Vermont Agency of Transportation

Intersection MIRE Data

Vermont's Approach to a Complete Intersection Inventory

SAFETY DATA CASE STUDY

FHWA-SA-22-005

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16. Abstract The Model Inventory of Roadway Elements (MIRE) Fundamental Data Elements (FDEs) are a subset of roadway, intersection, and interchange data elements that support robust safety management. Federal statute requires State DOTs to collect the MIRE FDEs by September 2026. This case study presents the Vermont Agency of Transportation’s (VTrans’) approach to develop a statewide intersection inventory representing the State’s entire public road network. This involved a combination of automated and manual collection that helped VTrans represent these complex operational features, as well as partnerships between the State and its regional planning commissions. Linear referencing serves as the foundation for the intersection inventory, and Vermont’s data collection framework will allow VTrans to maintain quality data over time. In addition to meeting federal data requirements, Vermont’s intersection data initiative will support safety performance function development and systemic safety analysis.

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Acronyms

Acronym	Description
AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
DDSA	data driven safety analysis
DOT	department of transportation
FDE	Fundamental Data Elements
FHWA	Federal Highway Administration
GIS	geographic information systems
GTFS	General Transit Feed Specification
HPMS	Highway Performance Monitoring System
HSM	Highway Safety Manual
LRS	linear referencing system
MIRE	Model Inventory of Roadway Elements
RPC	regional planning commission
SPF	safety performance function
VTrans	Vermont Agency of Transportation

Table of Contents

List of Figures

Executive Summary

The Model Inventory of Roadway Elements (MIRE) Fundamental Data Elements (FDEs) are a subset of roadway, intersection, and interchange data elements that support robust safety management. Federal statute requires State DOTs to collect the MIRE FDEs by September 2026. This case study presents the Vermont Agency of Transportation's (VTrans') approach to develop a statewide intersection inventory representing the State's entire public road network. This involved a combination of automated and manual collection that helped VTrans represent these complex operational features, as well as partnerships between the State and its regional planning commissions. Linear referencing serves as the foundation for the intersection inventory, and Vermont's data collection framework will allow VTrans to maintain quality data over time. In addition to meeting federal data requirements, Vermont's intersection data initiative will support safety performance function development and systemic safety analysis.

Introduction

In 2019, the Federal Highway Administration (FHWA) completed the second U.S. Roadway Safety Data Capabilities Assessment (FHWA, 2019). This nationwide survey documented the safety data processes, policies, and procedures of all 50 States plus Washington D.C. and Puerto Rico. This survey not only highlighted the state-of-the-practice with respect to all phases of safety data collection, management, integration, and analysis, but it also revealed that State Departments of Transportation (DOTs) were eager to improve their capacity for data management and integration.

This case study presents the Vermont Agency of Transportation's (VTrans') approach to develop a statewide intersection inventory representing the State's entire public road network. VTrans used a combination of traditional data sources, including the State's linear referencing system (LRS), non-traditional data sources, and crowd-sourced data collection. This process also used strong partnerships with regional planning commissions (RPCs) across the State to develop data on local roads. These data will fulfill two critical agency needs:

1. Satisfy Federal data collection requirements for all public roads, and
2. Support robust, predictive data-driven safety analysis (DDSA) on Vermont's roads.

Purpose and Need

The Model Inventory of Roadway Elements (MIRE) Fundamental Data Elements (FDEs) are a subset of roadway, intersection, and interchange data elements that support robust safety management (Lefler et al., 2017). Federal statute requires State DOTs to collect the MIRE FDEs by September 2026.[*] In addition to Federal requirements, Vermont's intersection data initiative will support several key safety analysis needs, including safety performance function (SPF) development to predict crash frequency, as well as systemic safety approaches that address risk. VTrans' Operations and Safety Bureau and Mapping Section collaborated with local safety data stewards to collect and maintain these data for all intersections on the State's public roads.

Target Audience:

- Executive Leadership.
- Information Technology Staff.
- Data Managers, Analysts, and Stewards.
- Local Technical Assistance Program Managers and Staff.
- State, Regional, and Local Planning Staff.

