BS EN ISO 19148:2021

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Geographic information — Linear referencing

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The UK participation in its preparation was entrusted to Technical Committee IST/36, Geographic information.

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European foreword

This document (EN ISO 19148:2021) has been prepared by Technical Committee ISO/TC 211 "Geographic information/Geomatics" in collaboration with Technical Committee CEN/TC 287 “Geographic Information” the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by October 2021, and conflicting national standards shall be withdrawn at the latest by October 2021.

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 211, *Geographic information/Geomatics*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 287, *Geographic Information,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 19148:2012), which has been technically revised.

The main changes compared to the previous edition are as follows:

— revision of the definition of the term linear element, removing a circular reference with the definition for the term linear referencing;

— introduction of the definition of the term referent;

— revision of the conceptual schema to meet current standards and harmonize with other ISO/TC 211 International Standards;

— refactoring of the core Linear Referencing System package, abstracting implementation classes into a new Application Schema package which is now presented as an example in Annex D;

— introduction of an approach addressing broken-chainage;

— introduction of an enumeration addressing directionality of measurements;

— introduction of an approach addressing Cross-Sectional Positioning (XSP) conventions;

— introduction of an approach addressing Measures with Uneven Distribution;

— refactoring of the Linearly Located Event package dropping the previous assumption that the Linear Element was always of a Feature type;

— introduction of simplifications of the conceptual schema;

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— additional example illustrating Measures with Uneven Distribution in Annex C;

— introduction of information about some standards implementing the conceptual schema described in this document in Annex C;

— additional example illustrating Secondary Linear Referencing Systems in Annex E;

— the correction of minor errors;

— introduction of a detailed overview regarding changes and backwards compatibility in Annex F.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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Introduction

This document is a description of the data and operations required to support linear referencing. This includes Linear Referencing Systems, linearly located events and linear segments.

Linear Referencing Systems enable the specification of positions along linear objects. The approach is based upon the Generalized Model for Linear Referencing[12] first standardized within ISO 19133:2005. This document extends that which was included in ISO 19133, both in functionality and explanation.

ISO 19109 supports features representing discrete objects with attributes with values which apply to the entire feature. ISO 19123 allows the attribute value to vary, depending upon the location within a feature, but does not support the assignment of attribute values to a single point or length along a linear feature. Linearly located events provide the mechanism for specifying attribution of linear objects when the attribute value varies along the length of a linear feature. A Linear Referencing System is used to specify where along the linear object each attribute value applies. The same mechanism can be used to specify where along a linear object another object is located, such as guardrail or a traffic accident.

It is common practice to segment a linear object with linearly located events, based upon one or more of its attributes. The resultant linear segments are attributed with just the attributes used in the segmentation process, ensuring that the linear segments are homogeneous in value for these segmenting attributes.

In accordance with the ISO/IEC Directives, Part 2, 2018, Rules for the structure and drafting of International Standards, in International Standards the decimal sign is a comma on the line. However, the General Conference on Weights and Measures (Conférence Générale des Poids et Mesures) at its meeting in 2003 passed unanimously the following resolution:

“The decimal marker shall be either a point on the line or a comma on the line.” In practice, the choice between these alternatives depends on customary use in the language concerned. In the technical areas of geodesy and geographic information it is customary for the decimal point always to be used, for all languages. That practice is used throughout this document.

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Geographic information — Linear referencing

1 Scope

This document specifies a conceptual schema for locations relative to a one-dimensional object as measurement along (and optionally offset from) that object. It defines a description of the data and operations required to use and support linear referencing.

This document is applicable to transportation, utilities, environmental protection, location-based services and other applications which define locations relative to linear objects. For ease of reading, most examples discussed in this document come from the transportation domain.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 19103, *Geographic information — Conceptual schema language*

ISO 19107, *Geographic information — Spatial schema*

ISO 19108, *Geographic information — Temporal schema*

ISO 19111, *Geographic information — Referencing by coordinates*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
attribute event
value of an attribute of a *feature* (3.4) that can apply to only part of the feature

Note 1 to entry: An attribute event includes the *linearly referenced location* (3.16) where the attribute value applies along the *attributed feature* (3.2).

Note 2 to entry: An attribute event can be qualified by the *instant* (3.8) in which, or *period* (3.20) during which, the attribute value applied.

3.2
attributed feature
feature (3.4) along which an *attribute event* (3.1) applies

3.3
direct position
position (3.21) described by a single set of coordinates within a coordinate reference system

[SOURCE: ISO 19136-1:2020, 3.1.20]

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3.4
feature
abstraction of real-world phenomena

[SOURCE: ISO 19101-1:2014, 4.1.11]

3.5
feature event
information about the occurrence of a *located feature* (3.17) along a *locating feature* (3.18)

Note 1 to entry: A feature event includes the *linearly referenced location* (3.16) of the located feature along the locating feature.

Note 2 to entry: A feature event can be qualified by the *instant* (3.8) in which, or *period* (3.20) during which, the feature event occurred.

3.6
geometric primitive
<geometry> geometric object representing a single, connected, homogeneous (isotropic) element of space

Note 1 to entry: Geometric primitives are non-decomposed objects that present information about geometric configuration. They include points, curves, surfaces and solids. Many geometric objects behave like primitives (supporting the same interfaces defined for geometric primitives) but are actually composites composed of some number of other primitives. General collections can be aggregates and incapable of acting like a primitive (such as the lines of a complex network, which is not connected and thus incapable of being traceable as a single line). By this definition, a geometric primitive is topological open, since the boundary points are not isotropic to the interior points. Geometry is assumed to be closed. For points, the boundary is empty.

[SOURCE: ISO 19107:2019, 3.50]

3.7
height
h, H
distance of a point from a chosen reference surface positive upward along a line perpendicular to that surface

Note 1 to entry: A height below the reference surface will have a negative value.

Note 2 to entry: Generalization of ellipsoidal height (h) and gravity-related height (H).

[SOURCE: ISO 19111:2019, 3.1.38]

3.8
instant
0-dimensional *geometric primitive* (3.6) representing *position* (3.21) in time

Note 1 to entry: The geometry of time is discussed in ISO 19108:2002, 5.2.

[SOURCE: ISO 19108:2002, 4.1.17]

3.9
linear element
one-dimensional object that serves as the axis along which measurements are made

Note 1 to entry: Also known as curvilinear element.

EXAMPLE *Feature* (3.4), such as "road"; curve geometry; directed edge topological primitive.

3.10
linear referencing
specification of a *location* (3.19) relative to a *linear element* (3.9) as a measurement along (and optionally offset from) that element

Note 1 to entry: An alternative to specifying a location as a two- or three- dimensional *spatial position* (3.23)

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3.11
linear referencing method
LRM
manner in which measurements are made along (and optionally offset from) a *linear element* (3.9)

3.12
linear referencing system
LRS
set of *linear referencing methods* (3.11) and the policies, records and procedures for implementing them

Note 1 to entry: Adapted from Reference [10].

3.13
linear segment
part of a linear *feature* (3.4) that is distinguished from the remainder of that feature by a subset of attributes, each having a single value for the entire part

Note 1 to entry: A linear segment is a one-dimensional object without explicit geometry.

Note 2 to entry: The implicit geometry of the linear segment can be derived from the geometry of the parent feature.

3.14
linearly located
located using a *linear referencing system* (3.12)

3.15
linearly located event
occurrence along a *feature* (3.4) of an attribute value or another feature

Note 1 to entry: The event *location* (3.19) is specified using *linearly referenced locations* (3.16).

Note 2 to entry: A linearly located event can be qualified by the *instant* (3.8) in which, or *period* (3.20) during which, the linearly located event occurred.

Note 3 to entry: ISO 19108 limits events to a single instant in time and does not include the specification of a location.

3.16
linearly referenced location
location (3.19) whose *position* (3.21) is specified using *linear referencing* (3.10)

3.17
located feature
linearly located feature
feature (3.4) that is *linearly located* (3.14) along an associated (locating) feature

EXAMPLE A feature “bridge” can be a located feature along the feature “railway” [a *locating feature* (3.18)].

3.18
locating feature
linearly locating feature
feature (3.4) that is used to identify the *location* (3.19) of *linearly located* (3.14) features

EXAMPLE A feature “road” can be the locating feature for a feature “pedestrian crossing” [a *located feature* (3.17)].

3.19
location
particular place or *position* (3.21)

Note 1 to entry: A location identifies a geographic place.

