Three location referencing method families: a new theoretical framework

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Three location referencing method families: a new theoretical framework

R Kenley[1,2], R Yeo[3] and T Harfield[1]

[1]Swinburne Business School, Faculty of Business and Law Engineering, Swinburne University of Technology, John St, Hawthorn VIC 3122, Australia
[2] Faculty of Engineering, Unitec Institute of Technology, Carrington Road, Mount Albert, Auckland, New Zealand
[3] Asset Management Task Force, Austroads, 287 Elizabeth Street, Sydney, New South Wales, Australia

E-mail: tharfield@swin.edu.au

Abstract. This conceptual paper provides a new theoretical framework for location necessary to enable integration of current road asset management systems with digital designs based on IFC standards. Three important concepts are proposed. The first is redefining the meaning of location data taking into account three different types of model view: linear/network location referencing methods, spatial earth coordinates, and digital design modelling. The creation of new families for location referencing methods takes into account these model views. The new families proposed are: Topological (Logical Linear and Network Referencing), Geospatial (Real World Coordinates), and Geometric (Model Coordinates). By expanding the definitions of each of these families, a more complex, and thus, more inclusive concept of location data can be utilised to support the storage and retrieval of both heritage and future road asset location information.

1. Introduction

Globally, road assets are a major responsibility. Approximately 40 million km of roads in 222 countries have been built and now must be maintained. This becomes more difficult because of the increased number and types of vehicles using the roads and ever increasing costs for repair due to the increasing intensity of major weather events. Thus, the escalating costs drives the need for more effective and efficient ways of managing road asset budgets. However, the technology that could be at the centre of the solution is still evolving. To put this into perspective, this paper focuses on future implications based on the importance of location referencing methods for road asset management.

Location Referencing Methods (LRMs) are a fundamental feature of road asset management systems. The location information generated by the LRMs can be collected from a number of sources and in a number of different formats. However, currently there is no theoretical framework to integrate the location data from past, present and future referencing methods. Therefore, the objective of this paper is to fill the theoretical gap concerning types of location referencing methods required for the road asset management transformation in the 21st century.

In order to understand the problem, a desktop critical review explored 120 documents. The extensive review focused on the location referencing requirements of road asset management. This included international standards that underpin current specifications and the expected data for emerging digital technologies. Analysis of the documents showed that, globally, individual jurisdictions have developed a wide variety of LRMs. However, the similarity of properties suggested the concept of clustering the variety of types into families of LRMs [1].

The balance of the paper outlines the findings of the critical review in section two. Section three describes the proposed alternative set of conceptual families; Topological, Geospatial and Geometric.

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Details of each of the families is provided in sections four, five and six. The last section provides a summary.

2. Critical literature review

The purpose of the literature review was two-fold; first to find instances of the term 'location' and second to find definitions that could be used to understand the types of applications for use. The first step was to do a content analysis of a sample of 120 documents. The content analysis criteria were:

- The purpose of the document
- Perspective of the writer and the expected reader of the document in relation to location referencing depending life-cycle of asset phase
- Asset type: road networks, transport systems or networks comprised of multiple asset types
- End uses for a location model, each with its own sub-categories. The uses of location included:
    - way finding (specific addresses, co-ordinates, etc.)
    - works & services (network service lines, proximity regions, resources optimisation, maintenance, works & services co-ordination, construction phase planning, etc.)
    - road users (public information, traffic information, haulage, road closures, flood & fire alerts, legal & registration, etc.)
    - co-operation with utilities (telecommunication, water, etc.)
    - future of roads (automated vehicles, GIS, BIM, etc.)

Summaries of each of the content analysis criteria were then considered in terms of location data utilisation, based on end-user perspectives. Four types of perspective were identified; the real world, a dataset, a model, and model view information exchange. These perspectives were used to categorise the documents. One sub-set is focuses specifically on LRMs.

Table 1 provides an example of some of the documents presented as a chronology that provided definitions of location referencing methods.

Table 1. Location referencing methods definitions from a variety of sources.

