California Department of Transportation **Enterprise Data and Geospatial Governance Practice**	**NUMBER:** DGP-04	**DATE ISSUED:** May 9, 2023
SUBJECT: Linear Referencing	**REFERENCES:** DD-120 – Enterprise Data Governance DES-1: Location Specification – County, Route and Postmile DES-4: Location Specification – Coordinates DES-5: Location Specification – Statewide Odometer DES-6: Location Specification – All Roads	

PURPOSE:
The purpose of this document is to recognize the Source System of Record (SSOR) and Authoritative Reporting Source (ARS), define what is a competing linear referencing system (LRS), describe the process for addressing competing LRS, and present best practices around the utilization of the LRS. Using a single authoritative LRS enables consistent location assignment of entities managed across all Caltrans systems. This will prevent shifting of entity positions that would otherwise occur when a location is assigned by one LRS and is subsequently mapped by a different LRS.

BACKGROUND:
Recognizing both the Federal government and States are already tracking and managing infrastructure and activity that occur on all roadways, such as bridges and accidents, on August 7, 2012, the Federal Highway Administration (FHWA) announced that the Highway Performance Monitoring System (HPMS) is expanding the requirement for State Departments of Transportation (DOTs) to submit their LRS to include all public roads. This single authoritative LRS will be/is used to support the National Address Database, National Bridge Inventory, Financial Management Information System, to name a few examples. For these systems to function and interoperate properly, they rely on a SSOR for location.

Similarly, for Caltrans systems to function and interoperate properly, they rely on a consistent source system of record for location and standardized data format. For example, when a postmile or odometer measure is assigned to an entity using one LRS and that same entity is later mapped using a different LRS, differences in spatial representation will naturally occur (entities will appear to shift location) and erroneous analysis can be the result. Further, differences in data formats results in additional staff work to transform data and the inability of systems to directly share location data. Using a single authoritative LRS for all Caltrans work eliminates this possibility.

DEFINITIONS:

Source System of Record (SSOR): Entity that has been designated as the single authoritative source for a given data element (or set of elements).

Authoritative Reporting Source (ARS): Entity that has been designated as an authoritative source for reporting, analysis or visualization for a given collection of data.

A linear referencing system (LRS) consists of a set of measured line features, called routes, on which events, elements, and characteristics can be located based on a reference to the line and measure (or measures) on the line rather than through absolute x, y coordinates. An LRS has at least one, and possibly multiple linear referencing methods (LRM).

Dynamic Segmentation: The process of assigning geometry (point and/or line) derived from an LRS to tabular data based on key fields in the tabular data that identify the LRS Route ID and measure values.

Event: An entity with an assigned location and route with associated event characteristics.

Event Characteristics: An entity's attribute, like speed limits, number of lanes, crash type, project type.

Event Table: A tabular representation of events that may describe an asset, collision, roadway condition, etc. that also contains entries describing the location as a measure (point) or measures (line) of the item along an LRS route.

Linear Referencing Method (LRM): The measure system used to locate events along a route from a known starting point. Examples of LRMs are state odometer and route, county, postmile.

LRS Measure: The value assigned to a particular location along a route based on a particular LRM rather than its x, y coordinate. Example measures could be 4.234 for the state odometer LRM and R12.321L for the Caltrans Postmile LRM.

Route: The linear geometry that represents a single named street or road or signed state route. Example routes are State Route 99 and K Street in Sacramento.

Route ID: The designation assigned to a route that uniquely identifies it from every other route in the LRS. The Route ID varies by linear referencing method. Example Route ID values by LRM for the state highway system (SHS) mainline and off the state highway system mainline are shown in the table below.

LRM		
All Roads	SHS_008._P	SD_CO_ANDERSON ST_P
State Odometer	008._R	N/A
Postmile	SD.008.R.R	N/A

Dual Carriageway (non-state highway mainline): A two-way facility with a curbed or positive barrier median or a median that is 1.2 meters (4 feet) or wider and occurring on 51% or more of a contiguous route segment (intersection to intersection). Secondary carriageways shall only occur on Functional Classes 3 through 6.

Competing LRS:
A competing LRS is defined as any digital representation of the road network that includes one or more LRMs representing Caltrans postmile, statewide odometer, or county odometer. It does not matter if the LRS is included as part of an existing application or is a standalone application. It does not matter if the LRS covers the entire state or only a portion of it. It does not matter if the geometry is based on land surveys.