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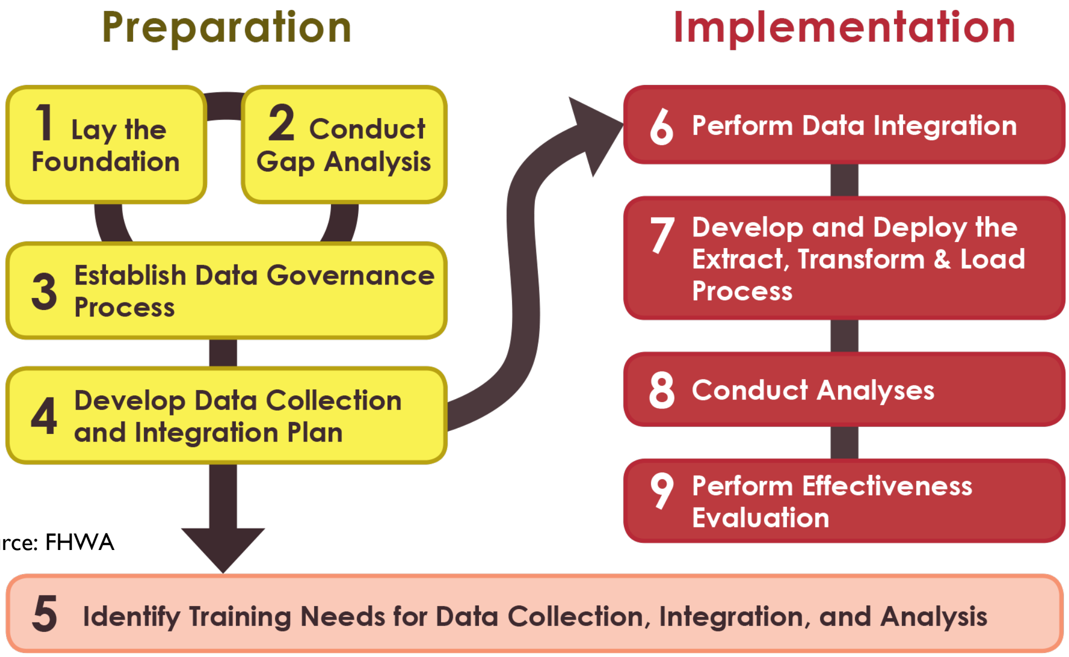
[*] "States shall have access to the FDEs on all public roads by September 30, 2026. [23 CFR 924.11(b)]" (FHWA 2016).

Data Requirements and Planning

Data integration is a collaborative process that requires data managers, data stewards, and end users to coordinate available capabilities with agency needs (figure 1; Scopatz et al., 2016). Vermont's data collection approach began in 2017 with a safety data implementation plan supported through FHWA's DDSA technical assistance program.



Source: FHWA

Figure 1. Chart. Nine-step process for safety data integration (Scopatz et al., 2016).

Key components of the implementation plan included an assessment of existing data sources that could support analytical methods defined in the First Edition of the American Association of State Highway and Transportation Officials (AASHTO) Highway Safety Manual (HSM). This assessment informed a gap analysis for data that still needed to be collected. The implementation plan covered all facility types analyzed in HSM (e.g., segments, intersections, intersection approaches, and ramps), and the gap analysis revealed that VTrans lacked most MIRE FDEs and other supplementary information used in HSM analysis. This was particularly true for MIRE FDEs for intersections and intersection approaches.

The gap analysis and resulting implementation plan provided the framework for a comprehensive approach to intersection data collection. Clearly defined requirements improved collection efficiency and supported the broad array of needs for Vermont's safety management program.

The key data elements, required as part of the MIRE FDE program or recommended in the HSM, that needed to be derived or collected at intersections and intersection approach legs included:

Intersection Data Elements

- Intersection type (e.g., roadway/roadway or roadway/railroad crossing).
- Intersection geometry (e.g., Y-, T-, or four-leg intersection).[*]
- Traffic control devices present.[*]
- Total number of bus stops within 1,000 ft of intersection location.
- Total number of alcohol sales establishments within 1,000 ft of intersection location.
- School zone indicator (within 1,000 ft of intersection).
- Intersection lighting indicator.
- Intersection skew angle.
- Roundabout lane count and width (if applicable).

Intersection Approach Leg Data Elements

- Major/Minor route name and type.[*]
- Major/Minor route milepost.[*]
- Route annual average daily traffic (AADT) for each approach leg.[*]
- Approach speed limit for each approach leg.
- One-way/two-way direction of travel at approach.
- Number of through lanes and exclusive right- and left-turn lanes.
- Exclusive turn-lane length.
- Median type present (e.g., undivided, depressed, etc.).
- Traffic control device present.
- Left-turn phasing (if applicable).
- Right-turn-on-red and other turn prohibitions.
- Total number of lanes that would be crossed by a pedestrian.

