, does not require sophisticated technology and it allows the user to reference locations in the field using physical markers and identifiers. There are several different approaches to linear location referencing including: kilometre post, kilometre point, reference post, reference point, link/node.*
>
> *"Each approach will use a different address to describe the same location on a road; however, they all follow the same principles of the linear reference method that is, it must have (HTC 2001): known start and end point, direction of travel (increasing or decreasing in distance) usually from the start point, the distance measurement from the point of reference (this could be the start point or intermediate points).*
>
> *"Hence it is important that start and end points are well defined within a road network."*

The Austroads AP-T190-11 report provides diagrams describing local variations of a common approach. Indeed, there are so many variations of this approach that it would be no small task to illustrate each. An example is given in Figure 3.2.

Figure 3.2: Kilometre point approach



Source: Austroads AP-T190-11: Page 9

From AP-T190-11, the following definition is extracted:

Linear Referencing Methods: ***A group of methods within the topological family of location reference methods that specify a start position, a direction and a distance (also known as LRM).***

A more extensive review of local linear referencing methods, outlining both advantages and disadvantages, is found in the 2001 report for Transit New Zealand (HTC 2001). Included are 14 examples from US states, four examples of Australian states, plus three explanations from the country level. There are many references discussing the advantages of linear reference methods. The current definitive reference is ISO19148:2012 that states:

> *"…linearly referenced systems are significant for several reasons. First, a significant amount of information is currently held in huge databases from legacy systems that pre-date geographic information systems (GIS). Many useful applications can and have been built on these data with no understanding of where on the earth's surface the data are located. Knowing where they are located relative to a linear element such as a roadway route or pipeline is sufficient to support these applications and can be used as a means of integrating data from multiple, disparate sources."*

The standard states, "…in some situations, having a linearly referenced location along a known linear element is more advantageous than knowing its spatial position".

What is missing from most of these analyses is the role of linear referencing in human cognitive models (Committeri 2004). Most people understand without assistance an instruction like '200m past the North bridge abutment of Smithson's Bridge on the BIG Highway'. In contrast, an (X,Y) coordinate requires tools for human decoding. Similarly, it is not possible to provide a coordinate reference without aids, whereas a linear reference is easily provided. While new and readily available technologies significantly enhance the efficacy of geospatial systems, there will always be a role for linear referencing specifically for humans.

3.1.2 Network Referencing

AP-T190-11 did not address network reference systems, despite their already widespread use in the emerging Intelligent Transport Systems (ITS field). This was most likely because the added features for linear referencing were not particularly helpful in the case of survey data collection and management (the prime reason for that study). However, such an exclusion is not applicable for asset management and particularly when considering the impact of BIM technology.

Network referencing explicitly recognises that the links and nodes of a transport (or other) system are complex, interconnected and may be routable:

Network*: A description of a complex arrangement of interconnected links and nodes that form an identifiable system.*

Constructing a routable path in a road network may also require information about grade separation, flow direction, and turn restrictions. These may have both physical and temporal dimensions. Location attributes may also be relevant. Examples are: road class, road purpose, and environmental conditions. Some networks may have complex 3D geometry, such as slope gradients for road and rail, or drainage networks.

Network referencing dominates the more recent standards, particularly those that deal with ITS. The difference is in some ways relatively minor, in that it must be possible to build a path (or a concatenation of shortest paths) through the network from one point to another. This requires the LRM to be able to manage logical connections.

3.1.3 Importance of Topological (Logical Linear and Network) Referencing

Topological networks provide the same advantages as linear referencing for human cognitive models. However, they also provide a method for solving problems relating to routes or journeys. The obvious use is for journey guidance, such as navigation systems. Yet, for asset management, a more critical use is for service delivery management. The performance of a network for providing service to road users requires this level of analysis. Similarly, in order to preserve quality of service, it is desirable to understand the route for a journey and to be able to manage alternative paths in the event of disruptions such as road works and accidents. Indeed, it is critical for service performance that roadworks be planned with travel paths in mind and disruptions coordinated over significant service paths.

While it is technically possible to rely solely on a geographic information system (GIS) for the management of roads (as at least one smaller Australian jurisdiction does), such a solution loses much of the important functionality required for road asset and service management, and fails to protect the spatial relationships of objects.

3.1.4 Relationship between Topological Reference Systems and Geospatial Coordinates

In the following section, the family of LRMs that use geospatial systems will be discussed. The main feature of geospatial data is that it is already usually associated with topological LRMs. The power of the topological approach is the ability to identify a location with known features rather than using geospatial data. However in practice, coordinates are most often applied to these known features.

Direct Inquiry Findings

In Australia and New Zealand, most (but not all) asset management location reference methods include coordinates for nodes, permanent reference points (PRPs), fixed reference points (FRPs), features (such as bridge abutments), etc. Several also include coordinate information as fixed intervals along the road-lines. These attributes also give the LRS a hybrid capability to provide geospatial data and mapping.

Modern geospatial databases, such as Oracle Geospatial, have made the storing of geospatial data within a topological LRS a relatively simple matter.

3.2 Geospatial (Real World Coordinates)

The geospatial family of LRMs includes those which Ries (2000) termed Geodetic and Geometric. This is a challengeable position. Ries' geometric LRMs have many of the same properties as the geometric LRM described below. However, there is a significant difference between systems used in modelling either design or construction and the modelling systems based on a variety of cartography scales and levels of accuracy. de Laat and van Berlo (2011) argue that these two types of modelling worlds do not really integrate. They express this difference directly, arguing:

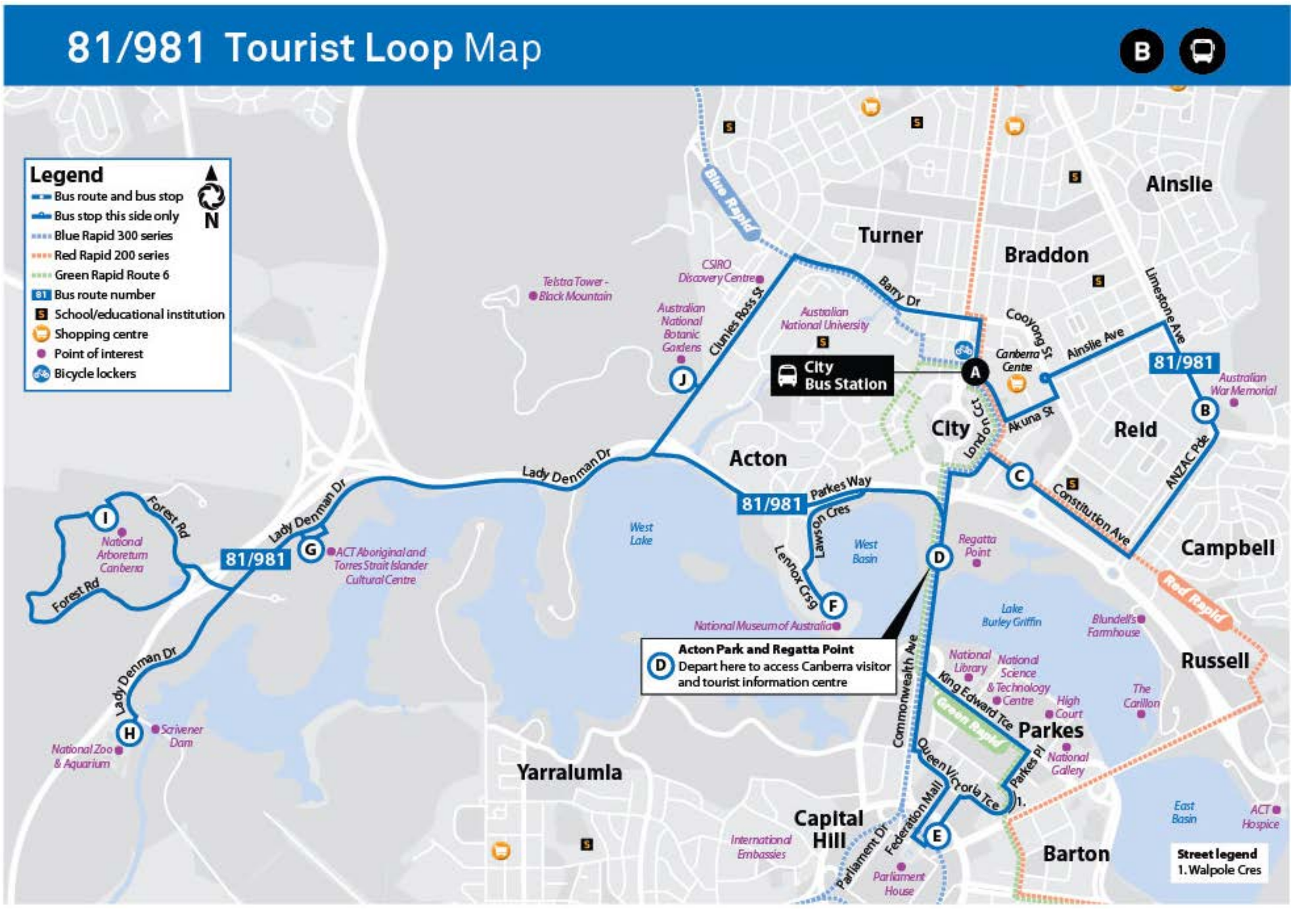
> *"…the 'BIM people' and the 'GIS people' still seem to live in different worlds. They use different technology, standards and syntax descriptions."*

This difference is important when considering the impact of that BIM technology has for location referencing (the aim of this Report).