Competing LRS Examples:
- The Integrated Maintenance Management System (IMMS) contains its own representation of the state highway network with county odometer and Caltrans postmile system LRMs.
- A Caltrans District has created a representation of the road network based on surveyed alignments and assigned postmile values along the alignments.

Not Competing LRS:
A linear referencing system whose sole purpose is to maintain a survey-based road network and district-wide engineering stationing linear referencing method that does not contain a representation of the Caltrans postmile system, statewide odometer, or county odometer.

Not Competing LRS Examples:
- A system that directly leverages source system of record or authoritative reporting source LRS web services.
- A Caltrans District created representation of the road network based on surveyed alignments whose only LRM is engineering stationing.
- Physical paddle markers placed on the roadside.

SOURCE SYSTEM OF RECORD:

State Highway System Mainline:
Caltrans' linear referencing Source System of Record for the state highway system mainline is the Transportation System Network (TSN) that is maintained by the Division of Research, Innovation and System Information (DRISI). TSN is tabular only and does not contain a geometric representation of the road network.

Non-State Highway System, Ramps and Connectors:
Caltrans' linear referencing Source System of Record for the non-state highway system, ramps and freeway-to-freeway connectors is the All Roads LRS that is maintained by DRISI.

AUTHORITATIVE REPORTING SOURCE:

State Highway System Mainline:
Caltrans' All Roads LRS maintained by the Division of Research, Innovation and System Information.

Non-State Highway System, Ramps and Connectors:
Caltrans' All Roads LRS maintained by the Division of Research, Innovation and System Information.

RESOURCES:

The Traffic Accident Surveillance and Analysis System (TASAS) Branch maintains the TSN database with highway inventory for all state highway facilities in California.
https://drisi.onramp.dot.ca.gov/traffic-accident-surveillance-and-analysis-system-tasas

The Linear Referencing Services (LRS) Branch maintains the geospatial representation of the California state highway system as described in the TSN database. The LRS Branch webpage provides information regarding available end user tools and documentation for the Roads and Highways Representational State Transfer Application Programming Interface (REST API) for applications needing direct access to the LRS.
https://gis.onramp.dot.ca.gov/linear-referencing-services

The Caltrans Postmile System guide that describes and illustrates the Caltrans Postmile System including Routes, Route Suffixes, Counties, Postmile Prefixes and Suffixes, Independent Alignments, Route Breaks and Equation Points in PDF and ArcGIS StoryMap formats.
https://gis.onramp.dot.ca.gov/linear-referencing-services

Postmile Web Query Tool is used to validate and/or determine postmile locations along the state highway system mainline using latitude/longitude, postmiles, or by clicking on a point on the map.
https://postmile.dot.ca.gov/ (public facing)
http://postmile-internal.dot.ca.gov/ (internal facing)

Tools and application development can access the Caltrans Roads and Highways REST API for the most current LRS.
https://gis.onramp.dot.ca.gov/randh-restapi

All Road Network of Linear Referenced Data (ARNOLD) Reference Manual from the Federal Highway Administration. This guidance document was published providing best practice information to state departments of transportation regarding how to construct an all roads linear referencing system.
https://www.fhwa.dot.gov/policyinformation/hpms/documents/arnold_reference_manual_2014.pdf

PRACTICE:

Currency of Data
State highway system data is updated in the TSN based on when the project as-builts are completed and staff are notified. The All Roads LRS makes periodic data extractions from the TSN and updates its representation of the road network accordingly. This process results in a lag between when a project is open to the public and when it is reflected in the TSN and the All Roads LRS. The state highway mainline portion of the LRS update schedule is described in its metadata as posted to the State Geoportal.

Non-state highway system data is updated on a periodic basis based on National Agriculture Imagery Program (NAIP) imagery releases and local agency provided geometry updates. The non-state highway system mainline portion of the LRS update schedule is described in its metadata as posted to the State Geoportal.

Data Formatting
Projects and other entities located on the state highway system can have multiple locations. In the small table below there are three projects, and two of the projects have multiple locations.

A common approach for this scenario is to combine the Counties into one field, the Routes into one field, and the Postmiles into one field. While this practice allows data to be stored in one row and is generally human-interpretable, it limits or precludes the ability to query, validate and otherwise use the postmile data with any postmile utilities.

The table below illustrates this scenario.