Appendix A contains a brief list of select values collected to support categorial data elements.

Data Collection Approach

VTrans' data collection approach combined a practical application of the State's existing safety data with a custom data collection effort using geographic information systems (GIS). This allowed Vermont to develop an efficient workflow and focused long-term maintenance of the dataset. VTrans refined its approach through an initial collection effort on federal-aid roads. This included collection for State-to-State, State-to-local, and State-to-major traffic generator

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[*] Denotes a data element required as part of MIRE FDEs.

driveway (such as shopping malls) intersections. With the core MIRE FDEs and analysis needs met for these facilities, the agency applied the lessons learned to engage RPCs to assist with intersections on local roads.

Intersection Framework: Data Integration

Vermont's LRS forms the foundation of the inventory. VTrans used a system of "nodes" (i.e., individual points) and "legs" (i.e., linear features leading to points) to define where centerlines intersect and the position of approach legs with respect to the street network. A series of IDs associate individual legs to a single node (or series of nodes) to represent the spatial dimensions of an individual intersection. These IDs also serve a data maintenance purpose, as these IDs can track the orientation of related nodes and legs (i.e., an intersection) along Vermont's LRS network. This allows VTrans to integrate data stored using the LRS with intersection locations (e.g., route names, AADT by approach, ownership by approach, etc.) and generate much of the data needed for maintenance analysis. Route log points, associated with these nodes, allow VTrans to track intersections as the agency edits its LRS or refines its associated data over time (figure 2); this is especially useful in quality control later in the process.

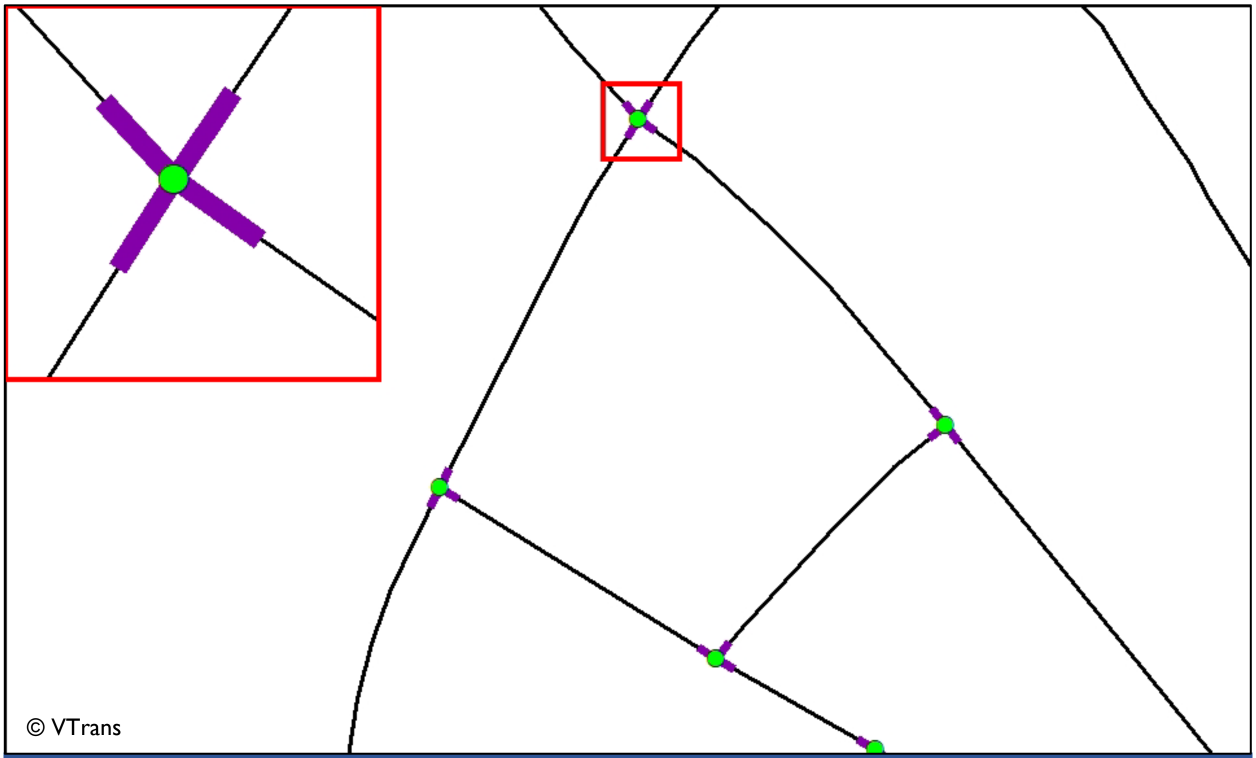
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Figure 2. Graphic. Example of VTrans' intersection framework.