Past efforts have paid little attention to this discrepancy due to the confusion between model geometry and cartographic geometry and systems. Thus, a logical alternative is proposed. Cartographic systems are included in the geospatial family of LRMs to avoid confusion with model geometry. This concept means that Ries' geometric family of LRM actually belongs to the world of 'GIS people'. It is framed according to the technology, standards and syntax of geospatial systems.

GIS is a system to capture, store, manipulate, analyse, manage, and present all types of geographical data. Traditionally, GIS is based on 2D maps, in which objects are assigned 2D references such as longitude and latitude. (Deng 2016). Figure 3.3 provides an example of this type of relational map of road assets.

Figure 3.3: Canberra tourist map with 81/981 bus stops



Source: 81/981 Tourist Loop Map, Transport Canberra-ACT Government

Geospatial referencing defines a location using a set of spatial coordinates, in addition spatial data can take many forms (West & Kenley, 2014). The Australian and New Zealand Land Information Council (ANZLIC—a body made up of representatives of the States and Territories and the Commonwealth with New Zealand) have outlined ten foundational data themes of national importance. The Foundational Spatial Data Framework (FSDF) includes:

1. Geocoded Addresses
2. Administrative Boundaries
3. Positioning
4. Place Names
5. Land Parcel and Property
6. Imagery
7. Transport
8. Water
9. Elevation and Depth
10. Land Cover.

Each of these data themes is typically made up of a number of datasets.

One of the spatial themes (3) is the most significant for this research:

Positioning: *provides coordinates with reference to the Earth*.

In Australia, positioning consists of coordinates and their uncertainty with respect to the Australian Fiducial Network and the Australian Height Datum. Positioning is supported by survey marks, Global Navigation Satellite Systems (GNSS), geodetic modelling (coordinate transformations) and the geoid and bathymetric reference surfaces (West & Kenley 2014).

Data collection is through a wide variety of technologies; from Total Stations (modern theodolites with built in GPS and laser ranging devices) to full 3D static or mobile laser scanners and photogrammetry cameras.

Traditional road asset management, and indeed current practice in all Australian and New Zealand jurisdictions, limits positioning to two dimensions. However, increasingly data is available for state road networks by survey with terrestrial laser scanners or mobile laser scanning systems to acquire 3D point clouds. These data are processed to extract the relevant information such as road centre-lines, profiles and the location of kerbs (West & Kenley 2014).

Geospatial referencing methods are consistently used in the management of roads in Australian. A good review of geospatial referencing and various types and uses of geospatial data is available in Austroads AP-T190-11.

Geospatial referencing methods are consistently used in the management of roads in Australia and this use is to be encouraged. Such uses include:

> *“Locating objects (finding): technologies such as GPS provide road authorities and individual work crews to locate assets rapidly.*
>
> *Positioning objects (recording): technologies such as laser scanning and GPS provide spatial coordinates for assets in the field.*
>
> *Mapping: assets are located on a map for publication or field use.*
>
> *Proximity measurement: assets may be assessed (for example counted) as being near to a feature; such as road lights adjacent to a road line.”*

Direct Inquiry Findings

The research into jurisdictional use of LRMs raised an interesting phenomenon: some road authorities considered that they should move toward linear reference methods and away from geospatial reference methods, while for others the situation was reversed. In all cases the opinion is that a natural progression of change is normal. It may be inferred that there is a level of dissatisfaction with existing solutions regardless of the LRM family presently emphasised.

Current use of geospatial LRMs only employs a two dimensional (X-Y) representation of location data. This is conventional use according to Deng, et al. (2016). Traditionally, GIS is based on 2D maps with objects being assigned 2D references, mostly longitude and latitude for the x and y coordinates.

Direct Inquiry Findings

With the exception of some key data (such as; invert levels for major culverts, bridge abutments and the like where a level may be recorded), the Y-coordinate is not used in Australian road asset management location reference systems.

3.2.1 Open Geospatial Consortium: CityGML

However, 3D GIS is emerging. Schemas such as KML, COLLADA and GML store 3D attributes of objects in GIS enhancing functionality (Deng 2016). Currently in the GIS world, the cross-over from the BIM world for 3D representation uses City Geography Markup Language (CityGML) (sometimes called City Modelling).

CityGML is defined in four levels of detail (LoD) to reflect the need to be able to visualize topographic objects in cities and regional models as well as relationships between objects and spatial properties. CityGML is applicable for large areas and small regions and can represent the terrain and 3D objects in different levels of detail simultaneously. Transportation features may be represented as a linear network (linear objects) or by geometrically describing their 3D surfaces. Polylines are not used by CityGML, which limits the opportunities for modelling from Geometric models.

This 3D functionality has the ability to represent built infrastructure and terrains as surfaces, but is relatively new in GIS. CityGML has the ability to represent 3D road-lines and data using vector geometry rather than points joined by straight links traditionally represented in 2D GIS.

3.2.2 Importance of Geospatial Referencing

Searching and mapping are two key advantages to geospatial location reference systems. Most governments rely heavily on GIS applications for managing geographic data. These provide searching (proximity-based) and modelling abilities. Particularly, the GIS systems are able to call on much more than the asset database. Population data, terrain models, ground cover maps, etc. are all searchable. The typical application is therefore able to display a huge number of different features onto a map and this can be processed according to user needs. Thus, it is arguable that no modern road LRS could avoid having a Geospatial LRM as part of the system.

3.3 Geometric (Model Coordinates)

The family of Geometric reference systems are those based on geometric models of infrastructure. They are typically created and used during design and construction. At the simplest level, geometric systems draft 2D representations of the design using relative coordinates (relative to a fixed and known point). Such systems use different methods to calculate the positioning of lines. Importantly, they are generally based on mathematical formula to form vectors. A line is from point A to point B and is straight or follows a mathematical curve. Thus, location references may be made in local coordinates and using mathematical vectors in 3D.

Geometric models of infrastructure includes traditional 2D drafting of a project, through to 3D modelling, with the possibility of extending to include modern BIM workflows. These are the tools and methods of ‘BIM people’ as identified by de Laat (2011). Their world-view is based on technology, standards and syntax related to modelling. They make intense use of 3D geometry modelled through Industry Foundation Classes (IFC). These provide the rules for using the concepts of constructive solid geometry and boundary representation using Boolean operations to design geometric models of infrastructure (de Laat 2011). However, it should be noted that the inclusion of older 2D and 3D modelling formats for infrastructure design means that Geometic LRMs are is much more than BIM.

At the most advanced level, there are complex and powerful integrated systems to build models of infrastructure. This is the domain known as Digital Design in the horizontal infrastructure community and as BIM in the vertical infrastructure arena. Vertical and horizontal infrastructure have developed types of software systems suited to their specific contexts.

Vertical Infrastructure: The term for built environment and infrastructure assets, that are suitable for object-oriented design. These typically are local and rise vertically, having the property of a location breakdown into discrete sub-divisions, such as floors, rooms, sections. Buildings and bridges are considered vertical infrastructure.

Horizontal Infrastructure: The term for built environment and infrastructure assets, that are suitable for string-based design. These typically are linear elements with alignment as the principle feature, having the property of a location breakdown into continuous centre lines, such as road lines, chainage or networks. Road and rail lines are considered horizontal infrastructure.