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Note 2 to entry: “Madrid”, “California”.

Note 3 to entry: Additionally, in this document, a location is represented by one of a set of data types that describe a *position* (3.21), along with metadata about that data, including coordinates (from a coordinate reference system), a measure (from a *linear referencing system* (3.12)), or an address (from an address system).

[SOURCE: ISO 19112:2019, 3.1.3]

3.20
period
one-dimensional *geometric primitive* (3.6) representing extent in time

Note 1 to entry: A period is bounded by two different *temporal positions* (3.24).

[SOURCE: ISO 19108:2002, 4.1.27]

3.21
position
data type that describes a point or geometry potentially occupied by an object or person

Note 1 to entry: A *direct position* (3.3) is a semantic subtype of position. Direct positions as described can define only a point and, therefore, not all positions can be represented by a direct position. That is consistent with the “is type of” relation. An ISO 19107 geometry is also a position, just not a direct position.

[SOURCE: ISO 19133:2005, 4.18]

3.22
referent
known *location* (3.19) along a *linear element* (3.9) from which relative measurements are made

EXAMPLE Milepost, kilopost or reference post.

3.23
spatial position
direct position (3.3) that is referenced to a two- or three-dimensional coordinate reference system

Note 1 to entry: An alternative to specifying a *location* (3.19) as a *linearly referenced location* (3.16).

3.24
temporal position
location (3.19) relative to a *temporal reference system* (3.25)

[SOURCE: ISO 19108:2002, 4.1.34]

3.25
temporal reference system
reference system against which time is measured

[SOURCE: ISO 19108:2002, 4.1.35]

3.26
valid time
time when a fact is true in the abstracted reality

[SOURCE: ISO 19108:2002, 4.1.39]

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4 Abbreviated terms and UML notation

4.1 Abbreviated terms

CRS	coordinate reference system
GIS	geographic information systems
IFC	industry foundation classes
LandInfra	land and infrastructure conceptual model
NCHRP	national cooperative highway research program
RDF	resource description framework
REST	representational state transfer
SOAP	single object access protocol
SPARQL	SPARQL protocol and RDF query language
SQL	structured query language
UML	unified modelling language
XSP	cross-sectional positioning

4.2 UML notation

In this document, conceptual schemas are presented in the UML. ISO 19103 presents the specific profile of UML used in this document.

5 Conformance

5.1 Conformance overview

Clause 6 of this document uses the UML to present conceptual schemas for describing the constructs required for Linear Referencing. These schemas define conceptual classes that shall be used in application schemas, profiles and implementation specifications. This document concerns only externally visible interfaces and places no restriction on the underlying implementations other than what is required to satisfy the interface specifications in the actual situation, such as:

— interfaces to software services using techniques such as SOAP, REST and SPARQL end points;

— interfaces to databases using techniques such as SQL;

— data interchange using encoding as defined in ISO 19118.

Few applications require the full range of capabilities described by this conceptual schema. Clause 6, therefore, defines a set of conformance classes that support applications whose requirements range from the minimum necessary to define data structures to full object implementation. This flexibility is controlled by a set of UML concepts that can be implemented in a variety of manners. Implementations that define full object functionality shall implement all operations defined by the types of the chosen conformance class, as is common for UML designed object implementations. It is not necessary for implementations that choose to depend on external “free functions” for some or all operations, or forgo them altogether, to support all operations, but they shall always support a data type sufficient for recording the state of each of the chosen UML types as defined by its member variables. It is acceptable to use common names for concepts that are the same but have technically different implementations.

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The UML model in this document defines abstract types, application schemas define conceptual classes, various software systems define implementation classes or data structures, and the XML from the encoding standard (ISO 19118) defines entity tags. All of these references the same information content. There is no difficulty in allowing the use of the same name to represent the same information content even though at a deeper level there are significant technical differences in the digital entities being implemented. This "allows" types defined in the UML model to be used directly in application schemas.

5.2 Conformance classes

5.2.1 General

Conformance to this document shall consist of either data type conformance or both data type and operation conformance. The related tests are provided in the abstract test suite in Annex A.

5.2.2 Data type conformance

Data type conformance includes the usage of data types in application schemas or profiles that instantiate types in this document. In this context, "instantiate" means that there is a correspondence between the types in the appropriate part of this document, and the data types of the application schema or profile in such a way that each standard type can be considered as a supertype of the application schema data type. This means that an application schema or profile data type corresponding to a standard type contains sufficient data to recreate that standard type's information content.

Table 1 assigns conformance tests, detailed in Annex A, to each of the packages in Clause 6. Each row in the table represents one conformance class. A specification claiming data type conformance to a package in the first column of the table shall satisfy the requirements specified by the tests given in the remaining columns to the right.

Table 1 — Data type conformance tests

Package	Conformance test					
	A.1.1	A.1.2	A.1.3	A.1.4	A.1.5	A.1.6
Linear Referencing System	X	—	—	—	—	—
Linear Referencing Towards Referent	X	X	—	—	—	—
Linear Referencing Offset	X	—	X	—	—	—
Linear Referencing Offset Vector	X	—	X	X	—	—
Linearly Located Event	X	—	—	—	X	—
Linear Segmentation	X	—	—	—	X	X

5.2.3 Operation conformance

Operation conformance includes both the consistent use of operation interfaces and data type conformance for the parameters, and return values used by those operations. Operation conformance also includes get and set operations for attributes.

Table 2 assigns conformance tests, detailed in Annex A, to each of the packages in Clause 6. Each row in the table represents one conformance class. A specification claiming operation conformance to a package in the first column of the table shall satisfy the requirements specified by the tests given in the remaining columns to the right.

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Table 2 — Operation conformance tests

Package	Conformance test					
	A.1.1 A.2.1	A.1.2 A.2.2	A.1.3 A.2.3	A.1.4 A.2.4	A.1.5 A.2.5	A.1.6 A.2.6
Linear Referencing System	X	—	—	—	—	—
Linear Referencing Towards Referent	X	X	—	—	—	—
Linear Referencing Offset	X	—	X	—	—	—
Linear Referencing Offset Vector	X	—	X	X	—	—
Linearly Located Event	X	—	—	—	X	—
Linear Segmentation	X	—	—	—	X	X

6 Linear referencing

6.1 Background

6.1.1 Linear referencing concepts

6.1.1.1 General

LRSs are in wide use in transportation but are also appropriate in other areas such as utilities. They allow for the specification of positions along linear elements by using measured distances along (and optionally offset from) the element. This is in contrast to using spatial positions that use two- or three-dimensional coordinates, consistent with a particular CRS.

Linearly referenced locations are significant for several reasons. First, a significant amount of information is currently held in huge databases from legacy systems that pre-date GISs. 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. Consider a crash in need of emergency assistance. Knowing the linear element (e.g. Northbound I-95) and the approximate linear location is superior to having a potentially more precise spatial GPS location that is not of significant accuracy to determine whether it is northbound or southbound I-95, especially if an impassable barrier separates the two carriageways.

The linearly referenced location as specified in this document as a position expression, therefore, has many uses. It can be used to tie information about a linear facility to a specific location along that facility. It can also be used to find a position on the face of the earth by specifying how far along the position is (and optionally offset from) on a particular linear element.

This document proposes a consistent specification for describing linearly referenced locations that also enables translation between different referencing methods and/or linear elements. It also specifies how these position expressions can be used to specify how information that pertains to only a part of a linear element can be specified as linearly located events.

A LRS is a set of LRMs and the policies, records and procedures for implementing them. There are numerous, seemingly disparate, LRMs in use today. There is no single, best method, as each has advantages in certain situations. It is, therefore, unreasonable to propose a single standard LRM. The Generalized Model for Linear Referencing[12] has been developed which instead categorizes LRMs into a basic set of common concepts. The additional advantage of this approach is that it also enables a singular method for translating linearly referenced locations into locations specified by another method or along an alternative linear element. This translation method is both closed and transitive,

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ensuring round-tripping and translation chaining. The Generalized Model for Linear Referencing has been summarized in Annex B.

The Generalized Model for Linear Referencing standardizes the content of a linearly referenced location as containing three components: that which is being measured (linear element), the method of measurement (LRM) and the measured value (distance expression).

6.1.1.2 Linear element

Linear element is the general term which encompasses anything that can be measured using linear referencing. This includes ISO 19109 features, and ISO 19107 linear geometries and linear topologies.