Intersection Definition: Simple and Complex

Although Vermont's framework is sufficient to delineate and track most intersections in the State, the combination of nodes and legs are still simple representations. These data alone may not capture real-world nuances in the operational and safety performance of intersections. To support complex HSM-based analyses, VTrans adapted the node and leg relationships to create "simple" and "complex" intersections. Simple intersections are locations where intersecting roads are represented by a single centerline (figure 3); a single node with three or more legs comprise a simple intersection.

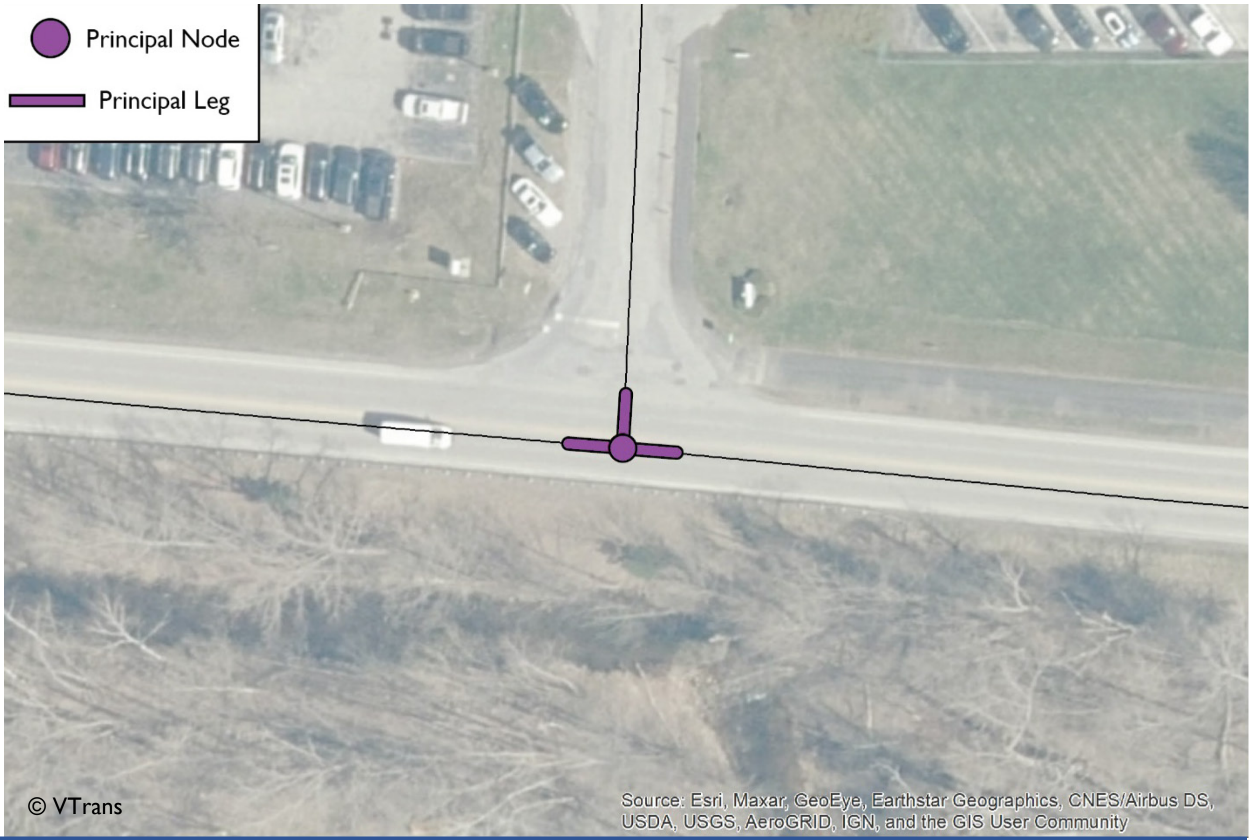
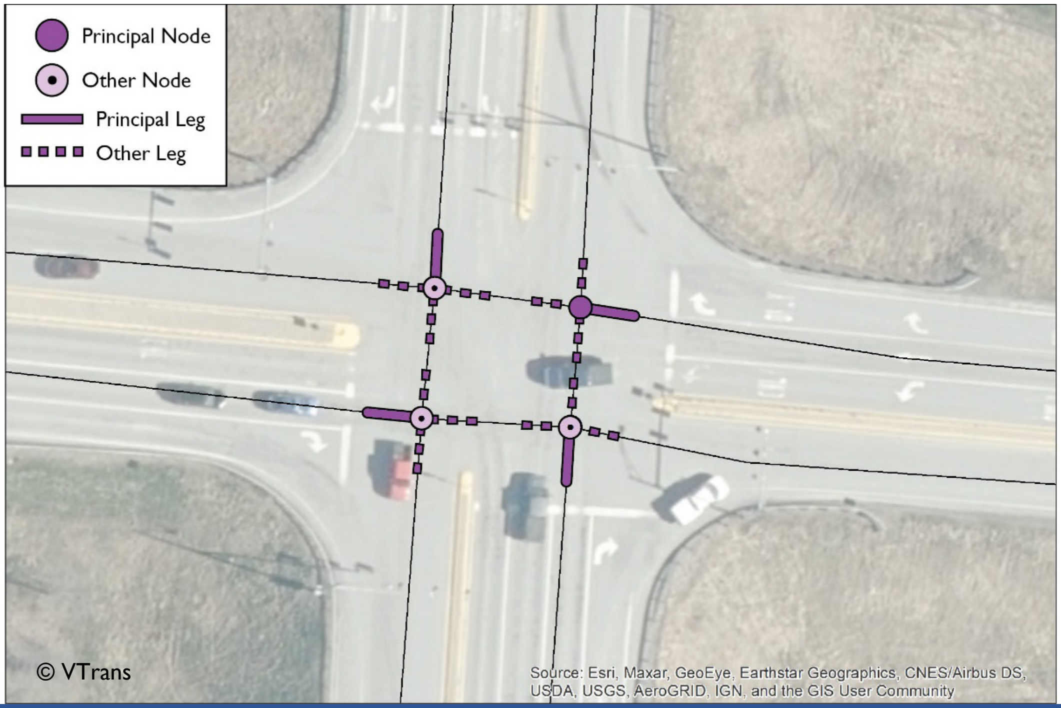