3.3.1 buildingSmartInternational: IFC-Alignment

Industry Foundation Classes (IFC) are the open and neutral data format for OpenBIM. The IFC specification is continually being developed and maintained by buildingSMART International (bSI). Version IFC4 was accepted as the ISO 16739: *for data sharing in the construction and facilities management industries* standard.in 2013).

The IFC4 data format is being extended to include aspects of horizontal infrastructure, including, bridges and roads. This is known as the OpenInfra initiative. The first component of this extension process, and the first standardization project that reached bSI Candidate Standard status, is IFC-Alignment.

IFC-Alignment is considered a baseline, or building block, for other horizontal infrastructure modelling processes and it provides the data model for 3D and 2D alignment information for spatial location of horizontal infrastructure assets. In the schema, an alignment is used:

> *“…to define a reference system to position elements mainly for linear construction works, such as roads, rails, bridges, etc”.*

Horizontal alignment can be a centre line, an edge of pavement, etc. and may consist of:

- a horizontal alignment (X,Y)
- a horizontal alignment (X,Y) and an accompanying vertical alignment (Vertical offset at distance along)

- a horizontal alignment, a vertical alignment and a generated 3D alignment (X,Y,Z)
- a 3D alignment (X,Y,Z).

An alignment is not made up of coordinate positions with straight lines between, as occurs in most geospatial location reference systems, but rather an alignment consists of known points (geo-referenced) and polylines: lines made of multiple segments each being a line segment, a circular arc segment or a clothoidal arc segment. For each (horizontal) segment, the following non-redundant information is required:

- the start point (X,Y) (geo-referenced)
- the start direction
- the segment length
- the curve parameter needed for circular and clothoidal segments.

Notably, this specification does not force continuity between a point at the end of one segment and the start of the next (a common modelling dilemma, as there is sometimes a mathematical trade-off between positions calculated by curves and desired end-points). Thus, the location is reset at each segment start to maintain the correct alignment. Tangential continuity (meaning that the blended surface does not change direction suddenly, but smoothly and the end tangents match at the common endpoint) is not enforced.

An alignment may be seen as the direct equivalent to a *Line Location* except that dimensionality is specific and each is made of segments. Amann (2015) states that the horizontal alignment [only] is used for linear referencing, which was one of the principles for the development of the schema.

From the above, the following definitions are extracted:

Alignment: a non-branching, continuous, single location constructed with polylines starting from a known geo-referenced point. An alignment may be horizontal, horizontal plus vertical, horizontal plus vertical with generated 2D, or 3D.

Alignment system: two or more alignments grouped into an alignment system, where two different alignments can be related to each other.

The important point of this discussion is that IFC-Alignment can theoretically form the basis for exporting data from a BIM environment to a GIS environment. However, it is important to note that the development of modelling building blocks must be incorporated into digital systems. At present the optimal practicality of IFC-Alignment for data exchange depends on progressing the new data and information standard: LandInfra.

3.3.2 Open Geospatial Consortium LandInfra: Proposed Response for Geometric Data

The OGC working in conjunction with buildingSmart International, have proposed the development of a new OGC Land and Infrastructure Conceptual Model Standard (LandInfra). A conceptual standard has been published, presenting implementation-independent concepts supporting land and civil engineering infrastructure facilities. LandInfra is to provide:

> *“Conceptual model subject areas include facilities, projects, alignment, road, rail, survey, land features, land division, and wet infrastructure (storm drainage, wastewater, and water distribution systems)”*
>
> *“The Alignment conceptual model in LandInfra was developed jointly with the bSI IFC-Alignment conceptual model. The objective is that they be as similar as possible, with only minor differences due mostly to the respective environments in which these standards exist. This consistency should enable linking of geospatial and BIM data based upon linear location”.*

The development of LandInfra is a cooperative effort to design a data and information standard; an attempt to get the ‘BIM people’ and the ‘GIS people’ to live in the same world. The proposed LandInfra standard is another step in the journey towards integration of their differences.

Within LandInfra, an alignment is a Positioning Element, which provides a Linear Referencing System for locating Physical Elements. Consistent with IFC-Alignment, LandInfra-Alignment can be defined in several ways:

- as a simple 2D linestring representation
- as a horizontal alignment: a 2D projection onto a horizontal plane of a Cartesian local engineering reference system
- as a horizontal alignment with an accompanying 2D vertical section taken along the horizontal alignment with a 3D linestring generated from the horizontal and vertical alignments if they also exist only as a 3D linestring.

LandInfra-Alignment is also continuous, non-overlapping, and non-branching (though it may contain intersections with other Alignments).

LandInfra is expected to become the standard of choice for modelling road locations in geospatial location reference systems and methods, once it becomes available.

There should be a direct correlation between IFC-Infra and LandInfra, making data exchange simple.

There is also a proposal for LandInfra (Land & Infrastructure GML standard) which will be more suitable schema for road networks than the current IFC schema. LandInfra, when developed, will include concepts compatible with BuildingSmart IFC Infrastructure, in particular horizontal alignments.

Geo-referencing is the term used for the practice of setting local coordinates to equivalence with geographic coordinates. Geo-referencing allows conversion of the local Engineering Coordinate System to a Map Coordinate Reference System according to the OpenInfra working group (Amann, 2015):

> *“Defining a local engineering coordinate system for the project is used in many construction projects. In context of BIM (and 3D solid geometry), it is also important to use smaller coordinate values to minimize the effect of tolerance issues to the validity of the geometric representations. Therefore a local coordinate system is used with a well-defined translation into the corresponding map coordinate reference system.”*

As LandInfra-Alignment is geo-referenced, it has the potential for information exchange between geometric models and related geospatial and even linear referencing systems. Specifically, IFC-Alignment has been developed in cooperation between buildingSMART (IFC) and OGC (CityGML) as a means to achieve a common conceptual schema for both the future GML extensions developed by OGC and the IFC extensions developed by buildingSMART.

3.3.3 Importance of Geometrical Referencing

Clearly geometric modelling using local coordinates is critical for the design and construction of infrastructure. As a coordinate system and with local coordinates for all objects and alignments, this forms a reference system. However, IFC-Alignment must form the basis for equivalency to topological and geospatial reference systems.

4. Integrating LRMs

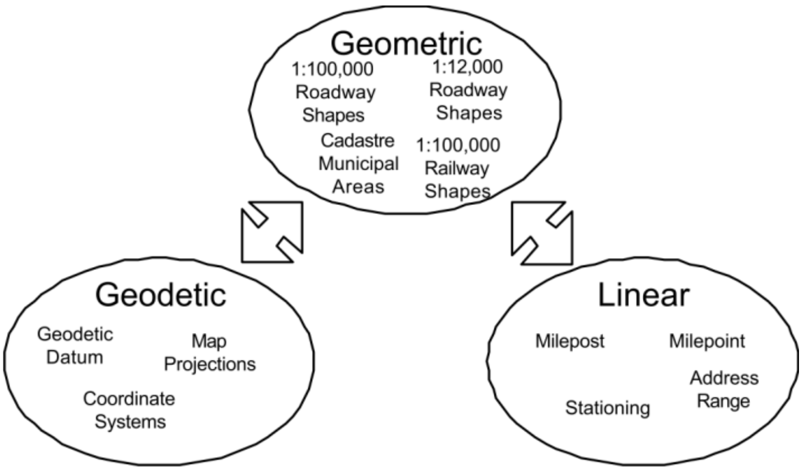
Direct Enquiry Findings

The review of current practice data collected highlights that jurisdictions usually maintain multiple LRMs within multiple-use LRS. Location reference conversion between their LRMs occurs now. This is done via proprietary or local solutions. However, for many this solution is ad-hoc and problematic.

4.1 Early Models for Integrated LRMs

Reis (2000) presented a model for the LRM groups and their relationships (Figure 4.1). His model was extrapolated to provide for a common method of data exchange between the families, by establishing a Master Spatial Geometry (Geometric), a Control Section (Linear), and a set National Coordinate System (Geodetic). In his model, the Geometric group of LRMs was placed in the dominant position, and data exchange was through that family.

Figure 4.1: Early model of data exchange relationships between LRMs



Source: Ries 2000 Integrating Traffic Management Data Via an Enterprise LRS

As discussed previously, this representation for LRMs groups is too narrow for the future needs of road asset management. As explained in Section 3 the preferred alternative families are Topological, Geospatial and Geometric.