ProjectID	Cost	ProjectName	County	Route	Postmile
0417000363	$128,400,000	MacArthur Maze Bridges	ALA/ALA/ALA	580/580/880	46.521L/46.525R/R34.540L
0617000222	$7,800,000	I-5/SR-99 OC	KER	5	R15.823R
1017000113	$13,700,000	San Joaquin County I-5 Bridges	SJ/SJ	5/5	10.656/R21.447

The proper way to store multiple locations for a single entity is to store locations in a separate table where each discrete ***location*** can be stored in a single record. This requires a unique identifier upon which the two tables can be related. As an example, the table above can be separated into a Projects table and a Locations table. There is one record in the Projects table for each project, one record in the Locations table for each location, and the ProjectID can be used to relate the two tables.

Projects Table		
ProjectID	**Cost**	**ProjectName**
0417000363	$128,400,000	MacArthur Maze Bridges
0617000222	$7,800,000	I-5/SR-99 OC
1017000113	$13,700,000	San Joaquin County I-5 Bridges

Locations Table						
ProjectID	**Route**	**Route_Suffix**	**County**	**Postmile_Prefix**	**Postmile**	**Postmile_Suffix**
0417000363	580		ALA		46.521	L
0417000363	580		ALA		46.525	R
0417000363	880		ALA	R	34.54	L
0617000222	5		KER	R	15.823	R
1017000113	5		SJ		10.656	
1017000113	5		SJ	R	21.447	

Various Locations
The use of “Various”, “VAR”, “Var”, etc. to describe the location of projects decreases the usability and interoperability of data. It results in increased staff hours spent recreating individual location records to conduct analysis, map projects, and respond to questions from management. All source systems of record and authoritative reporting sources must eliminate the practice of maintaining records with “Various” field entries or generalized representations of location.

Generalized Location / Partial Location Listing
Generalizing location or partially listing locations is only acceptable under specific conditions:

- Legacy system only supports a limited number of location entries (e.g., three locations in CTIPS for a project)
- Output is a report or similar non-technical document where listing each location is impractical (e.g., CTC Agenda Book Item)

When a legacy system is updated, it must be enhanced to allow for unlimited location information to be maintained.

Generalized or partial location data must not be propagated across systems as though it was authoritative.

When a partial list of locations is displayed or provided in a report, it must include “,et al.” at the end of the list to indicate that there are other locations not listed that are associated with the item.

When necessary, possible generalizations could be:

- Southern/western most location to the northern/western most location for the route where the most individual locations reside
- Southern/western most location to the northern/eastern most location for the route where the largest portion of funding is spent
- Southern/western most location to the northern/eastern most location for the route with the lowest numeric designation

LRS Measure Rounding
Rounding measure values does not simply reduce the precision of the measure, it can result in invalid values, or collapse short From-To linear segments to have the same value and thus may confused as a point location.

Measure rounding is not appropriate where a specific “landmark” location (e.g., begin route, county line, end route, etc.) is known.

Example: SB 101 crosses the SB/SLO county line at PM 90.988. Rounding to two decimals results in an invalid location (SB 101 PM 90.99).

Example: PLA 028 begins at PM 0.085. If the postmile was rounded to the nearest tenth to be displayed in a report which was stated to be the beginning postmile of the route, a gap of 0.015 miles would result from the starting location designated in the TSN and shown in the LRS and what is reported. This is problematic if these values were then used to create a map of the roadway alignment where gaps in the network could result.

Note that rounding, then adding zeros in these cases does not fix the problem as SB 101 90.990 is still an invalid postmile and PLA 28 0.100 still results in the same 0.015-mile gap.

It is not technically necessary to add zeros to a postmile properly landing at one or two decimal places as 90.900 is the same as 90.9.

Measure data shall be managed to three decimal places to the greatest extent practical, where unable to do so, rounded values shall be confirmed as valid before committing to a database, used in reports, or generally shared.

Alignment

State Highway Mainline
The Caltrans LRS' geometric representation of the state highway mainline consists of full left and right alignments. The end user can specify whether a dataset will be mapped to the left, right or both alignments.

When data needs to be assigned to a particular "side of the road", the alignment must be specified. Without specification of alignment, an item may be duplicated when geometry is created and the item is generated on both left and right alignments. If assignment of the entry to a specific alignment of the geometry is required on a record-by-record basis then an Alignment field is required.

The LRS Alignment field is distinctly different than the notion of independent alignments as defined by the Caltrans postmile system and assigned in the TSN database using the postmile suffix of L and R. Independent alignments occur when a portion of the physical roadway alignment separates resulting in different lengths for each direction of travel.