Source	Year	Definition of Location Referencing Methods (LRMs)
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.
ISO 19133	2006	The manner in which measurements are made (and optionally offset from) a curvilinear element
Austroads AP-T190-11	2011	The method used to identify a specific point or event on the road by providing it with a unique address.
ISO 19148	2012	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.
ISO 17572	2015	Methodology of assigning location references to locations

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Throughout this paper the definition of location referencing methods is not specifically given. This is because the critical review found that meanings vary between standards, government or industry reports, and academic papers as shown in table 1. Indeed, variation is the driver of the necessity for the new theoretical framework.

3. Defining a three family theoretical framework for location referencing methods

The proposed theoretical framework has evolved from early 21st century groups of location referencing methods. Ries identified three groups of LRMs: geodetic, geometric, and linear [2].

Table 2. Definitions of Ries' LRM groups

Type	Location Referencing Methods that:
Geodetic (Geographic)	describe locations on the earth's surface
Geometric	represent discrete features on the earth as a map coordinate
Linear	describe locations along discrete network features

Although as table 2 shows Ries proposed three groups and definitions, he also recognized the attributes of a number of sub-sets within each group. The importance of the sub-sets is that they can be conceptualized as families of location referencing methods. Thus, providing a framework for different types of location referencing methods for road asset management [3].

The Ries groups have either a linear or a spatial focus, or a combination of both [2]. Indeed, during the last 20 years road network asset management functions have come to require both linear and spatial LRMs as Ries suggested they would.

However, more recently scholars suggest that emerging digital technologies, such as BIM (3D, information loaded, digital design) should also be incorporated into the future functionality of road asset management.

The belief that these technologies will drive changing requirements for future road asset management performance, means that an expanded framework of location referencing methods is required. That is the purpose of the proposed theoretical framework outlined in this paper.

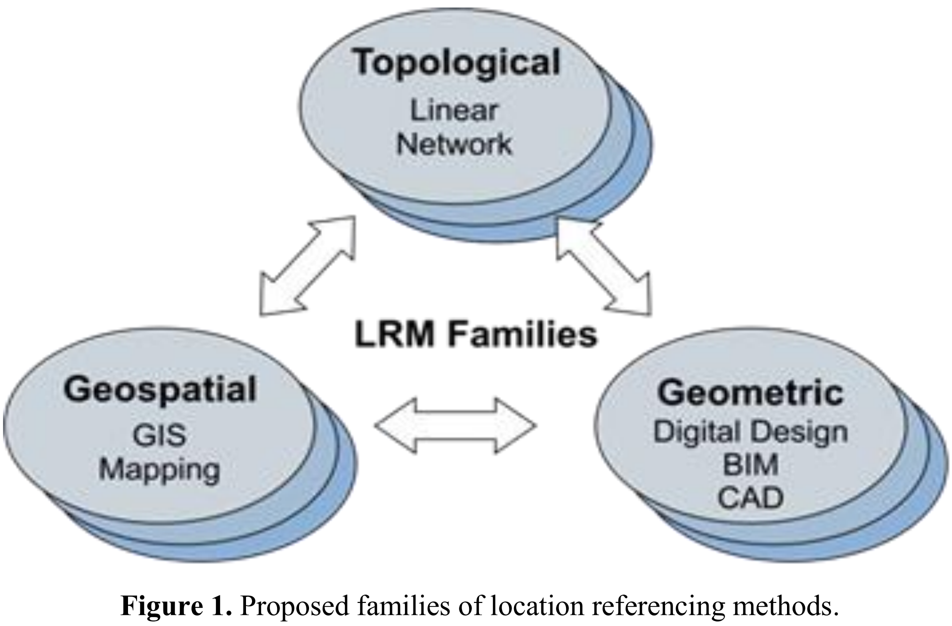

Figure 1. Proposed families of location referencing methods.

4. Family one: Topological (Linear/Network)

The two groups of LRMs within the Topological family are:

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

4.1. Linear referencing

Many studies of linear location referencing methods provide the wide variety of referencing methods for road infrastructure asset management [1, 4, 5]. They are a group of methods that, at the base level, describe locations relative to a one-dimensional object, measured along (and optionally offset from) that object [6]. This group of LRMs does not rely on spatial coordinate information, but often spatial coordinate information is included in their attributes.

An extensive review of locally used linear referencing methods is found in the 2001 report for Transit New Zealand [4]. The report outlines 14 examples from US states and four examples of Australian states. The authors provide the advantages and limitations of the linear reference methods reviewed. This specifically outlines the problem of the wide variety of types of location referencing methods.