Ries' model shows multiple datasets in each family. The movement of data is an important concept. However, as can be seen in Figure 4.1, there is no direct exchange between Geodetic and Linear systems, thereby forcing the exchange model to rely on GIS coordinates. In addition, the definitions provided are GIS-centric, in that the difference between Geodetic and Geometric are issues of levels of detail rather than being different conceptual frameworks. It is concluded that these more appropriately belong in a single family.

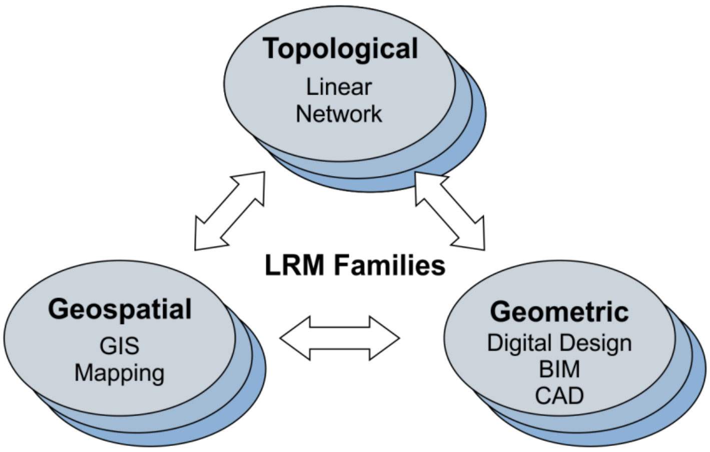
Ries describes the building blocks of a Location Referencing System necessary to support and supply the location referencing needs for transport organisations. However, he apparently missed a major requirement for emerging technologies. He did not consider digital design data from either vertical or horizontal infrastructure models, even though the development of this technology was concurrent with ITS development, which was the topic of his paper. While it is true that such digital models are geometric and of high detail, they do not belong to a GIS-based systems conceptual framework.

Thus, there is a need to revisit and revise the approach of grouping LRMs.

4.2 Impact of Digital Design (BIM) on LRMs

Two-way exchange of location referencing information between different groups was the intent of the Ries' communication concept. A model based on the revised LRM families and allowing for two-way communication between all families is presented in Figure 4.2.

Figure 4.2: Potential for information exchange between LRM families



Data conversion within the topological or geospatial families is relatively simple. Different linear location references may be converted with each other and a specific set of heuristics for conversion can be created. Similarly, geographic location references can be converted by the application of coordinate system rules, generally a simple mathematical conversion.

However, the same is not true for conversion between different geometric systems. Geometric systems location data are more complex due to the reliance on proprietary modelling software and data formats. Surprisingly, converting models from one software solution to another is not an easy task.

OpenBIM has been established to provide a mechanism for data and information exchange between different geometric models. Using the analogy given earlier, OpenBIM seeks to be a dominant secondary model, with all proprietary systems communicating with it. Within the digital design of vertical infrastructure community, there is a continuing interest in solving the interoperability problem of model data utilising the OpenBIM framework of Industry Foundation Classes (IFC).

The current version at time of writing (IFC4) extends specifically for horizontal infrastructure (see 3.3). IFC-Alignment schema is published and has the potential to encourage interoperability between horizontal infrastructure design systems. More importantly, if each digital design-authoring tool were to export and import IFC-Alignment data, then the results would form an excellent basis for two-way communication to other families of LRMs. This because IFC-Alignment has been specifically developed to communicate with linear objects in horizontal infrastructure models.

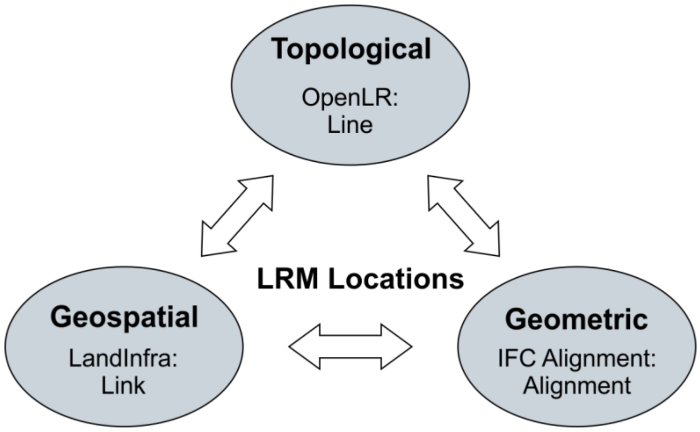
It must be recognised that current capability of digital design has severe limitations. Currently, to move data from a digital design model into a linear reference in an asset management system requires a manual process. The most common practice (confirmed by the leading software provider) is for the design to be printed to scale, then the result is manually scanned into the asset management application. Alternatively, field inspection of as-built work is performed and the resulting location coordinate data recorded within an asset management application. These data are then exported into a GIS platform, sometimes enabling two-way communication.

Clearly, how to better integrate digital design data information exchange with a range of location data types is a major question. However, to-date there little research has addressed this question in relation to road asset management. The balance of this Report project provides one option.

Reis wrote that an integrated information system was a powerful tool to integrate data for analysis based on continued updated data. This dynamic ideal is now the basis of most road traffic management systems. More importantly he wrote, “It relies on a **location attribute** commonly existing in disparate databases (e.g., pavement, AADT, crash) to link the databases together.”

Placing the idea of a **virtual location** at the centre of a new model still is the place to start. If we redraw the model to show location as the key information to be exchanged, then we can see that each system has the equivalent primitives to be exchanged. Figure 4.3 illustrates this concept using the example of respectively; line, link or alignment location components.

Figure 4.3: Focus on conversion of location components



This means that each individual Location Reference Method (LRM) should be able to exchange location data using each family’s open dominant secondary system. Unfortunately, this utopia is not yet available as there is no uniform model extant in the topological family. Also, the development of IFC-Infra is nascent and LandInfra remains conceptual (and thus CityGML must be relied upon, a sub-optimal solution).

This means that more work is required: buildingSMART needs to continue to develop IFC-Alignment and ensure its uptake in the digital design community; OGC need to develop LandInfra; and an open source dominant secondary system for linear referencing needs to be developed.

While there is potential in the Figure 4.3 model for location references to be understood between families, this method relies on potentially circular processes that would be extremely liable to error. Consider conversion of a model (IFC-Alignment) to Geospatial (LandInfra), then subsequent conversion to a Topological virtual location. What happens when further design is required? Potentially the path is direct to Geometric. However, exchange error is very likely at each step and the chance of getting the same result back in the originating model would be low.

The alternative is to create a new model that places location at the centre and in which location has properties from each of the families.

It was argued in Section 2.2.1 that location was a virtual object. Given this, there is no reason why this concept cannot be used to create a new primary model.

5. Proposal for a New Primary LRS

This section proposes a new Primary Location Reference System designed to support and to depend upon existing secondary reference systems and families of LRMs. The new system is an open standard location referencing method for horizontal network infrastructure and is designed to support an Austroads Building Information Management (BIM) environment.

5.1 Business Drivers for Location Reference Methods

Direct Inquiry Findings

Within Australia and New Zealand, experience suggests that business drivers overwhelm well-intentioned moves to reform location referencing to a common method.

This study accepts the Direct Inquiry Findings that each authority's various LRMs need to be preserved until business drivers no longer apply or have been superseded based on decisions that can only to be made by the relevant road authority.

Business units can have business critical drivers for their selection of LRMs. Drivers might include:

- Sunk investment in available technology
- Technical or regulatory requirements
- Operational systems for maintenance
- Public interface requirements
- Legacy systems and references
- Need for data harmonisation with other business units or external common transport standards

Further to this list, many assets that are related to roads are not always managed by the road authority, such as drainage, power, other transport modes, etc. The needs of other authorities should also be considered.

These drivers suggest that harmonisation of location referencing, by using a single method, is unlikely to succeed. In Australia, harmonisation is difficult because the variety of individual sector business, technical or regulatory drivers described above have been found in the past to thwart such efforts (for example the USA attempt outlined by Scarponcini 2002). Transport for NSW has been notable in its recent efforts to identify a common LRM across all transport modalities in their state (their reports are not publicly available at the time of writing). Any such harmonised LRM, requires integration of all relevant existing and proposed LRMs.