Features do not have to be linear. A road feature, for example, can have multiple spatial representations to support multiple applications. These can be high-precision linear curves to support civil engineering design, low-resolution straight linestrings to support GIS applications, or areas to support pavement management applications. The only requirement is that it be possible to measure along the feature in a linear, one-dimensional, sense.

Features can represent fundamental entities, like a road element between two intersections, or more complex entities, such as a highway route spanning an entire state or country. Depending on the application schema, the feature can represent the entire road (width-wise) or only one of its carriageways. Therefore, this document uses the word “roadway” intentionally to mean either the full road or a single carriageway.

Linear element features can have no geometry at all. Many existing systems store information about roads by defining roadway characteristics along the roadway, without specifying where the road is physically located. This does preclude the ability to translate spatial positions into linearly referenced locations along the feature. However, it is possible to translate linearly referenced locations to other linear elements or to other LRMs. Using linear referencing instead of its geometry to define roadway characteristics directly against the feature enables the definition of multiple geometries for the feature without having to repeat the roadway characteristics for each spatial representation. It also allows for the definition of roadway characteristics when no geometry exists.

The linear geometry type of linear element includes instances of geometric curves, as these can be used for measuring along and their geometric location is known. It is, therefore, possible to project a spatial position onto the linear geometry and represent its location as a linearly referenced location along the geometry. It is also possible to translate a linearly referenced location along the geometry into two- or three-dimensional space.

Geometric curves are typically represented as attributes of features. Once a spatial position has been projected onto the curve, it is then possible to translate this location into a linearly referenced location on the feature itself.

The linear topology type of linear element includes instances of directed edges. Edges usually do not have a length attribute but do have one or more weights associated with the cost of traversing the edge. Measuring along an edge, therefore, entails *pro rata* distribution based upon the weight value(s). Only a limited number of LRM types can be used for measuring edges.

Linear elements can have attributes. If specified for the linear element, the value of these attributes applies to the entire linear element. Attribute events enable attribute values to apply to part of the linear element (see 6.1.1.5).

6.1.1.3 Linear Referencing Method (LRM)

How a linear element is measured is specified by the LRM. Example LRMs are included in Annex C. The LRM specifies whether the measurement is absolute, relative or interpolative. Absolute measurements, such as milepoint, hecto-metre or kilometre-point, are made from the start of the linear element. Relative measurements, such as a milepost, kilopost or reference post, are made from some known location along the linear element, called a referent. Interpolative measurements, such as percentage or normalized, use linear interpolation along the entire length of the linear element.

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The LRM specifies if an additional, offset measurement can be made perpendicular to the linear element to specify a location that does not lie directly on the linear element. The offset measurement can be made from the linear element itself or relative from an offset referent, for example, 5 m from the reference line of a road or 5 ft from the back of the curb, respectively.

The LRM specifies the units of measure for measuring along the linear element. This results in the fundamental difference between a milepoint versus a kilometre-point LRM: the first measures in miles, the second in kilometres. If an LRM allows offsets, the LRM also specifies the units of measure for offset measurements.

Due to the wide variety of LRMs currently in use, it is possible to enumerate particular constraints about the method, for example, to allow only reference marker type of referents for a reference post LRM. Constraints for commonly used LRMs are suggested in Annex C.

6.1.1.4 Distance expression

6.1.1.4.1 Distance along

The measured value which defines the location along the linear element in accordance with the LRM is specified with a distance expression. In its simplest form, this is the "distance along" the linear element for an absolute LRM. It specifies how far along the linear element to measure from the start of the linear element in the direction towards the end of the linear element. The resultant "along" location A is on the linear element, as shown in Figure 1. For example, a distance expression with a "distance along" of 4.0 for a kilometre-point LRM along Route 1 specifies a location on Route 1 that is measured 4.0 km along the route from its start.

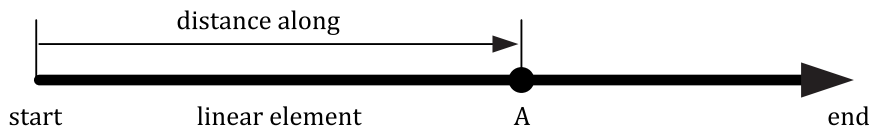

Figure 1 — Linearly referenced along location A with an absolute LRM

It is often the case that the measure at the start of the linear element is not equal to zero for a particular absolute type of LRM. For example, in Figure 2, the linear element start has a kilometre-point value of 0.5 km. An "absolute zero" point is, therefore, introduced to specify where an absolute LRM shall begin measuring distance along values.

In Figure 2, absolute zero occurs 0.5 km prior to the start of the linear element for the specified absolute LRM. A position expression with this LRM of kilometre-point and a distance expression with a distance along value of 4.0 km specifies a location that is measured 4.0 km along the linear element from absolute zero. The result is an along location A that is 3.5 km from the start of the linear element.

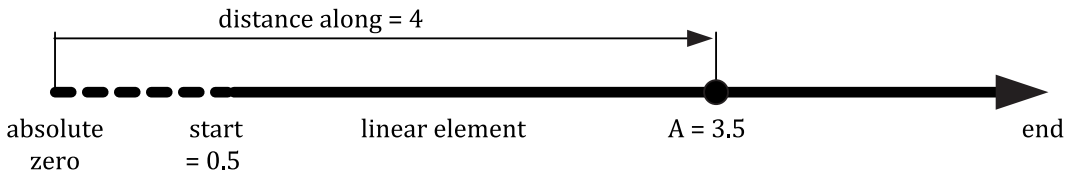

Figure 2 — Absolute LRM with non-zero linear element start

For an interpolative LRM, the distance expression comprises a single measure value. Here this value is used with linear interpolation to determine the location along the linear element based on the length (or weight) of the linear element as shown in Figure 3. A distance expression with a measured value of 60 for a percentage LRM along Route 1, which has a length of 50 km, specifies an along location A on Route 1 which is 30 km along the route from its start.

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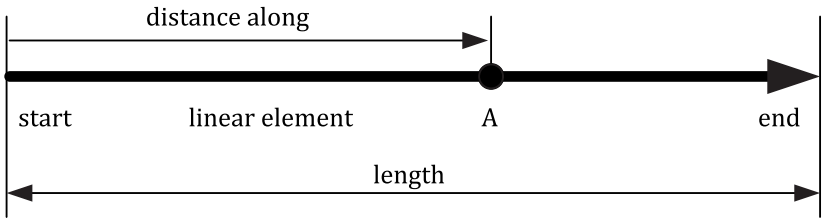

Figure 3 — Linearly referenced along location A with an interpolative LRM

6.1.1.4.2 Referents

For relative LRMs, the "distance along" is measured along the linear element from a known location on the linear element, called a "from referent", as shown in Figure 4. For example, a distance expression with a "distance along" of 0.5 for a kilometre-post LRM along Route 1 specifies an along location A on Route 1 that is 0.5 km along the route from the specified kilometre-post located at referent location R. If the kilometre-post is located 4.0 km from the start of Route 1, then the resultant location is 4.5 km from the start of the route.

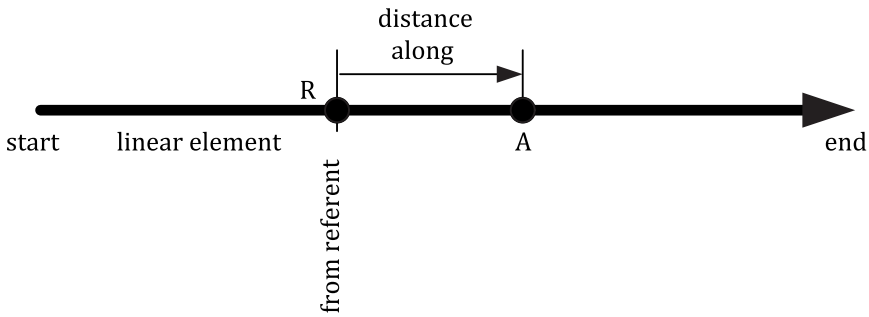

Figure 4 — Linearly referenced along location A with a relative LRM

Referent types vary between LRM. These include, for example, intersections, administrative and maintenance boundaries, landmarks and physical reference markers.

If the LRM is of type Linear Referencing Method With Towards Referent, a "towards referent" can be added to a distance expression to disambiguate the direction in which the measurement is made, as shown in Figure 5. Measurements are made in the direction from the "from referent" towards the "towards referent", regardless of the directional sense of the linear element being measured.