Figure 3. Graphic. Example of a simple intersection.

However, there are exceptions to this rule, as some centerlines represent one direction of travel on a divided highway, channelized turn lanes, or other uncommon designs (e.g., roundabouts). To accommodate these intersections within the statewide framework, VTrans devised a principal node system to capture complex intersections. Each node that participates in an intersection is tied to a single principal node with a principal ID; each participating node has its own ID, as well as the principal node ID. The principal node acts as the single source of information for the entire intersection, although the constellation of nodes allows VTrans to track an entire intersection on its LRS. Similarly, principal legs allow VTrans to track the primary location where approach information is stored (figure 4). This complex intersection approach has two purposes:

1. A wide array of intersection types can be flexibly modeled without creating exceptions or deviations from the original framework.
2. By preserving all individual nodes and linear approaches (not just the principal locations), VTrans can track changes over time and continue to tie updated data to the broader, complex intersection.



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Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 4. Graphic. Example of a complex intersection.

Piloting MIRE Data Collection: Federal Aid Roads

While many intersection data elements, such as the presence of lighting, exclusive turn lanes, turn prohibitions, and left-turn signalization had to be collected manually (using photo logs and street-level imagery), some data elements could be derived automatically.

Examples of automatically derived data elements include:

- General Transit Feed Specification (GTFS) to identify transit stops.
- Vermont's Division of Liquor Control Alcohol to locate sales establishments.
- Vermont Agency of Education to locate Kindergarten through 12th grade schools, including private schools.

The data collection process supported quality control checks. For example, if a data collector indicated that a protected left turn was present at an intersection approach, but no exclusive left-turn phase was present, analysts knew to verify on-the-ground conditions. By combining manual collection with the automated framework, VTrans established a multi-layer process for collecting and verifying intersection information.