5.2 The Concept of a Dominant Secondary LRM

Direct Enquiry Findings

Austroads members have invested a great deal of effort, over the past twenty years, seeking a better location referencing method. This study found at least two jurisdictions attempting to do so with, at least in one case, the aim of replacing all existing methods with a better location referencing method. The attempt may also seek to extend their new model to include other transport infrastructure such as rail.

If we consider all LRMs as **secondary** models, then the pursuit of a better replacement would be the search for a **dominant** secondary model. The idea is to replace all existing LRMs with a better one. This type of LRM already exists in the geometric (IFC-Alignment) and the geospatial (LandInfra) families. There are also suitable candidates for dominant secondary topological models found in the various standards. Given the potential of dynamic systems, it is suggested that for this purpose an ITS-based standard that allows for both static and dynamic referencing would be most appropriate (ISO17572 or CEN 16157 DATEX II). However, the identification of a dominant secondary location reference model may actually be redundant.

This Report recommends against seeking a dominant secondary LRM.

5.3 An Alternative: Primary Location Reference System

Rather than trying to find a best replacement LRM, this report suggests allowing existing and proposed LRMs to co-exist. This approach follows and extends the approach proposed by Ries and adopted by the VicRoads RoadsOne Project: a model with individual LRMs maintained and exchanging location references via a central hub. The major difference of the new proposal is that rather than maintaining different control hubs within each family, a single referencing solution is suggested across all LRM families.

Think of it as a new data model with features from each of topological, geospatial and geometric referencing included, that will also accommodate BIM.

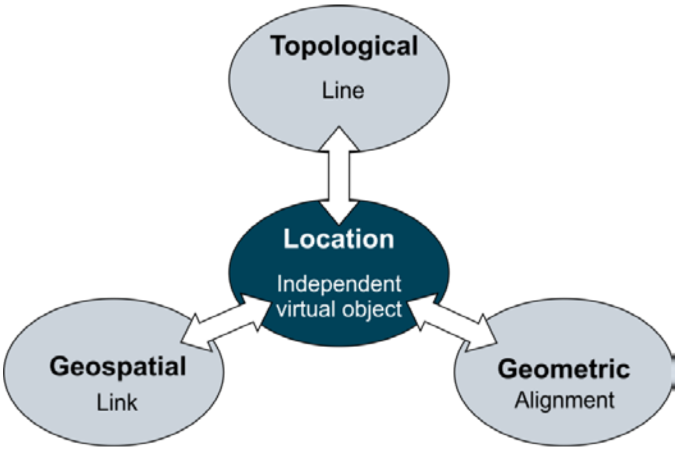
This new system includes data exchange methods, termed a **Primary Location Reference Method**. This does not yet exist, but development of such a system would be relatively simple by incorporating the features of each of the families outlined in Section 3. Methods could then be designed to exchange data for each individual LRM. The key attribute is that the Primary LRM is a **Virtual** location reference. Unlike the other families of LRM, the primary model does not have its own physical reality but actually requires the topological, geospatial and geometric LRMs to exist. In other words, the primary LRM must co-exist with secondary LRMs.

It is preferable to establish a single virtual location reference hub. This would be independent of each family. Figure 5.1 displays this concept, with the notion that the central hub could work through common understanding of the basic elements of location from any perspective.

This concept is not new. It currently forms the basis for static and dynamic location referencing within ITS systems, such as DATEX II: CEN/TS 16157 and ISO 17572. The concept of map-independent locations adopted in this Report arose from those standards. However, the use-case for Asset Management is different.

Essentially the suggested Primary Location Reference System would use a virtual location reference to communicate with all three families of location referencing: for example, with topological Lines, geospatial Links and geometric Alignments (Figure 5.1).

Figure 5.1: Inserting an independent location for information exchange



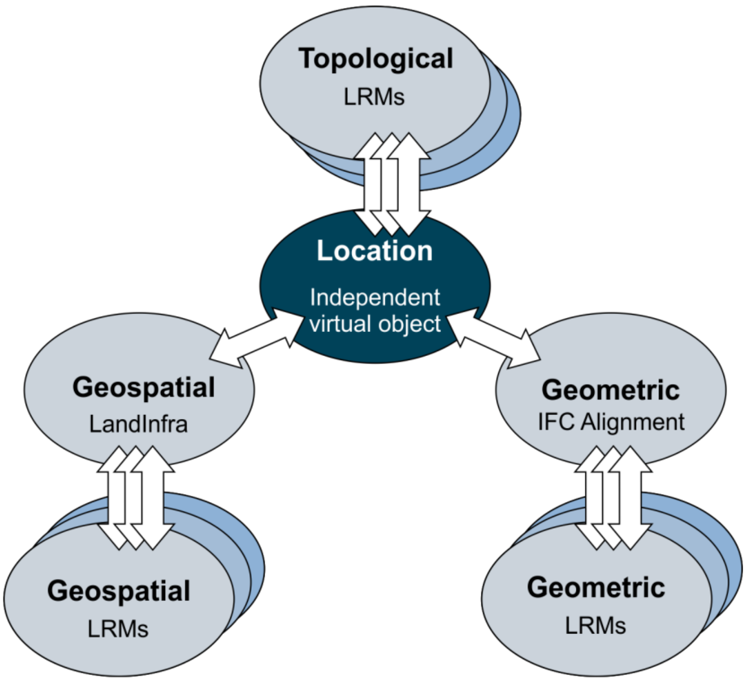
This primary method would be able to communicate with all LRM families, either directly, or by using designed dominant secondary models (such as LandInfra and IFC-Alignment). The linear components of the primary system could also become the dominant secondary model for topological LRS and thus communicate directly (Figure 5.2).

There are two candidates for such a solution:

- TPEG™: ISO 17572 relies on TPEG (a proprietary protocol controlled by TISA). This standard has been adopted into ISO17572. However, it is not an open standard; royalties may be associated with its use.
- OpenLR: DATEX II relies on OpenLR (an open protocol developed by Tom Tom). This is an open and royalty-free location referencing standard.

The recommended method is the Open Location Referencing Method. OpenLR is a stand-alone location referencing exchange protocol that is both designed to, and supports, extension for other purposes (providing such extension is contributed back to the OpenLR standard). The owners of OpenLR (Tom Tom) support extending its use for asset management with on-line resources and a community group support. One of their key adoption and adaptation resources is based in Auckland, New Zealand.

Figure 5.2: Using standards to exchange information between LRMs



In order to be consistent with Open source modelling methods (LandInfra and IFC-Alignment), an Open standard for encoding, transmitting and decoding location references will need to be adopted.

5.3.1 DATEX II: http://www.datex2.eu/content/datex-background

DATEX II is the European Union funded data exchange interoperability solution for ITS. It is relevant in the Australian and New Zealand contexts because it was specifically designed to deal with different types of location information and data transmission between levels of government (State to Council) and between jurisdictions (State to State, Council to Council). DATAEX II is designed to provide the framework for delivery of road network service, the driver for future road asset management policy outcomes.

The European Commission ITS action plan for co-ordination of traffic management through the development of seamless pan-European services, states:

> *"Delivering European Transport Policy in line with the ITS Action Plan of the European Commission requires co-ordination of traffic management and development of seamless pan European services. With the aim to support sustainable mobility in Europe, the European Commission has been supporting the development of information exchange mainly between the actors of the road traffic management domain for several years. In the road sector, the DATEX standard was developed for information exchange between traffic management centres, traffic information centres and service providers and constitutes the reference for applications that have been developed in the last 10 years. The second generation DATEX II specification now also pushes the door wide open for all actors in the traffic and travel information sector."*

The 10-year development of the DATEX platform has provided the basis for the European ITS standard. The standard is the foundation for understanding the concepts that underpin the data model, the use of the Unified Modelling Language and the data elements. As with IFC4, DATEX is designed for development of digital products and systems that can be used to harmonise management systems from multiple organisations or multiple unites within organisations.

But, as always, the major barrier to implementation of digital technology is the lack of information exchange interoperability between of different systems. In the case of DATEX, the need is to utilise the wide range of LRMs required for functional communication between Intelligent Transport Systems and location based systems.

The development of a solution was the joint effort of national transport agencies in Sweden and the Netherland working directly with a software provider, Tom Tom. The outcome of the collaboration was an extension for OpenLR in DATEX II taking into account specific user needs, national requirements and new specifications and standards.