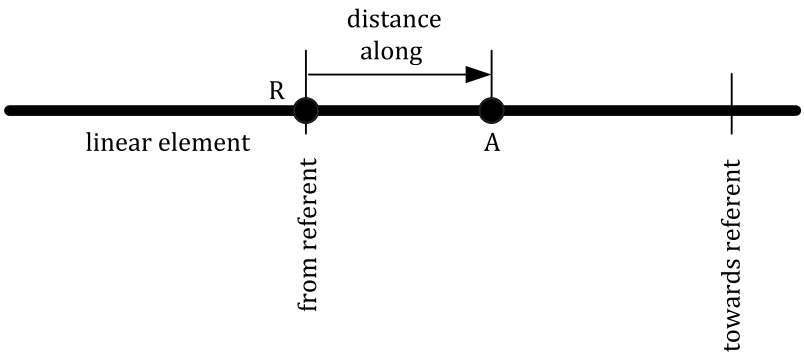

Figure 5 — Linearly referenced along location A with from and towards referents

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6.1.1.4.3 Offsets

If the LRM is of type Linear Referencing Method With Offset, the distance expression can include an offset expression to specify locations not directly on the linear element. Each position expression can have either:

a) a lateral offset

   1) measured left or right perpendicular to the linear element reference line from the distance along point,

   2) measured left or right perpendicular to a lateral offset referent,

   3) measured in a "lateral" direction defined by the LRS from the distance along point,

   4) specified by convention;

b) a vertical offset

   1) measured opposite to or in the direction of gravity, above or below the linear element from the distance along point,

   2) measured opposite to or in the direction of gravity above or below a vertical offset referent,

   3) measured in a "vertical" direction defined by the LRS from the distance along point;

c) a lateral offset and a vertical offset, measured as stated above;

d) a vector offset measured along a vector from the linear element; or

e) no offset at all.

For lateral offsets, the lateral offset distance specifies the distance measured perpendicular to the linear element at the location specified by the "distance along" (point A) to the linearly referenced offset location O, as shown in Figure 6.

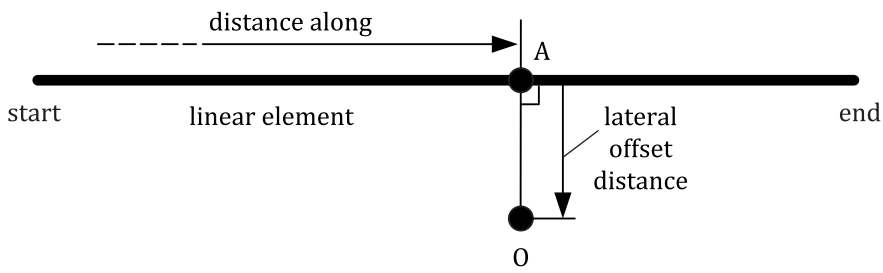

Figure 6 — Linearly referenced offset location O with a lateral offset distance

If a lateral offset referent is also included, then the resultant location is determined as shown in Figure 7. First, an along location A is determined by the distance along the linear element. Then a referent offset location (RO) is determined by intersecting the lateral offset referent with a normal to the linear element through location A. If A is a vertex of the linear element, then that part of the linear element occurring just prior to A is used to determine the direction of the normal. Finally, the offset location O can be determined by measuring the lateral offset distance along a line that is normal to the lateral offset referent at location RO. If RO is a vertex of the lateral offset referent, then that part of the lateral offset referent occurring just prior to RO is used to determine the direction of the normal. Here, "just prior" assumes that the lateral offset referent is defined in the same relative direction as the linear element.

The lateral offset referent can be the name of an entity in the real world, such as curb, to enable the specification of the location as "5 ft back of curb". Alternatively, the offset referent can be an instance of a feature, such as a feature representing the curb. If the linear element and feature instance

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have associated linear geometries, then it is possible to calculate the spatial position of the linearly referenced location.

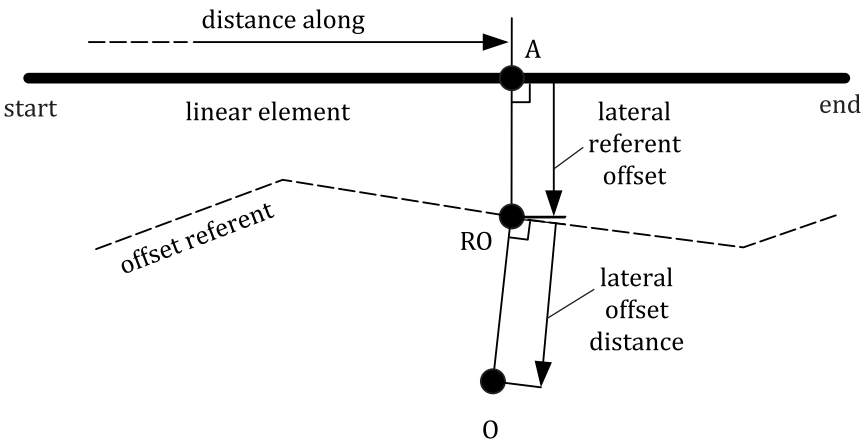

Figure 7 — Linearly referenced offset location O with an offset referent

In some countries, lateral positioning conventions have been established for named partitioning of the roadway cross-section. For example, in the UK and Canada, the XSP convention assigns abbreviations and indexes to strips and lines that comprise the roadway cross-section. Strips are roadway cross-section sub-features, like individual lanes, whereas lines represent edges of features, such as the edge of a carriageway.

EXAMPLE Strip –L1 is the right-most left additional nearside lane and line RE is the right (carriageway) edge (see C.5.5 for definitions of -L1 and RE).

These positions are accommodated by specifying them as an offset referent.

With a Linear Referencing Method With Offset, a distance expression can have a vertical offset. If no lateral offset is specified, then the resultant linearly referenced location is directly above or below the linear element at along location A. If a lateral offset is specified, then the resultant linearly referenced location is directly above or below laterally offset location O as shown in Figure 6 or location RO as shown in Figure 7 if a lateral offset referent is included. Vertical offsets are measured in the direction away from (up) or towards (down) the centre of the earth.

If the distance expression contains a vertical offset referent, then the vertical offset distance is measured up or down from that referent. Otherwise, it is measured up or down from the height of along location A on the linear element.

The approach taken with lateral (and vertical) offsets is appropriate for many transportation, utility or environmental domains where the linear elements are close to being horizontal. There are, however, some anomalies. Determination of the linearly referenced location of a point from a linear element cannot be deterministic, as many such linearly referenced locations are possible. There are also offset points that cannot be linearly located offset from a linear element using lateral offsets. In other domains, such as piping, lateral and vertical offsets cannot apply if the linear element is a section of pipe that is itself vertically oriented. For these cases, the LRS can include semantic rules for defining “lateral” and “vertical” directions. An alternative approach, vector offsets, is also available.

Figure 8 demonstrates the case where the determination of a linearly referenced location along a linear element is non-deterministic for offset location O. An along location A_1 with a lateral offset distance lod-1 results in the specification of offset location O. However, along location A_2 with a lateral offset distance lod-2 specifies the same offset location O. In order to make the projection operation deterministic, the along location with the lowest absolute distance along measure shall be returned. For the projection of location O onto the linear element, A_1 shall be returned as the resultant location because its absolute distance along the linear element is less than that of A_2.

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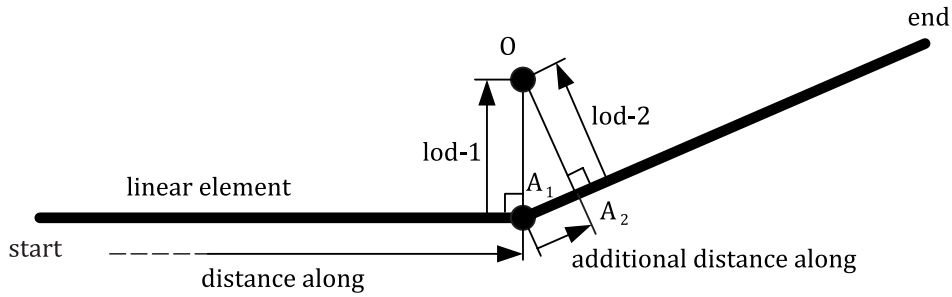

Figure 8 — Non-deterministic offset location

Of greater concern is the unsatisfiable condition shown in Figure 9. Two possible offset locations, O_1 and O_2, can be reached from the same along location A using equal lateral offset distances lod-1 and lod-2. There is no way of specifying offset locations in the grey region between O_1 and O_2 using a linearly referenced location and the linear element shown. The size of this region is dependent upon the deflection angle of the linear element at A as well as the magnitude of the lateral offset distance. If the discontinuity in the linear element were replaced by a circular arc, this problem would no longer exist, though the deterministic case mentioned above can still result.