VTrans began data collection on the State's federal-aid network. These intersections have the most comprehensive data requirements, and many of these locations represent the most complex designs in the State. As a result, they also tend to have the highest priority for safety improvements. VTrans piloted a mix of automated and manual data collection on federal-aid roads in the City of Brattleboro in southeastern Vermont. This location presented an opportunity to test several unique circumstances, including:

- **Intersections with more than four approaches.** This included mapping complex intersections that might form a five-point intersection or a roundabout. VTrans accommodated these as domain values for complex intersections.
- **Intersections at railroad crossings.** Although Vermont's LRS does not split at isolated railroad crossings, VTrans noted locations where roadway intersections also involved a railroad crossing.
- **Complex intersections and associated principal features.** VTrans used principal features for simplifying intersections into concise models for analysis (i.e., three principal legs representing each approach to the intersection). As a result, tools and methods for associating basemap data with principal features were essential.

Other examples of key circumstances can be found in the Challenges section of this case study. After reviewing the Brattleboro results and assessing potential outliers, VTrans formalized its approach to special circumstances and expanded its data collection to the entire federal-aid network. With nearly 18,000 intersections and over 70,000 principal approach legs collected on the State's federal-aid network complete, the State used a collaborative approach to supplement local intersection collection.

Local Data Collection: Engaging Regional Agencies

VTrans documented its formal approach based on its experience with federal-aid roads, and compiled guidance for data stewards at local RPCs. RPC analysts started with priority locations first (i.e., paved roads with all legs designated with a local functional classification). Like the federal-aid network, VTrans was able to derive some of the intersection approach data elements from the State's Highway Performance Monitoring System (HPMS) submittals. VTrans prioritized validating existing data elements before requesting entirely new information from stakeholders:

- Complex intersection status.
- Intersection ownership.
- Intersection type (e.g., roadway/roadway or roadway/railroad crossing).
- Geometry (e.g., Y-, T-, or four-leg intersection).
- Traffic control device(s) present.
- Major/minor leg approach designation.
- Posted speed limit by approach.
- Direction of travel (e.g., one-way or two-way).
- Turn prohibitions.
- AADT.

RPC analysts also helped validate or correct information in VTrans' databases (e.g., one-way operation or street names). VTrans established a method to edit existing data or obtaining new data from RPC stakeholders via the State's ArcGIS Online™ organizational account. This method allowed VTrans to effectively control access to the State's data while also providing a direct link to local stakeholders. The system prevented RPC users from editing or altering intersection geometry data, but they could update feature attributes and provide comments. VTrans periodically reconciled this externally edited version with the agency's internal database and reviewed for quality.

Quality Assurance and Quality Control

The LRS and formal intersection data structure allowed VTrans to run a host of internal quality checks. For instance, GIS topology, or the spatial relationships between the digital nodes, approach legs, and the base LRS, provides a framework to facilitate the transfer of data between the LRS and the associated intersection elements. Information such as AADT and ownership can be readily aggregated and updated as needed. Furthermore, VTrans analysts can use the linear reference measure (i.e., milepoint) of underlying calibration points, which are associated with intersection nodes, to accurately locate (or move) intersections as changes are made to the LRS. This helps VTrans analysts track node locations as the LRS is calibrated over time.

VTrans uses the data structure to validate MIRE FDEs and other roadway data collected by local stakeholders. Logic checks can alert VTrans to irregularities in intersection node or approach values. These checks can be characterized as attribute- or geometry-based.

Examples of attribute-based checks might include:

- An intersection node might indicate a four-way intersection, but only three approach legs contained data; this could represent an erroneous data entry.
- An approach leg might include a median type other than undivided, but it is also classified as representing one-way traffic.
- Domain values (i.e., categorical values) across both nodes and approach legs are consistent with documentation; this is essential for maintaining accurate queries.

Geometry-based checks are more important for the underlying integrity of the data. Examples of geometry-based checks include:

- Nodes and approach legs are spatially contiguous and synced with Vermont's all roads basemap.
- Approach legs intersect at a single node point; this is essential to maintain synchronicity during calibration activities.
- The number of nodes and approach legs for complex intersections are consistent over time; if nodes or approach legs are missing, this may indicate fundamental changes to the physical road or LRS network.
- The position of nodes relative to upstream and downstream nodes on the network; deviations from expectations may indicate fundamental changes in the LRS that should be tracked.

Although these checks do not necessarily correct the potential issue automatically, they can be a useful tool for efficiently managing errors in the dataset.