5.3.2 OpenLR^{TM}

Importantly for Austroads, OpenLR does not solely relying on coordinate systems for location referencing. While the primary aim of the OpenLR methodology is dynamic referencing, it is also able to handle static referencing. In addition, it is designed to handle the *full road network*.

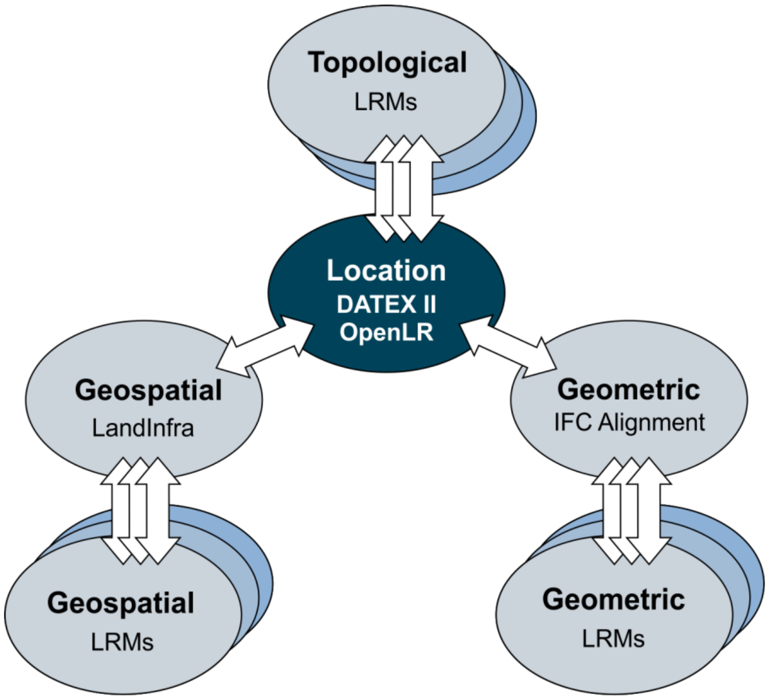
Direct Inquiry Findings

Most road authorities do not currently have the capacity to handle both static and dynamic referencing data, yet it is critical for communication between different authorities and authorities at different levels.

OpenLR was a natural fit for DATEXII because it is an open source, royalty-free, dynamic location reference standard and communication protocol. It enables reliable data exchange and cross-referencing using digital maps of different vendors and versions. OpenLR is specifically designed to handle topological routes as well as multiple mapping environments.

> *"The process of encoding a location is also called Location Referencing. This assumes a map on the sender side from which the location is encoded and a map on the receiver side in which the decoded location is found back. An obvious way of Location Referencing is using geographic coordinates. One important disadvantage of using coordinates is that it needs identical maps at both sides of the communication chain which often is not the case. As a consequence, the decoded location may not be found back in the receiver map, or decoding (i.e. map-matching) may be inaccurate or ambiguous."*
>
> *"OpenLR™ helps to enhance existing applications and generates opportunities for new services. It facilitates new business opportunities in various areas of Intelligent Transport Systems (ITS) such as traffic information services, map content exchange and Cooperative Systems where precise and compact dynamic location information is needed."*
>
> *"Compared to the existing RDS-TMC method every location in a map can be transferred using OpenLR™. Besides the XML format a binary format for compact and bandwidth efficient transmission is supported.*
>
> *"The OpenLR™ extension for DATEX II makes it possible to use DATEX II with an extended location referencing model containing OpenLR™."*
>
> *"From the fact that RDS-TMC makes use of pre-coded location it follows that the amount of locations fit to be transferred is limited. OpenLR™ does not have that restriction. With OpenLR™ every location in a map can be transferred."*

Figure 5.3: Jurisdictional concept for location referencing using DATEXII/OpenLR™



OpenLR has been designed as a stand-alone two-way referencing method. Some key business and technical benefits of OpenLR:

- An open and royalty-free industry location referencing standard
- Open Source Model based on Apache license v2.0
- OpenLR™ Trade Mark available to use free of charge with the technology
- A map-agnostic dynamic location referencing method
- Applicable to the full road network, including secondary and urban roads
- Compact and bandwidth efficient data transmission.

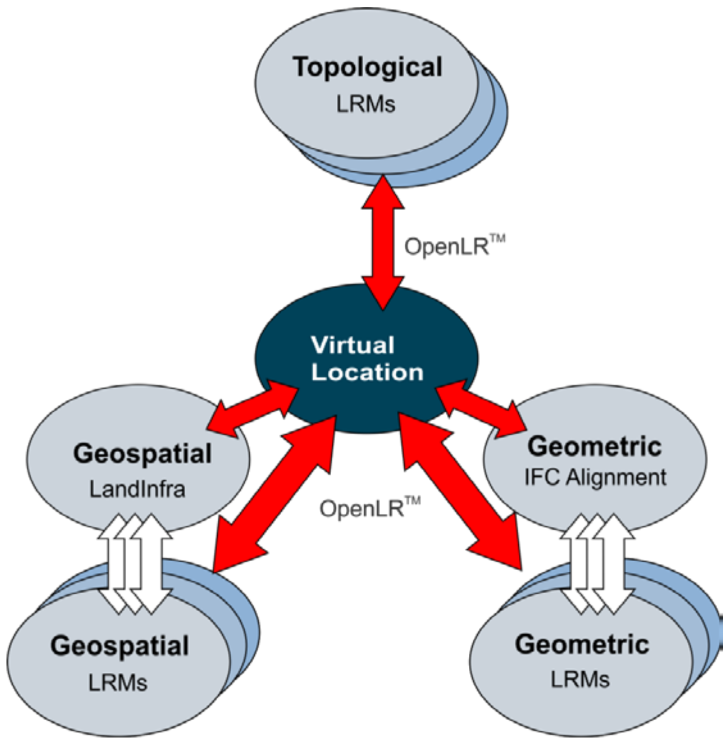
All these advantages are important for service performance such as route planning alternative including local roads in the event of road works, accidents or natural disasters.

To accommodate sharing data between jurisdictions, the first step is for each jurisdiction to attempt a common format for data exchange, such as the VicRoads RoadsOne project. Thus, the selected system needs will have the capability of handling all the data required for the business drivers of the organisation.

If no such selection has been made, the organisation should consider OpenLR as a solution.

Figure 5.3 suggests a referencing system that could be developed as a location hub shown in Figure 5.4.

Figure 5.4: Virtualisation of jurisdictional location reference hub



5.4 Vertical Location Information

The storage and exchange of vertical information across each of these concepts is a critical requirement for full realisation of the potential of geometric models. However, linear systems, including all current standards, do not support vertical alignment data. This would therefore be an important extension potentially required for OpenLR.

The approach adopted by both IFC-Alignment and LandInfra is recommended. These each provide for:

- horizontal (X,Y)
- horizontal (X,Y) and an accompanying vertical offset
- horizontal, horizontal with a vertical offset or a generated 3D (X,Y,Z)
- 3D (X,Y,Z)

These coordinate types would be extended to the virtual location objects:

- point
- line
- path
- area

The extended reference standard would also be required to be able to handle coordinate data that are samples along a line (current practice in geographical systems) through to polylines in both 2D and 3D.

5.5 A National Location Reference Hub

While a primary location reference system would deliver substantial benefits to individual organisations, the most gains in productivity would be at the national level, across jurisdictions (Figure 5.5).

It is proposed that a central hub be designed to store all road location references at both State and Local levels, with the potential to include related networks such as drainage. This would be a *National Location Reference Hub*. All locations in the hub will be independent virtual objects, based on the location components described earlier in this Report, using OpenLR as the referencing method for exchanging information. This will require some extension to OpenLR.

Each location object would need a combination of map independent coordinate information in order to satisfy the location definition: a virtual object that is temporal, graphical and model-independent. The virtual object will be a point, a line, a path or an area, each representing a physical place on a road network that may be identified in any given model by a suitable location reference.