The main reason for the variety is LRMs is differing business drivers for the local conditions within which roads are built and maintained [1]. These legacy practices are also embedded in legacy asset management systems. Thus, the benefits for the most commonly implemented LRMs are found in Geographic information: linear referencing, the current international standard ISO19148:2012:

"… 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…in some situations, having a linearly referenced location along a known linear element is more advantageous than knowing its spatial position" [6].

4.2. Network referencing

However, it is also possible to hybridize the linear location referencing methods by including geospatial data as attributes (particularly with modern geospatial databases such as Oracle Geospatial [7].

The international standard, ISO 17572-1 requires that location referencing methods should also enable referencing of the relative spatial relationship of objects and, more importantly, not change topological relationships by its own action [8]. For example, the order of points along a line should not get confused.

The network referencing standard ISO19133 explicitly recognizes that the links and nodes of a road system are complex, interconnected and may be routable [9]. Constructing a routable path in a road network may also require significant information other than the information provided by the location referencing methods. For example, addition information could include: grade separation, traffic flow direction, or turn restrictions. These may have both physical and temporal dimensions.

A routable path also requires location attributes such as: road class, road purpose, and environmental conditions. Some networks may also have complex 3D geometry, such as slope gradients for road and rail, or drainage networks. Thus, network referencing has been included in the more recent transport standards [10, 11, 12].

4.3. Importance of Topological Location Referencing

Topological networks provide the same advantages as linear referencing for human cognitive models [13, 14, 15]. 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 [8]. ISO 19133-2016 defines a navigation as "combination of routing, route transversal [changing] and tracking" [9].

At the same time, for asset management, a more critical use of topological networks is for service delivery management [16]. Network service performance is central to the concept of road user service.

This requires current-time analysis based on routes or journeys providing the possibility of alternative paths in the event of planned or unexpected disruptions, such as road works or accidents provided through all road asset management systems [17, 18].

5. Family 2: Geospatial (Real World Coordinates)

Cartographic systems are included in the geospatial family of location referencing methods. It is framed according to the technology, standards and syntax of geospatial systems [16].

GIS is a system that captures, stores, manipulates, analyzes, manages, and presents all types of geographical data. Traditionally, GIS, based on 2D maps, assigned 2D virtual references to real objects. The most common are longitude and latitude locations [19].

Geospatial referencing methods use a set of spatial coordinates by which location can be interpreted through many forms such as addresses or physical features. However, positioning is the most important locator for road asset management. Positioning consists of coordinates with reference to the Earth. It is supported by survey marks, Global Navigation Satellite Systems, geodetic modelling (coordinate transformations) and the geoid and bathymetric reference surfaces [20].

5.1. Positioning: location data

Geospatial data collection technologies including Total Stations (modern theodolites with built in Global Positioning Systems and laser ranging devices), full 3D static or mobile laser scanners, and photogrammetry cameras.

Traditional road asset management, and current practice for all Australian and New Zealand jurisdictions, limits positioning to two dimensions [1]. However, the traditional 2D location referencing method, is increasingly changing. The state road networks can now be surveyed with terrestrial laser scanners or mobile laser scanning systems to acquire 3D point clouds. These data are processed to extract the relevant location information, such as road centre-lines, location of kerbs, and other roadside furniture [20].

5.2. Importance of Geospatial Referencing

Searching and mapping are two key advantages of geospatial location reference systems. Most governments rely heavily on GIS applications, such as ESRI, for managing geographic data. Thus, they create local standards that provide searching (proximity-based) and modelling abilities [16].

GIS systems are able to utilise much more data than found in the road asset database. For example datasets that provide population, terrain, or ground cover information .The typical application is therefore able to display a huge number of different types of features on a map providing searchable functionality.

Thus, features can be processed according to road user needs, as well as the needs of traditional road asset management systems. It can be argued that no modern road Location Referencing System will be able to avoid having a Geospatial location referencing method based on real world coordinates as part of their asset management system in the future.

6. Family 3: Geometric (Model Coordinates)

de Laat and van Berlo argue that there are two types of modelling worlds that are not able to integrate. The authors indicate this difference by suggesting that "…the 'BIM people' and the 'GIS people' still seem to live in different [modelling] worlds. They use different technology, standards and syntax descriptions." [21].