To make calculations deterministic, the following assumption shall be made. If the distance along results in a point of discontinuity in the linear element, the offset shall be measured perpendicular to that part of the linear element that is terminated by the point of discontinuity. In Figure 9, location A represents a discontinuity in the linear element shown. A linearly referenced location having a distance along resulting in location A shall, therefore, specify location O_1 for an offset measure of lod-1.

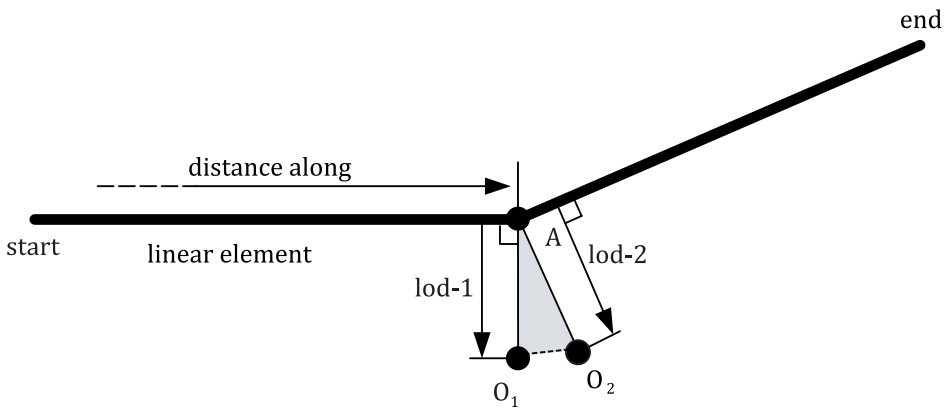

Figure 9 — Unsatisfiable offset location

To accommodate the above unsatisfiable case as well as cases where the linear element is not close to horizontal, vector offsets are appropriate. For vector offsets, the offset distance and bearing from along location A is given by an offset vector as shown in Figure 10. An accompanying CRS is necessary to orient the offset vector. For each vector offset distance expression, a CRS shall be specified or else the CRS of the expression's linear element is used. Offset referents are not supported with vector offsets. Vector offsets cannot be combined with lateral or vertical offsets.

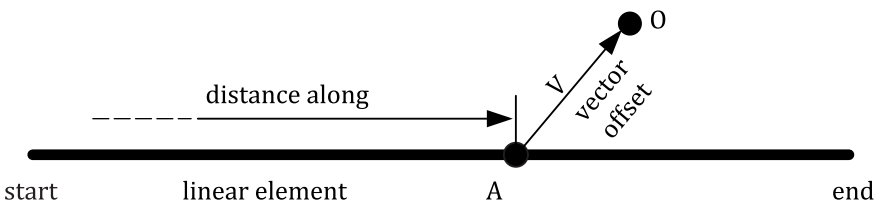

Figure 10 — Linearly referenced offset location O with a vector offset

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6.1.1.5 Linearly located events

6.1.1.5.1 Feature and attribute events

A linearly located event is an event that is located using an LRS. It can reflect something which happens, like an automobile crash, or something that exists, like a roadway characteristic such as pavement type. Linearly located events are either feature events or attribute events. Feature events allow the location of a (located) feature along another (locating) feature. Attribute events allow the application of an attribute value to only a portion of a linear element, like the asphalt pavement type can apply only to the first half of Route 1, after which it changes to concrete.

Feature events locate a feature that occurs at a spatial extent defined by linearly referenced locations along another feature and possibly further qualified as occurring at an instant in, or during a period of, time. In the first case, they have an event location. Events can be further qualified with an instant or period event time. The occurring feature is referred to as a "located feature" and the other feature along which it is located is referred to as a "locating feature".

An attribute event is an attribute value of a feature that applies to a limited extent along that feature. The applicable spatial extent is defined by linearly referenced locations along the attributed feature and possibly further qualified as applying at an instant in, or during a period of, time. In the first case, they have an event location. Events can be further qualified with an instant or period event time. The feature is referred to as an "attributed feature".

The choice between feature and attribute event is similar to the choice between features and attributes. A feature represents something in the real word about which information is kept. Attributes are the bits of information kept about a feature. Features have a unique identifier; attributes do not. Features can have one or more geometries, each of which is an attribute of the feature.

A similar case can be made for feature event versus attribute event. If a feature is linearly located along another feature, it is represented as a feature event of the locating feature. The feature event tells where, and optionally when, along the locating feature that the located feature exists. The located feature is a feature, so it has a unique identifier and can have any number of attributes, including spatial geometry, to indicate where it exists on the face of the earth, independent of the locating feature.

If a feature has an attribute, the value of that attribute applies to the entire feature. If this is not the case, then an attribute event is used instead of a traditional attribute. Like a traditional attribute, an attribute event has a value. But, unlike the traditional attribute, it also has linearly referenced locations to specify where it is along the attributed feature that this particular value applies.

6.1.1.5.2 Event location

Event locations are used to specify where a linearly located feature event occurs or where a linearly located attribute value applies. An event location can be either an "at" location or a "from/To" location.

If the event occurs at a single point along or offset from the locating feature, an "at" location is specified as the event location. The spatial extent is specified with a single linearly referenced location. If the event occurs throughout a contiguous spatial interval along or offset from the locating feature, a "from/To" location is specified as the event location. The spatial extent is specified with two linearly referenced locations marking the start and end of the interval. "At" and "from/To" locations are depicted in Figure 11. The location labelled as L_{AT} is the location "at" which the event occurs along the linear element. The locations labelled as L_{FROM} and L_{TO} are the "from" and "to" locations, respectively, along the linear element which bound the spatial interval throughout which the event occurs.

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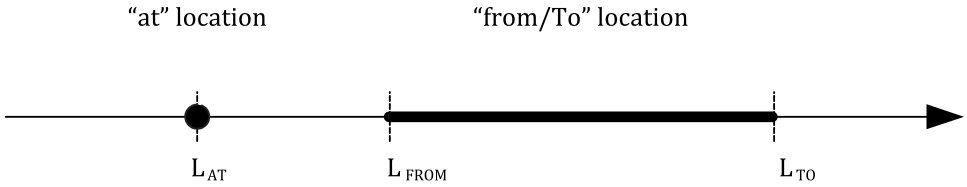

Figure 11 — At and from/To event locations

A single event instance occurs only in a single place. However, this single place can be described by both "at" and "from/To" locations. For example, a single city feature instance can have separate, scale-dependent "at" and "from/To" locations even though these two locations represent the same place.

6.1.1.5.3 Event time

It is also possible to specify the time at or during which an event is relevant [11]. The instants and periods used to specify the temporal extent are valid times. Instant granularities vary and can be as short as defining a time precise to a fraction of a second or as long as an entire day or more.

Figure 12 shows how event times can be combined with event locations. The location labelled as L_{AT} is the event location, being the location "at" which an event occurs along the linear element. The locations labelled as L_{FROM} and L_{TO} are the "from" and "to" event locations, respectively, along the linear element which bound the spatial interval throughout which an event occurs. The time labelled as T_{AT} is the event time, being the instant "at" which the event occurs along a timeline. The times labelled as T_{FROM} and T_{TO} are the "from" and "to" event times, respectively, along the timeline which bound the time interval during which the event occurs.