Direct Inquiry Findings

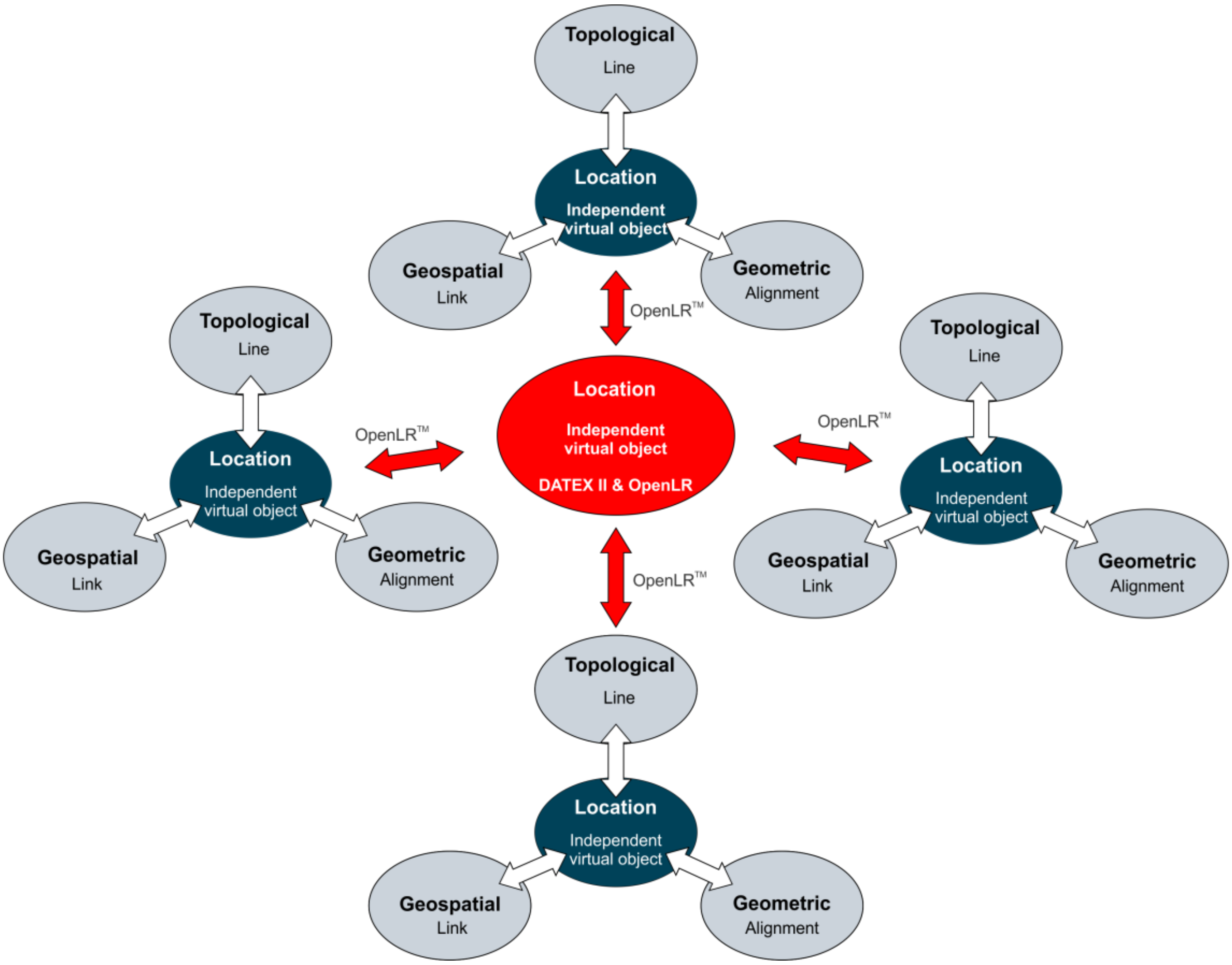
A path is not currently tracked by Austroads members, but it would be used for hierarchical definition of service lines.

The central hub could then be accessed by all road management organisations, whether road authorities or service providers.

The hub would use an extended version of OpenLR to support:

- Inputs:
  - be updated by the asset owner on creation or revision of assets, most likely in batch mode
  - as a minimum support location referencing at the same level of detail as the authority
  - be capable of accepting data input via the asset owners' centralised database or directly for input from LandInfra or IFC-Alignment (ie. Direct from BIM models)
- Outputs
  - understand a map-specific location reference query framed by the appropriate LRS
  - be able to provide map-specific location referencing for interpretation by the appropriate LRS
  - be capable of supplying information for interpretation by LandInfra or IFC-Alignment

Figure 5.5: Central hub of virtual location objects designed for OpenLR™



5.5.1 Required Location Attributes

The types of information to be available in a central hub are as diverse as necessary to meet the location reference needs of individual jurisdictions. From current practice, the following components are required to be stored for roads:

- Road lines (2D)
  - Centre lines
  - Driven paths
  - Curb lines
  - Points at intersections
  - Points at fixed reference points or known features
  - Hierarchical structure of pathways (according to route significance)
  - Reference levels for known points

Interest has been expressed in extending the location system to include:

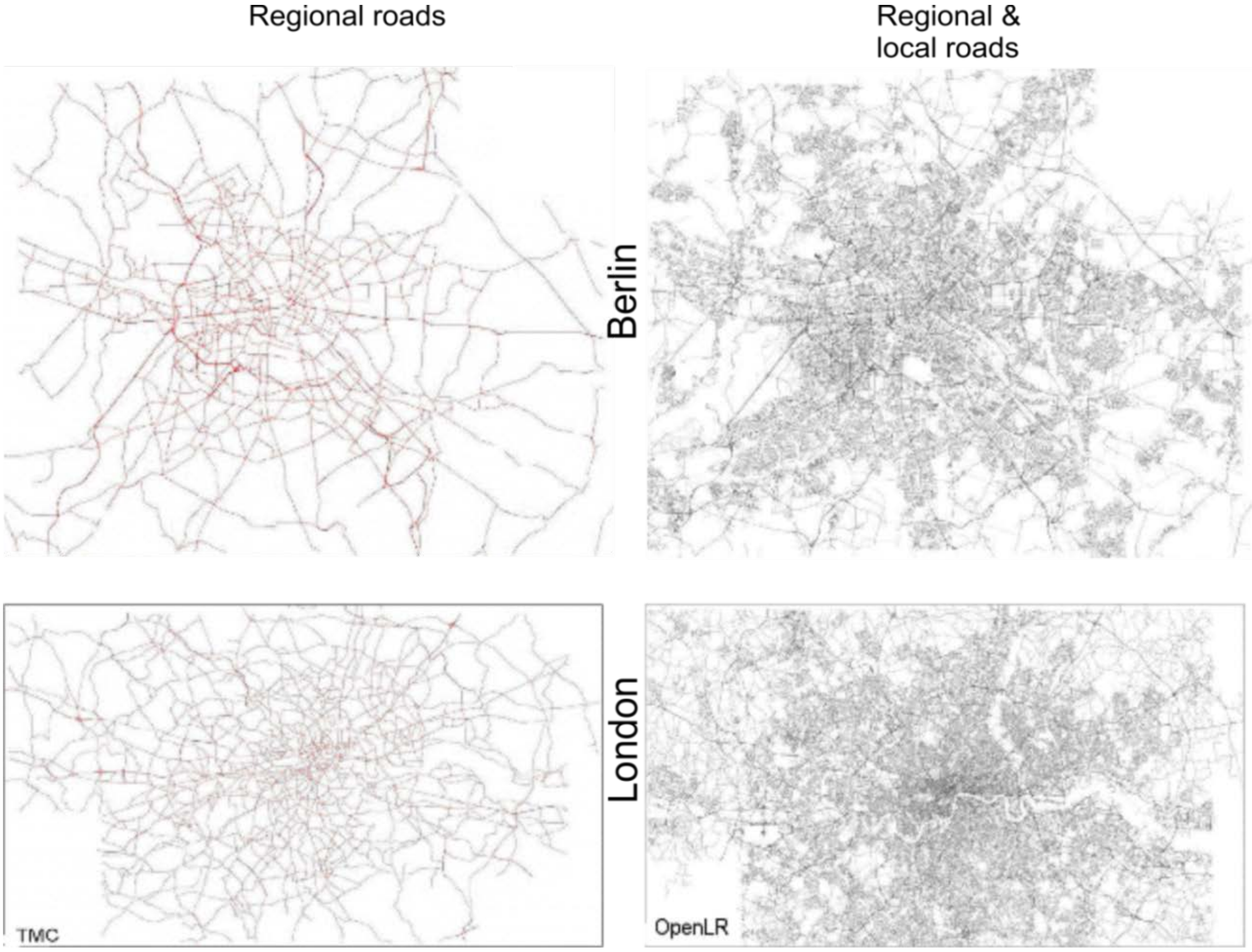
- Road lines 2D
  - Routable topological network
  - 2D polylines
  - Intersections with drainage networks
  - Intersections with other transport networks
  - Reference levels for intersections
- Road lines 3D
  - 3D offsets
  - 3D polylines
- Drainage networks
  - 2D locations (point, a line, a path or an area)
  - 3D locations (point, a line, a path or an area)
  - Intersections with roads
- Other transport networks

Once the system has been established, there is no reason why it could not be extended to further services such as drainage and other transport services. Even rail (despite significantly differences a rail LRS) could be accommodated.