Non-State Highway Mainline
The Caltrans LRS' geometric representation of non-state highway mainline consists of a single centerline geometry except in locations where the road is designated as dual carriageway. In dual carriageway locations, a second and parallel geometry is shown whose RouteId is assigned a "_S" suffix instead of the default "_P" suffix. Use of the primary and secondary carriageway designation as part of the RouteId makes the alignment field not applicable. Example: SAC_SAC_MAIN ST_P where P designates the primary carriageway or right side of the road in the direction of increasing measure value.

Storing Point and Linear Events
Location data should be managed in a consistent fashion to enable interoperability across systems and minimize errors when the same person enters or manages location data across multiple applications.

Point and Linear records can be stored in the same Locations table. Use the "Begin" fields to store point data or begin linear data. Filtering criteria can then be applied to separate out the point and linear events as needed.

Postmile Measures

The table below illustrates how point and linear location data can be intermixed and stored in the same table as well as showing how linear events that span multiple counties can be entered.

Locations Table

ProjectID	Route	RteSuf	Beg_County	Beg_PM_Prefix	Beg_Postmile	Beg_PM_Suffix	End_County	End_PM_Prefix	End_Postmile	End_PM_Sufffix	Alignment
0113000100	101		HUM		79.03	R			79.812		R
0113000100	101		HUM		78.429	L			79.825		L
0317000006	50		SAC		12.525		ED	R	1.785	R	R
0317000006	50		SAC		12.525				23.136		R
0317000006	50		ED		0			R	1.785	R	R
0417000363	880		ALA	R	34.54	L					L
0417000363	580		ALA		46.525	R					R
0417000363	580		ALA		46.521	L					L
0617000222	99		KER	L	0						
0617000222	5		KER	R	15.823	R					R
1017000113	299		SHA	G	24.087						
1017000113	5		SHA	M	29.303	L					L

Storing linear locations that span counties shall be split into one record per county, which allows the use of a single County field. Note that this can result in a small gap at the county line if the end postmile of the first record is not precisely the end postmile of that county.

Locations Table

ProjectID	RTE	RTE_SUFFIX	CO	PM_BEGIN_PREFIX	PM_BEGIN	PM_BEGIN_SUFFIX	PM_END_PREFIX	PM_END	PM_END_SUFFIX	PM_DATE
0317000006	50		SAC		12.525			23.136		5/25/2022
0317000006	50		ED		0		R	1.785	R	5/25/2022

LRS Measure Date
A date field should be maintained that records the date that the measure value was determined. This field can be helpful in determining if an invalid measure value is due to a data entry error or due to a change in the road network (e.g., a section of roadway no longer exists or has been realigned). The date can also be used to select a temporal version of the linear referencing system for mapping historic data.

Statewide Odometer and All Roads Measures
These LRMs do not reset their measures when crossing jurisdictional boundaries therefore linear events located using these measures crossing jurisdictional boundaries will always consist of a single record.

Latitude and Longitude
Staff may want to manage location through the use of latitude and longitude values. The use of latitude and longitude cannot directly calculate the distance along the roadway between two locations. Latitude and longitude values can be cumbersome to use in the field without use of a GPS device as compared to an odometer or postmile measure.

Though not a LRM that can be directly interacted with a LRS, coordinates can still be used to manage location and can be assigned a RouteID and measures based on the closest route to the coordinate (with caveats noted below). The use of a coordinate (point event) or set of coordinates (begin and end point of an event) can be helpful when All Roads or Odometer LRMs change with route changes. However, this is not necessary when using the Postmile LRM as it accounts for route changes over time through the use of the postmile prefix.

Caveats of managing location using coordinates:

1. Locating a coordinate (a point) on a LRS (a line) involves proximity. Rarely is the point exactly on a LRS route, which necessitates an acceptable distance tolerance (how close is considered "on the line").
    a. There are numerous locations where multiple routes may be within an acceptable distance threshold of the coordinate (most commonly at route intersections and grade-separated routes), and the closest route may not be the intended route.
    b. A coordinate located inside a curve along a very windy road may be closest to a location on the LRS route that is an unacceptable distance from the intended location.
2. Coordinates cannot provide the distance between two points along a given route without first being assigned a RouteID and measures.
3. Coordinates cannot provide linear geometry between two points along a given route without first being assigned a RouteID and measures.
4. One should take care in using coordinate pairs to reassign postmile values when a route changes alignment. It would be inappropriate to do so in certain cases such as historic crash data which would attribute crashes to a new segment of roadway which the crashes never occurred.
5. Care should be given when converting between linear referencing methods and coordinate pairs which could have different accuracies associated with them and that the conversion process could change those accuracies.