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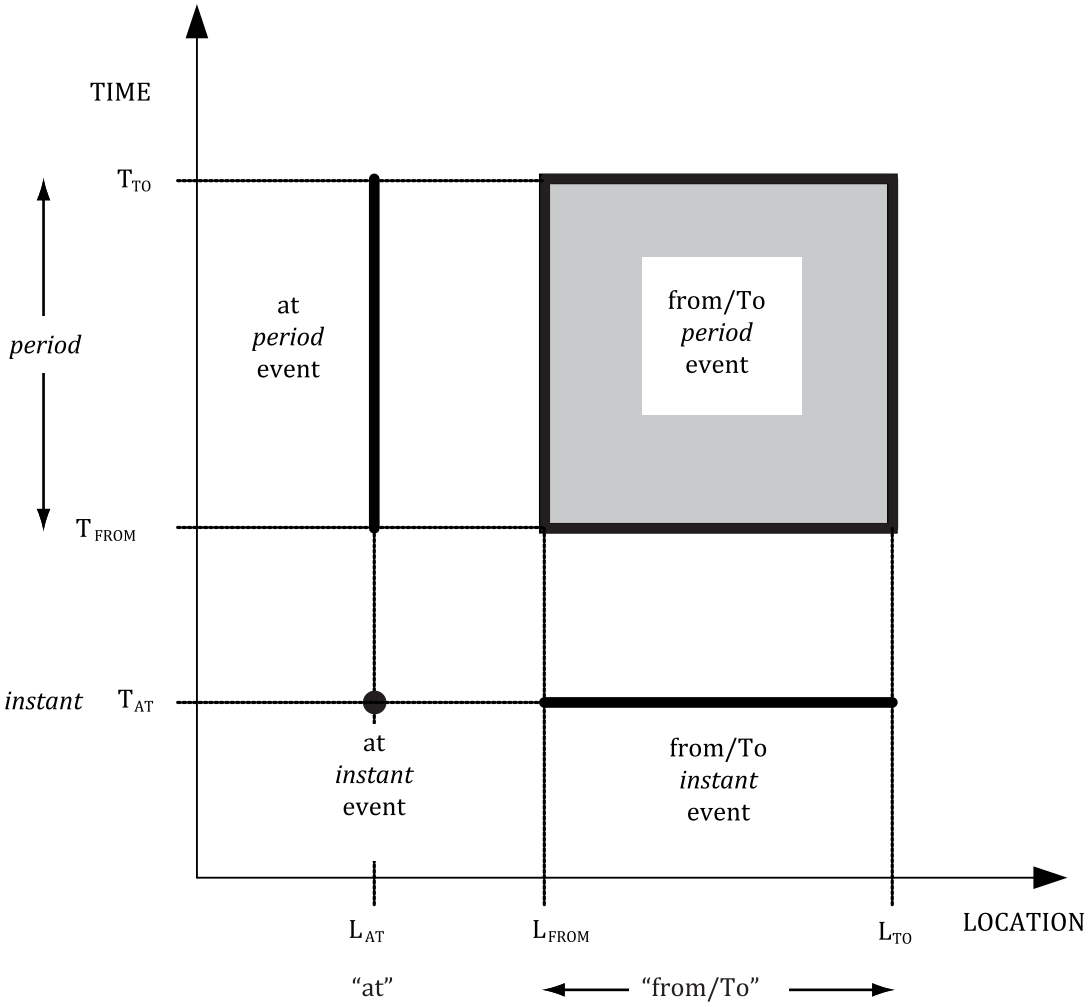

Figure 12 — Events with location and time

Examples of events with location and time are:

— at instant event: traffic crash;

— at period event (with offset): traffic sign;

— from/To instant event: street sweeping;

— from/To period event: pavement type.

Organizations can classify their events differently without deviating from this document. The examples given are just possible choices among several possibilities. In a particular application schema, a particular crash can be modelled as a from/To period event to reflect a higher level of location precision. The key consideration is whether the location is specified at a single location or along a continuum delimited by two locations. This is analogous to a city feature having separate, scale-dependent point and polygon geometries.

6.1.1.6 Linear segmentation

Linear elements can have a number of attributes. Some of these have a single value for the entire linear element. Others can change their value as the linear element is traversed. For example, for the linear element representing a road, the pavement type value can change part of the way down the road. Different attributes can change their value at different locations along the linear element. Some

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systems have segmented linear elements whenever any attribute value changes. As the number of attributes increases, this can result in numerous very short segments with most of the attribute values being retained for the subsequent segment. An alternative approach is to use attribute events to specify where along a linear element a particular attribute value changes. Then, for a particular display or analysis, the linear segment can be dynamically segmented by only the subset of the attributes that are of interest at the time. This results in linear segments homogeneous in value for all of the segmenting attributes.

A linear segment is a one-dimensional object having no explicit geometry, generated by segmenting a linear feature according to a particular subset of the attribute events along the feature. The resultant linear segments are attributed with the attribute values defined by the events such that every one of the resultant segment attributes has the same value for the entire length of the linear segment. Linear feature attributes not included in the segmentation subset are abstracted away and are not included in the attributes of the generated linear segments (see segmentation example in D.2). Each linear segment corresponds to a part of the parent linear feature, enabling a derivation of the geometry for the linear segment from one of the possible geometries of that feature.

The primary purpose of providing this functionality is to be able to generate segments homogeneous in a particular set of attributes, usually for display or analysis purposes. Because the resultant segments are abstractions of this original segmented linear element (the only attributes retained are those that participated in the segmentation operation), they are intended to persist only long enough to ensure read consistency. It is not advisable to edit segment attribute values directly. Instead, attribute events along the linear element should be edited and then the linear element should be re-segmented.

It is conceivable that an application schema needs to segment by feature events as well as attribute events. Though this document does not explicitly support such segmentation, it does not preclude it.

6.1.2 Linear referencing packages

This document incorporates the following UML packages:

— (Core) Linear Referencing System;

— Linear Referencing Towards Referent;

— Linear Referencing Offset;

— Linear Referencing Offset Vector;

— Linearly Located Event;

— Linear Segmentation.

The Linear Referencing System package represents the core functionality of this document and shall be implemented by all conforming implementations. All other packages are optional. Conforming implementations shall state which of these optional packages are supported. If a package is claimed as being supported, it and all of the packages it is dependent upon shall be supported in their entirety. Dependencies between packages are shown in Figure 13.

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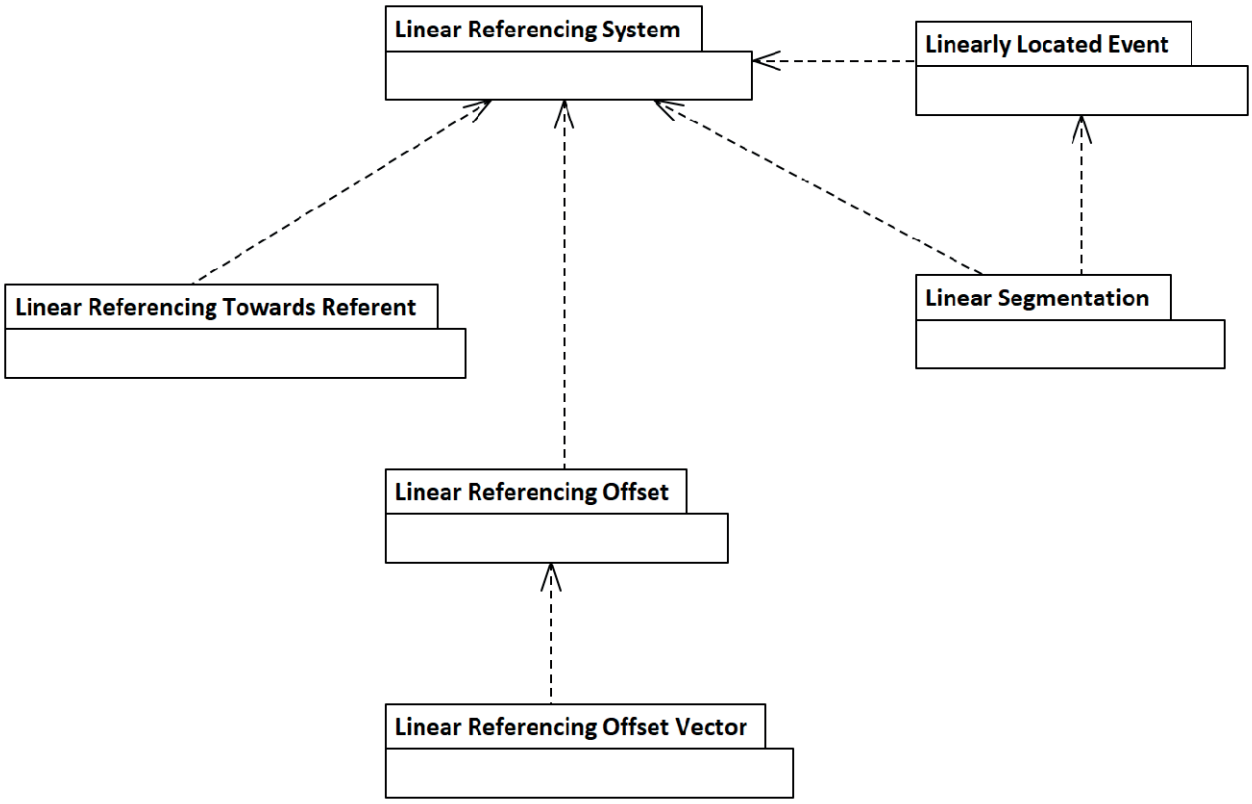

Figure 13 — Linear referencing package dependencies

6.2 Package: Linear Referencing System

6.2.1 Semantics

The core package "Linear Referencing System" supplies classes and types to the definition of LRSs. The UML classes for LRSs and their relationships are depicted in Figure 14. An application claiming conformance to this document shall support all of the Linear Referencing System package classes shown in Figure 14.