5.5.2 Levels of Detail Concepts

One of the most difficult issues to be managed is the level of detail of the location reference system. The term *Levels of Detail* is widely used but inconsistently applied within digital engineering. The meaning In vertical infrastructure applies to the design resolution of the model, or how complete (detailed) the design is. In horizontal infrastructure, the term tends to be used to suggest the extent of detail, like zooming into the image. One common effect of differing levels of detail is the effect of including local roads versus only showing regional roads (Figure 5.6 shows the increased level of detail that typically follows the inclusion of local roads). Extending this logic, higher levels of detail might resolve individual lanes rather than only centre lines.

Figure 5.6: Differences in levels of detail expressed as regional versus local roads



Source: Combined for this Report from images on the OpenLR web page

5.5.3 Application in Asset Management

The functional mechanism for asset management is that an asset would have a location reference according to the owners' LRS. This could be converted to any other reference system via the central reference system and the translated reference made available to the client LRS to locate the asset.

A primary advantage is the ability to greatly increase the range of locations available to any authority working within a road network. For example, in New Zealand data would be shared between NZTA and Regional Councils. Similarly, in Australia, data would be available within jurisdictions and include both state and local council roads allowing states to share data across their boundaries.

Searching and mapping are two key advantages to geospatial location reference systems. Most governments rely heavily on GIS applications for managing geographic data. These provide searching (proximity-based) and modelling abilities. Particularly, the GIS systems are able to call on much more than the asset database. Population data, terrain models, ground cover maps, etc. are all searchable. The typical application is therefore able to display a huge number of different features onto a map and this can be processed according to user needs. Thus, it is arguable that no modern road LRS could avoid having a Geospatial LRM as part of the system.

As a demonstration of the ability of the OpenLR LRS to model road networks, selected city networks may be viewed at the Tom Tom City website (Figure 5.7) that allows the public to see, in real time, the road network performance of 181 major cities drawn from both static and dynamic data sources.

Figure 5.7: Tom Tom City image – network image generated using OpenLR™

Source: https://www.tomtom.com/en_gb/traffic-news/wellington-traffic/traffic-flow

Topological networks provide the same advantages as linear referencing for human cognitive models. However, they also provide a method for solving problems relating to routes or journeys. The obvious use is for journey guidance, such as navigation systems. Yet for asset management, a more critical use is for service delivery management. The performance of a network for providing service to road users requires this level of analysis. Similarly, in order to preserve quality of service, it is desirable to understand the route for a journey and to be able to manage alternative paths in the event of disruptions such as road works and accidents. Indeed, it is critical for service performance that roadworks be planned with travel paths in mind and disruptions coordinated over significant service paths.

6. Implementing Change

The proposed system is based on the view that both static and dynamic road asset management functionality is necessary to keep pace with changing technological advances driving change.

The concept is independent of current or future location referencing systems within each jurisdiction. The proposal is for an independent central system that can operate at all levels of road network asset detail within any family of location referencing that is used. However, optimal efficiency is expected from the three location referencing families outlined in Section 3, and it is strongly suggested that jurisdictions should consider some adjustment.

6.1 A Primary Location Referencing System

As outlined in Section 5, support for a new Primary System would be more beneficial than any one of the current location referencing models becoming a dominant secondary model.

To ensure that all road authorities can benefit from a Primary Location System they should develop and maintain their secondary location referencing models by:

1. Supporting, at a minimum, a linear referencing system, plus consider expanding into a full network topological referencing system.
2. Supporting a geospatial referencing system using time-specific coordinates with at least 2D coordinate information at regular intervals along each road line, plus consider moving toward support for 3D polylines and 3D coordinates using LandInfra when it becomes available.
3. Moving toward direct import of Digital Design data, particularly BIM models using IFC-Alignment and other IFC Infrastructure objects for assets. Plus, consider adding topological location models at the design phase by providing the network model to designers.

These three actions will in the long-term, provide the foundation for the recommended harmonization project of a *National Location Data Hub* illustrated in Figure 5.5.While a primary location reference model would deliver substantial benefits to individual organisations, the most gains in productivity would be at the national level, based on the accumulated asset service performance of all road networks.

Sharing data in this way is not exclusive to roads. The *Semantic Web*, a key communication innovation, (https://www.w3.org/standards/semanticweb/), is a platform to support a “Web of data” and includes a Web Ontology Language (OWL) with principles for sharing common meaning for differing terms.

6.2 Integrating the Future

Unfortunately, as outlined in 3.3, the technology for Digital Design data for horizontal infrastructure that could be generated through BIM is still in development. Thus, there needs to be investment in the interface technologies; IFC-Alignment and LandInfra. Also, other technologies for data communication such as the Semantic Web, will require further investment.

The time-frame for completion of the development of international standards for digitised models of road assets and other horizontal infrastructure cannot be predicted. However, setting an agenda and investing in support of these new standards, should be considered. Support for development of a more useful specification for horizontal infrastructure in IFC or LandInfra could be useful.

The absolute dependency on location models for road asset management means that development of a *National Location Reference Hub* should be the top priority.

6.3 Proposed *National Location Reference Hub*

The recommendation of this Report is to prioritise the development of a *National Location Reference Hub*. At the same time, it is important to reiterate that functionality must be defined by the needs of the stakeholders based on their past, current and future location models.

Section 5 notes that existing location reference methods are maintained for business, technical or regulatory reasons and should be respected. Accordingly, a major finding of this research is the requirement for existing referencing methods to coexist with any proposed solution. In particular, business aspects that LRMs support need to be incorporated into a recommended new solution.

Therefore, this proposal does not seek to replace existing road asset management technical solutions, rather it assumes that they may be maintained and only replaced or enhanced over time only as technology improves and business needs change.

In ensure that *National Location Reference Hub* is acceptable to stakeholders, the proposed solution also includes both State and Local road assets as an intended goal. Network access should also be available to all road management organisations, whether road authorities or service providers. In addition, as technology allows, including other road-relevant infrastructure, such as drainage networks and other modes of transport, seems the logical destination for network assets.

The comprehensive central location referencing hub is illustrated in Figure 5.5.

Optimal effectiveness will be measured by ease of access for stakeholders. Thus, the recommendation of this Report is based on using currently available methodologies. The Unified Modelling Language (UML), and DATEXII/OpenLR information exchange, for all types of location data, appear to be the logical foundation for designing a *National Location Reference Hub* for managing horizontal network assets.

6.4 Influencing the Future

Development of digital technology is a global project. Development depends on institutions, organisations and volunteers to work cooperatively. The outcome of all these efforts are specifications and standards that form the foundation for digital systems, storing vast amounts of data, and exchanging information via multiple protocols.

OpenBIM is one example of a buildingSmart collaborative digital development outcome for vertical infrastructure. For horizontal infrastructure, the DATEXII/OpenLR standard is another example a working relationship between the national transport agencies in Sweden and the Netherland working directly with the software provider, Tom Tom to solve identified problems in the DATEXI ITS standard.

This Report recommends that the communication with the proposed *National Location Reference Hub* for horizontal infrastructure be based on an extension of OpenLR, and be framed in accordance with Semantic Web principles. This will also provide each road jurisdiction with the platform to incorporate additional features into their LRMs linked to road network asset service performance. This includes horizontal infrastructure network data such as:

- Time-based coordinate information
- 3D coordinate data
- 2D and offset data
- Polylines

Fortunately, OpenLR is fully documented and code is freely available. Thus, this project could continue working directly with the OpenLR Foundation to develop road asset management specific extensions. In this way, Austroads best practice would contribute to the global outcomes related to integrating 3D lifecycle location data for use in road asset management systems.

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