Understanding this difference is important when considering the potential impact of BIM technology on location referencing methods and systems for road asset management.

Past efforts have paid little attention to either accuracy or discrepancy of location data due to the confusion between how systems use model geometry or cartographic geometry. However, modelling functionality resulting in 3D images continues to be developed. Therefore, road transport agencies are being urged to move towards integration of digital engineering road design data in their asset management systems [1].

6.1. CityGML: linking Geospatial and Geometric location data?

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3D GIS is an emerging technology [19]. Schemas such as KML, COLLADA and GML store 3D attributes of objects in GIS enhancing functionality. Currently in the GIS world, the cross-over from the BIM world for 3D representation uses City Geography Markup Language (CityGML).

CityGML is applicable for large areas and small regions and can represent the terrain and 3D objects in different levels of detail simultaneously integrating model geometry or cartographic geometry. Because of this functionality, both linear and coordinate location referencing datasets can be integrated into road asset management Location Referencing Systems. However, CityCML points do not take into account the curvature of the earth, the continuing problem when using digital platforms [20].

6.2. Designing road infrastructure

The family of Geometric reference systems are those based on geometric models of infrastructure. They are typically created and used during the design phase of road 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 [1].

Geometric models of infrastructure include traditional 2D drafting of a project, through to 3D modelling, with the possibility of including modern BIM workflows. These are the tools and methods of 'BIM people' identified by de Laat & van Berlo [19].

Their world-view is based on technology, standards and syntax related to object-based modelling. These types of models make intense use of 3D geometry embedded in Industry Foundation Classes (IFC) [22]. IFC4 provides the rules for using the concepts of constructive solid geometry and boundary representation using Boolean operations to design geometric models of infrastructure, currently this means mainly vertical infrastructure.

However, it should be noted that the inclusion of older 2D and 3D modelling formats for infrastructure design means that Geometic location referencing methods are much more than BIM. At the most advanced level, complex and powerful integrated systems build models of infrastructure [23].

6.3. Alignment, horizontal infrastructure, and modelling

Horizontal Infrastructure is the term that describes built environment and infrastructure assets created through string-based design such as networks. These typically are linear elements with alignment as the principle feature. The location breakdown structure creates continuous centre-lines.

However, BIM modelling has yet to develop effective methods of sending road alignment location information to road asset management systems. This is because an alignment is not composed of coordinate positions with straight lines between, as occurs in most geospatial location reference systems.

Road alignments 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 [22]. This specification does not force continuity between a point at the end of one segment and the start of the next [1]. This is a common digital modelling dilemma, because of the need for a mathematical trade-off between positions calculated by curves and desired end-points.

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An alignment may be seen as the direct equivalent to a Line Location except that dimensionality it is specific and is made of segments. However, some scholars claim that the horizontal alignment [only] is used for linear referencing, which was one of the principles for the development of the IFC Alignment schema [22].

6.4. Importance of Geometric Location Referencing
Clearly geometric modelling using local coordinates is critical for the design of infrastructure. As a coordinate system and with local coordinates of all objects and alignments, this forms an extensive referencing system. Until IFC-Alignment forms the basis of equivalency to topological and geospatial reference systems, CityGML is more likely to be used for road asset management modelling data.

7. Conclusions
Clearly geometric modelling using local coordinates is critical for the design of infrastructure. As a coordinate system and with local coordinates of all objects and alignments, this forms an extensive referencing system. Until IFC-Alignment forms the basis of equivalency to topological and geospatial reference systems, CityGML is more likely to be used for road asset management modelling data.

The Topological, Geospatial and Geometric categories capture the necessity to consider past, present and future location data for road asset management systems. Both the functionality and problems of utilization of each of the families are described to encourage consideration of how each of the families can be adopted.

For many road asset management systems legacy linear/network location referencing methods can be considered mature. The location data from geospatial methods utilising GIS coordinates is becoming more common. However, the inclusion of location information captured in digital models is the most challenging, because it is integrating this category of information integration is at an early stage for road asset management systems.

Therefore, the continuing business drivers for digital information exchange benchmarks suggests the proposed location referencing methods framework will be the foundation of future adoption strategies.

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