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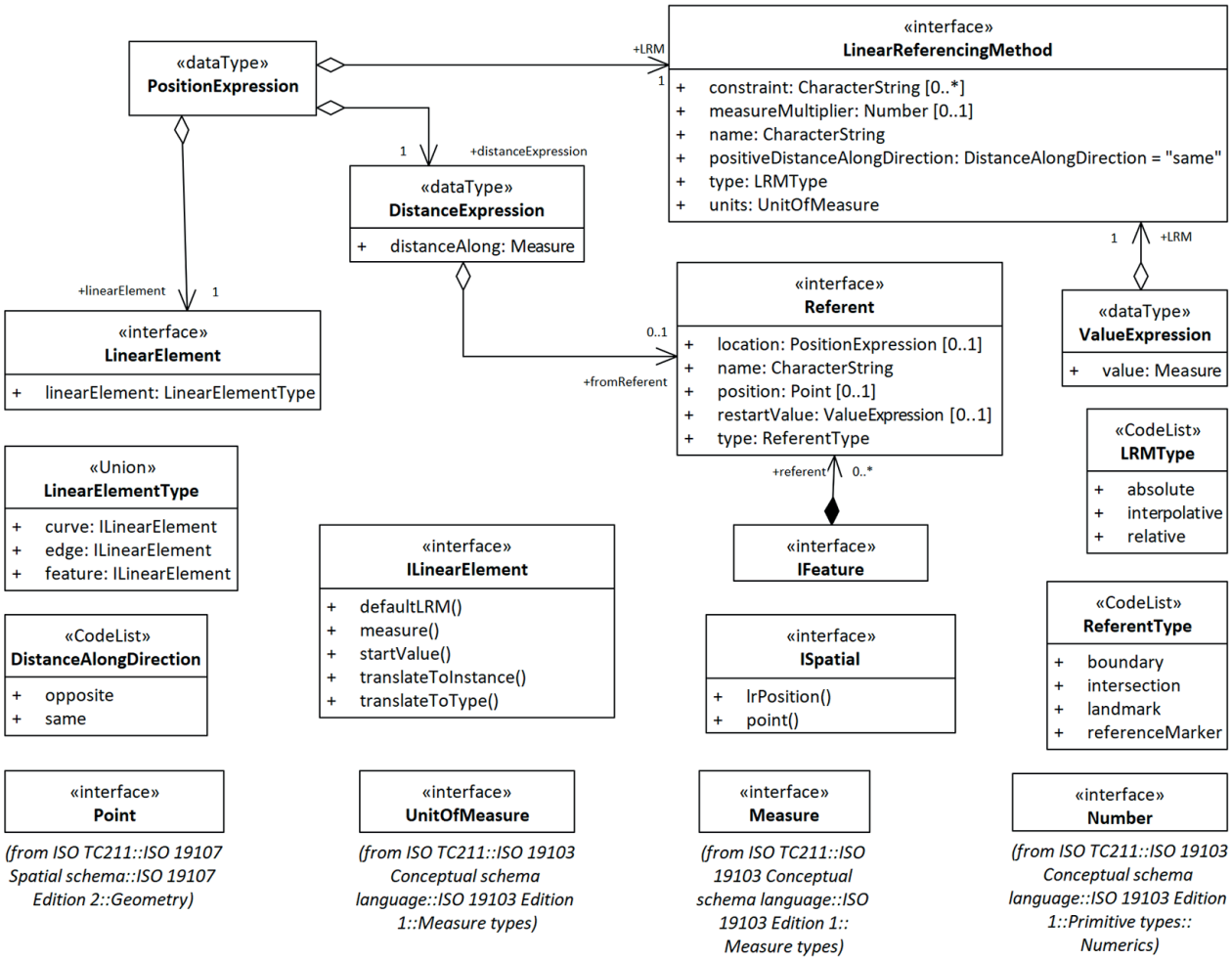

Figure 14 — Linear Referencing System classes

Figure 14 includes all of the classes in the Linear Referencing System package. To aid understanding, it is presented incrementally in 6.2.2 to 6.2.14. The reader can also refer to Annex C, which shows which parts of Figure 14 apply to which LRMs in common use today.

6.2.2 PositionExpression

6.2.2.1 Semantics

The data type *PositionExpression* is used to fully describe a linearly referenced location given by the linear element being measured, the method of measurement and a measure value specified with a distance expression. The UML for *PositionExpression* is shown in Figure 15. In situations where the first two values (linear element and measurement method) are known or can be implied, it is sufficient to specify only a distance expression in order to describe the linearly referenced location.

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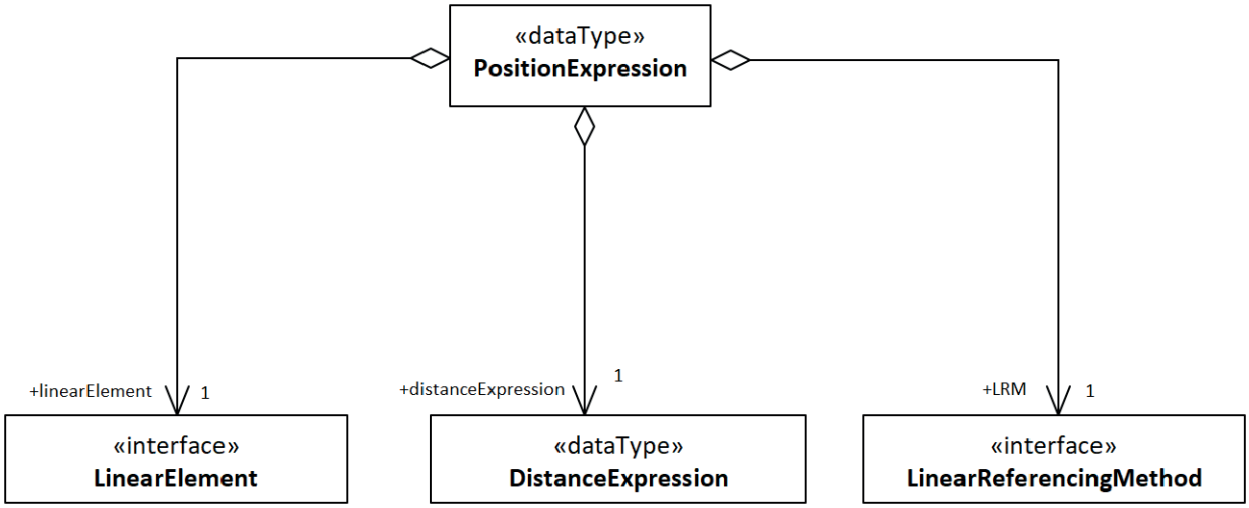

Figure 15 — Context diagram: PositionExpression

6.2.2.2 Role: linearElement: LinearElement

The role "linearElement" specifies the linear object being measured.

```
PositionExpression:: linearElement: LinearElement
```

6.2.2.3 Role: distanceExpression: DistanceExpression

The role "distanceExpression" specifies the measure value.

```
PositionExpression:: distanceExpression: DistanceExpression
```

6.2.2.4 Role: LRM: LinearReferencingMethod

The role "LRM" specifies how the measurement is made.

```
PositionExpression:: LRM: LinearReferencingMethod
```

6.2.3 LinearElement

6.2.3.1 Semantics

The interface *LinearElement* specifies the underlying linear element upon which the measures in the Linear Referencing System are made. The UML for *LinearElement* is shown in Figure 16.