Accuracy
There may be a desire to use the LRS geometry directly or locating physical assets using the LRS for design purposes. How the LRS was created and maintained will determine appropriate use cases.

The Caltrans LRS measures are reported to the thousandths of a mile per Highway Performance Monitoring System requirements. The creation methodology and current horizontal accuracy of the Caltrans LRS is described in its metadata.

TIME FRAME:

This practice document shall take effect immediately and corporate datasets and their derivative works should leverage the ARS for validating postmiles, performing dynamic segmentation and other activities directly related to the linear referencing system and its products.

IMPLEMENTATION:

New Systems using Linear Referencing
All new applications or systems to be developed for Caltrans that will use road network linear referencing data must be designed to directly use the ARS.

Existing Systems using Linear Referencing
Implementation of this Practice Document may result in significant impacts to some existing systems requiring funding allocations to modify them to interface with the authoritative LRS maintained using Esri's Roads and Highways. Changes may be required to data formats and table structures, connections between systems, and the formatting of reports created from systems that are modified. In addition, there will likely be opposition to abandon existing competing LRSs due to past investments and familiarity that have to be overcome. The long-term benefits of a single representation of the road network and locations along it will outweigh the short term implementation costs of the Practice document.

Implementation of the Practice document will consist of three tasks:

1. Identification and remediation of competing linear referencing systems
2. Identification and remediation of Caltrans manuals, guidance and other documentation that is inconsistent with this Practice document
3. Identification and remediation recommendation of Caltrans enterprise systems that are inconsistent with this Practice document

Competing Linear Referencing Systems
Caltrans staff must develop and submit a plan to the Enterprise Data Steward Committee to sunset any and all competing linear referencing systems and create workplans to migrate systems and datasets to utilizing the ARS identified in this practice document. Any implementation activities at the system or tool levels shall utilize the version of the LRS managed using Esri's Roads and Highways platform.

As part of the initial implementation of this Practice Document, the Enterprise Data Steward Committee will identify competing and non-competing LRS's using the following process:

1. Create an inventory of existing systems and determine which utilize an LRS or are an LRS
2. Determine status of each system (sunset, continue to use)
3. Document feasibility of transitioning to the ARS
4. Develop cost estimate of transitioning to the ARS
5. Make transition/implementation recommendation
6. Submit recommendation to Enterprise Data and Geospatial Governance Board for approval of recommendation and action for its implementation

Inconsistent Manuals, Guidance, and Documentation
Caltrans staff must develop and submit an inventory of Caltrans manuals, guidance, and other authoritative documentation that is contrary to or otherwise inconsistent with the practices outlined in this document (e.g., Plans Preparation Manual only requires postmiles to be shown to one decimal place). The inventory must include the title of the document, the business area name responsible for its maintenance, the required update(s), and proposed update schedule. This listing is to be provided to the Enterprise Data and Geospatial Governance Board for approval and will then be submitted to the Enterprise Data and Geospatial Governance Council for implementation.

Inconsistent Enterprise Systems
Caltrans staff must develop and submit an inventory of Caltrans enterprise applications/systems that manage location data that is inconsistent with the practices outlined in this document and all relevant location data element

standards. The inventory must include the name of the enterprise application/system, the business area name responsible for its maintenance, the required update(s), cost to update, and proposed update schedule. This listing is to be provided to the Enterprise Data and Geospatial Governance Board for approval and will then be submitted to the Enterprise Data and Geospatial Governance Council for implementation.

ROLES AND RESPONSIBILITIES:

Enterprise Data Stewards and District Enterprise Data Governance Liaisons shall work to ensure competing LRS's are not created in the future by bringing potential items to the Enterprise Data Steward Committee for discussion and action.

Enterprise Data Stewards, District Enterprise Data Governance Liaisons, Business Data Stewards, Data Custodians and other identified staff shall assist with efforts to modify their practices and update their systems to utilize the authoritative LRS in their data management and quality practices, where applicable and as described under *Implementation* of this document.

Division Chiefs and Deputy District Directors shall, where applicable, direct and support staff to develop and implement workplans for migrating from competing linear referencing systems and instead utilize the identified linear referencing SSOR and ARS.

APPROVAL:

Chad Baker Digitally signed by Chad Baker
Date: 2023.06.14 11:44:00 -07'00' Date: _____

Chair, Enterprise Data and Geospatial Governance Board or Designee
California Department of Transportation