Project Status to Date

Vermont completed MIRE FDE data collection for the State's federal-aid system in early 2020. VTrans plans to develop a complete inventory of MIRE FDEs for the entire State network by fall 2022. The State is currently expanding beyond these minimum requirements, collecting data for all intersections regardless of road ownership. Although there is not an anticipated date for completion as of this case study, these data would include unpaved town highways and legal trails.

Challenges

VTrans' framework provides a sustainable method for acquiring, storing, and maintaining intersection data on the State's public roads. As the agency refines its LRS and attribute data over time, the intersection inventory will reflect this evolution. Still, these data are representations of real-world infrastructure, and they may not be able to capture every contingency or operational characteristic of an intersection.

VTrans noted several challenges and key considerations during the data collection process, all of which VTrans has identified a temporary or permanent solution, that might be useful for other DOTs to consider:

- Not all instances of intersecting GIS centerlines represent physical intersections and conflicts between traveling vehicles. For instance, nodes can denote grade-separated crossings or the beginning and endings of median splits.
    - Although VTrans does not use these nodes as part of the intersection attribute inventory, the agency flags and retains the locations for quality control purposes and for potential future enhancements (e.g., a routable GIS network).
- Commercial and private driveways, as well as other traffic generators, were not typically represented in the State's LRS; however, they still represent an operational leg of an intersection. VTrans records these locations as "leg exceptions."
    - Leg exceptions provided useful context for quality control checks, as four-leg intersections may only have three approaches represented and accounted for in the LRS; with leg exceptions, VTrans had confidence that all legs were accounted for in subsequent checks.
    - VTrans plans to digitize legs at major traffic generators and driveways to capture non-HPMS traffic information and complete the intersection model.
- Major and minor routes can typically be defined by associating AADT with route IDs to sort leg approaches by unique route ID and decreasing AADT. However, there are several unique circumstances that require additional considerations when defined through automation:
    - Intersections where a single route represents two perpendicular legs (i.e., the route makes a 90-degree turn at the intersection).
    - Intersections with three or more routes at leg approaches (e.g., intersections where one route ends, and another begins).
    - Intersections where AADT is estimated on one or more of the side streets, and this might be higher than the observed AADT on the mainline.
    - VTrans applied a series of checks that denoted if the legs with the highest traffic counts were closer to 90 or 180 degrees apart from each other and of the same route name. Although this did not remove the need for visual checks in all cases, this added confidence to automated processes.
    - If VTrans made any manual edits, these situations are typically fixed long-term.
- Two, three-leg intersections in close proximity to one another could be considered one offset intersection or two separate intersections. Data managers and engineering practitioners should coordinate to determine the most appropriate definition and standard in these cases.

    - A key indicator of whether these should be one or two intersections is the coordination of traffic controls on all approaches (i.e., does the traffic signal treat all approaches as one intersection or two separate intersections).

Finally, VTrans can efficiently translate data between the existing road characteristic databases maintained by the DOT (e.g., HPMS) and the intersection inventory via the LRS. However, changes to real world conditions and physical infrastructure represent a more difficult challenge for data maintenance. Coordination with local stakeholders represents the best method for VTrans to maintain these data long term.

Conclusions

Vermont's approach to intersection data collection has produced a sustainable framework for collecting and maintaining MIRE FDEs and has supported the roadway safety management process. The LRS framework allows VTrans to maintain the inventory spatially, integrate other agency data with the inventory, and streamline many of the quality control checks to promote data integrity. Although there are challenges associated with representing complex real-world traffic and operational conditions in a static data schema, VTrans' partnership with RPCs provides a method for keeping the inventory current.

Appendix A: Key Categorical Attribute Values

Intersection Node Data Elements

Intersection Type

- R1 - Roadway/roadway (not interchange related).
- R2 - Roadway/roadway (interchange ramp terminal).
- R3 - Roadway/pedestrian crossing (e.g., midblock crossing, pedestrian path or trail).
- R4 - Roadway/bicycle path or trail.
- R5 - Roadway/railroad grade crossing.
- R6 – Other.

Intersection Geometry

- 1 - Tee intersection - Two or more roadways intersect at grade in a Tee intersection.
- 2 - Y intersection - Two or more roadways intersect at grade in a Y intersection.
- 3 - Four-leg intersection - Two or more roadways intersect at grade in a four-leg intersection.
- 4 - Traffic circle/roundabout - Two or more roadways intersect at grade in a traffic circle or roundabout.
- 5 - Multileg intersection, five or more legs - Two or more roadways intersect at grade in a multileg intersection of five or more legs.
- 0 - Other - Two or more roadways intersect at grade in another intersection type.
- 99 - Unknown - Two or more roadways intersect at grade in an unknown intersection type.