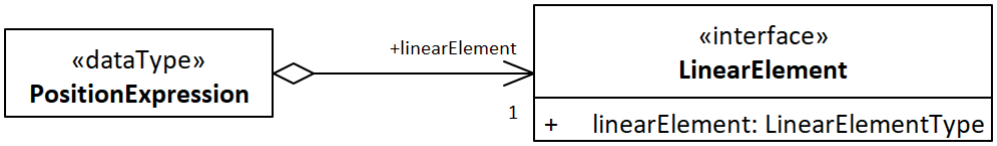

Figure 16 — Context diagram: LinearElement

6.2.3.2 Attribute: linearElement: LinearElementType

The attribute "linearElement" specifies the linear element along which measurements are made.

```
LinearElement:: linearElement: LinearElementType
```


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6.2.4 LinearElementType

6.2.4.1 Semantics

The union *LinearElementType* provides a choice for specifying the underlying linear element upon which the measures in the Linear Referencing System are made. The UML for *LinearElementType* is shown in Figure 17.

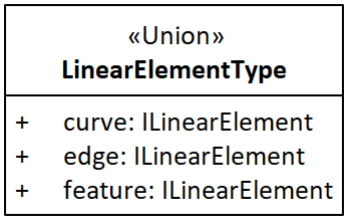

Figure 17 — Context diagram: LinearElementType

The linear element being measured shall be one of the following types:

— "curve" – a Curve instance that realizes the *ILinearElement* and *ISpatial* interfaces;

— "edge" – a Directed-edge instance that realizes the *ILinearElement* interface;

— "feature" – a Feature instance that realizes the *ILinearElement* and *IFeature* interfaces.

6.2.5 ILinearElement

6.2.5.1 Semantics

The interface *ILinearElement* is realized by all *LinearElements*. It includes operations that return:

a) the default LRM of the *LinearElement*;

b) one of the measures (length or weight) of the *LinearElement*;

c) a distance expression that represents the translation of a linearly referenced location on this *LinearElement* onto a specified target element using a specified LRM;

d) one or more position expressions that represent the translation of a linearly referenced location on this *LinearElement* onto the appropriate element instances of the specified target type, using a specified LRM;

e) the measure value at the beginning of the linear element for the specified LRM.

An example of how an application schema can implement the *ILinearElement* interface in terms of types defined in ISO 19107 is described in Annex D. The UML for *ILinearElement* is shown in Figure 18.

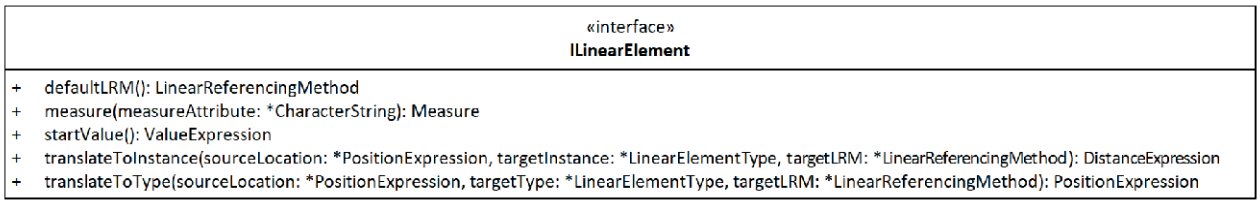

Figure 18 — Context diagram: ILinearElement

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6.2.5.2 Operation: defaultLRM

The operation "defaultLRM" returns the default LRM of the *LinearElement*. This is used for all measurements made along the *LinearElement* unless specified otherwise in a *PositionExpression* or otherwise explicitly overridden.

```
ILinearElement::
     defaultLRM(): LinearReferencingMethod
```

6.2.5.3 Operation: measure

The operation "measure" returns the value of one of the measure attributes of the *LinearElement*. This is usually one of its length attributes or, in the case of a directed-edge, one of its weight attributes. The default attribute name is "defaultLength".

```
ILinearElement::
     measure(measureAttribute: CharacterString = defaultLength): Measure
```

6.2.5.4 Operation: translateToInstance

The operation "translateToInstance" translates a *PositionExpression* defined along the subject (source) *LinearElement* into a *DistanceExpression* measured along a known, specified target *LinearElement* using the target LRM. The target LRM defaults to the defaultLRM of the target instance, unless explicitly overridden with the "targetLRM" input parameter.

```
ILinearElement::
     translateToInstance(sourceLocation: PositionExpression,
     targetInstance: LinearElement, targetLRM:
     LinearReferencingMethod = targetInstance.defaultLRM):
     DistanceExpression
```

6.2.5.5 Operation: translateToType

The operation "translateToType" translates a *PositionExpression* defined along the subject (source) LR_Feature, LR_Curve, or LR_DirectedEdge type of *LinearElement* into one or more *PositionExpressions* measured along the appropriate instances of the element type specified, using the target LRM. The returned *PositionExpressions* include the appropriate element instances as well as the resulting *DistanceExpressions*. The target LRM defaults to the defaultLRM of the target type, unless explicitly overridden with the "targetLRM" input parameter. This operation is used instead of "translateToInstance" when the source has been mapped to a list of contiguous target instances and it is not known a priori upon which instances the position will fall.

```
ILinearElement::
     translateToType(sourceLocation: PositionExpression, targetType:
     CharacterString, targetLRM: LinearReferencingMethod =
     targetType.defaultLRM): PositionExpression[]
```

6.2.6 IFeature

6.2.6.1 Semantics

The interface *IFeature* is realized by any feature that can be linearly measured, that is, any feature that realizes the *ILinearElement* interface. The UML for *IFeature* is shown in Figure 19.

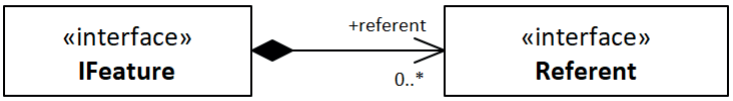

Figure 19 — Context diagram: IFeature

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6.2.6.2 Role: referent[0..*]: Referent

The optional association role "referent" aggregates the referents along this feature and considers them to be owned by the *IFeature*.

```
IFeature:: referent[0..*]: Referent
```

6.2.7 ISpatial

6.2.7.1 Semantics

The interface *ISpatial* is realized directly by spatial representations that also realize the *ILinearElement* interface. The *ISpatial* interface includes operations that return:

a) a spatial position of type *Geometry::Point*, as described in ISO 19107, spatially equal to the specified linearly referenced location along the subject curve;

b) a *DistanceExpression* that specifies the linearly referenced location along the subject curve using the curve's default LRM and that is spatially equal to the specified spatial position.

The UML for *ISpatial* is shown in Figure 20.

ISpatial is not realized by all *ILinearElement* implementations as they can have no or many spatial representations. In order to convert a spatial position into a linearly referenced location along a *LinearElement* implementing *ISpatial*, it is necessary that the spatial position first be projected onto one of the geometries associated with it and then the resultant *PositionExpression* on the geometry can be translated into a *PositionExpression* on the *LinearElement*.

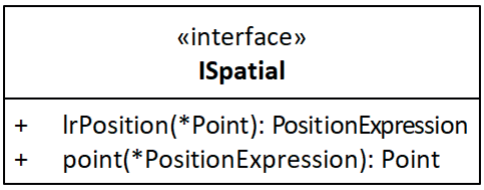

Figure 20 — Context diagram: ISpatial

6.2.7.2 Operation: lrPosition

The operation "lrPosition" determines the measure of a point on the *Geometry::Curve*, as described in ISO 19107, closest to the given point using the default LRM of the *ILinearElement* implementation. The returned position expression contains the *Geometry::Curve* instance, its defaultLRM and the resultant measure value. If the point is precisely on the *Geometry::Curve* instance, the returned position expression's distance expression will have no offset expression. If the point is equidistant to more than one *Geometry::Curve* location, the one closest to the start of the *Geometry::Curve* is selected.

```
ISpatial:: lrPosition(point: Point): PositionExpression
```

6.2.7.3 Operation: point

The operation "point" returns a *Geometry::Point* representing the spatial position spatially equal to a linearly referenced position specified by an *PositionExpression*. The operation is called on the *Geometry::Curve* contained in the *PositionExpression*.

```
ISpatial:: point(lrPosition: PositionExpression): Point
```

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