Traffic Control Devices Present

- 1 - No control - No Traffic control at intersection.
- 2 - Stop signs on cross street only - Traffic control at intersection consists of stop signs on cross street only.
- 3 - Stop signs on mainline only - Traffic control at intersection consists of stop signs on mainline only.
- 4 - All-way stop signs - Traffic control at intersection consists of all-way stop signs.
- 5 - Two-way flasher (red on cross street) - Traffic control at intersection consists of two-way flasher (red on cross street).
- 6 - Two-way flasher (red on mainline) - Traffic control at intersection consists of two-way flasher (red on mainline).
- 7 - All-way flasher (red on all) - Traffic control at intersection consists of all-way flasher (red on all).
- 8 - Yield signs on cross street only - Traffic control at intersection consists of yield signs on cross street only.

- 9 - Yield signs on mainline only - Traffic control at intersection consists of yield signs on mainline only.
- 10 - Other non-signalized - Traffic control at intersection consists of other non-signalized.
- 11 - Signals pre timed (2 phase) - Traffic control at intersection consists of signals pre timed (2 phase).
- 12 - Signals pre timed (multi-phase) - Traffic control at intersection consists of signals pre timed (multi-phase).
- 13 - Signals semi-actuated (2 phase) - Traffic control at intersection consists of signals semi-actuated (2 phase).
- 14 - Signals semi-actuated (multi-phase) - Traffic control at intersection consists of signals semi-actuated (multiphase).
- 15 - Signals fully actuated (2 phase) - Traffic control at intersection consists of signals fully actuated (2 phase).
- 16 - Signals fully actuated (multi-phase) - Traffic control at intersection consists of signals fully actuated (multiphase).
- 17 - Other signalized - Traffic control at intersection consists of other defined signalized.
- 18 - Roundabout - Traffic control at intersection consists of roundabout.
- 99 - Unknown - Unknown traffic control at intersection.

Intersection Approach Leg Data Elements

Major/Minor Route Type

- I - Interstate - Route category interstate.
- US - US route - Route category US route.
- SR - State route - Route category state route.
- BR - Business route - Route category business route.
- BL - Business loop - Route category business loop.
- SP - Spur route - Route category spur route.
- CR - County road - Route category county road.
- TR - Township road - Route category township road.
- L - Local road - Route category local road.
- \- Other - Route category other.
- X - Unknown - Route category unknown.

Median Type

- 1 - Raised median with curb - Intersection median type is a raised median with curb.
- 2 - Depressed median - Intersection median type is a depressed median.
- 3 - Flush paved median [at least 4 ft in width] - Intersection median type is a flush paved median, at least 4 ft in width.
- 4 - Other divided - Intersection median type is classified as other divided.
- 5 - Undivided - Intersection median type is undivided.
- 0 - Other - Intersection median type is classified as other.
- 99 - Unknown - Intersection median type is unknown.

Left-Turn Phasing

- 1 - Protected left-turn - Protected left-turn phasing provided on the approach.
- 2 - Protected/permitted left-turn - Protected/permitted left-turn phasing provided on the approach.
- 3 - Permitted left-turn - Permitted left-turn phasing provided on the approach.
- 4 - No left-turn phase - No left-turn phasing provided on the approach.
- 98 - Not applicable - Left-turn phasing is not applicable on the approach.
- 99 - Unknown - Unknown left-turn phasing provided on the approach.

Turn Prohibitions

- 1 - No left turns any time - Left turns are prohibited at all times for vehicles leaving the approach.
- 2 - No left turns during specific times - Left turns are prohibited during specific times for vehicles leaving the approach.
- 3 - No right turns any time - Right turns are prohibited at all times for vehicles leaving the approach.
- 4 - No right turns during specific times - Right turns are prohibited during specific times for vehicles leaving the approach.
- 5 - No U turns - U turns are prohibited for vehicles leaving the approach.
- 6 - Other - Other prohibitions apply for vehicles leaving the approach.
- 98 - No turn prohibitions - No turn prohibitions for vehicles leaving the approach.
- 99 - Unknown - Unknown prohibitions for vehicles leaving the approach.

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