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16. ABSTRACT

The report resents the development and evaluation of a Smart Work Zone application for California, designed to enhance safety and efficiency in work zones through improved data collection, processing, and dissemination. The system delivers accurate work zone geometry and metadata in the Work Zone Data Exchange (WZDx) format, supporting both human and automated users. It consists of two main components: the Work Zone Server, which stores and serves data via an API, and the Mapping Tool, which refines work zone geometry using manual edits or automated inference from video and map data.The project rejected integration with the Crash Avoidance Metrics Partners (CAMP) tool due to usability and accuracy limitations. Instead, it focused on leveraging datacam streams and smart cones for live updates, expanding data sources, and improving real-time precision. The aim is to transition from static to dynamic, cloud-based dissemination of high-fidelity work zone data, enabling safer and more efficient travel through active work areas.Key recommendations for Caltrans include improving the precision, granularity, and timeliness of work zone data, especially spatial boundaries, temporal information, and worker presence. The report emphasizes the importance of integrating multiple data sources, real-time updates, and confidence scores to support emerging mobility technologies and comply with national data sharing standards. Future work should prioritize mechanisms for timely updates on accurate work zone geometry and real-time worker presence, utilizing technologies such as dashcam video streams and smart cones to enhance situational awareness and roadway safety

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Improving the Safety and Efficiency of Work Zones in California

Final Report

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July 23, 2025

Project Summary

This report by California Partners for Advanced Transportation Technology (California PATH) details the development of a Smart Work Zone application designed to enhance the safety and efficiency of work zones by improving data collection, processing and dissemination. The system enables the structured delivery of accurate work zone geometry and metadata in the Work Zone Data Exchange (WZDx) format, supporting both human and automated users.

The Smart Work Zone system comprises two core components: the Work Zone Server, which stores and serves data through an Application Programming Interface (API), and the Mapping Tool, which refines the geometry of the work zone using manual edits or automated inference from video and map data. The refined work zone data are made available in the WZDx v4.2 format.

The project rejected integration with the Crash Avoidance Metrics Partners (CAMP) tool (developed under FHWA sponsorship) due to usability and accuracy limitations, such as manual data entry, lack of real- time integration, poor interface design, and lack of support in the last five years.

Key future directions include taking advantage of datacam streams and smart cones for live updates, expanding data sources, and improving real- time precision. The aim is to transition from static to dynamic cloud- based dissemination of high-fidelity work zone data that enables safe and efficient travel through active work areas.

1 Introduction

In this project, California PATH developed and demonstrated a Smart Work Zone application to enhance work zone data collection and dissemination. The deliverables allow users to obtain California work zone locations, geometry, and lane configuration via a cloud interface. Work zone information is distributed in the Work Zone Data Exchange (WZDx) format, enabling easy access to information via the national standard. The main data source of the work zone metadata is Caltrans' Lane Closure System (LCS). Since the LCS lacks detailed lane- level geometry information, the research team developed a Work Zone Mapping tool that extracts work zone geometry based on video data from dashcams. Once the geometry is obtained using our artificial intelligence (AI) video image processing model, it is fused to the existing work zone records, resulting in an enriched data set ready for user queries. The work zone application helps connected automated vehicles understand the work zone operation based on the structured data we provided. It allows automated vehicles to plan routes safely and efficiently through complex work zones.

The related work of state and regional transportation departments (DOTs) is listed below.

Colorado DOT implemented integrated planned and real- time work zone data using WZDx to dynamically update traveler information systems and roadway management tools. This includes merging data from maintenance vehicles and worker presence apps to improve accuracy. The implementation focuses on improving the quality of the data, addressing issues such as directionality mismatches and road event inconsistencies. [6]

North Carolina DOT developed a WZDx Translator to map data fields of the internal work zone (e.g., road names, lane closures) to the WZDx specification, enabling interoperability with third- party applications. [5]

California and San Francisco Bay Area explored the adoption of WZDx for the readiness of CAVs and inter- jurisdictional collaboration. The projects include aggregating work zone data feeds from multiple agencies to improve regional coordination. [5]

Maricopa County, Arizona utilized WZDx in connected work zone applications to share real- time data on lane closures and speed limits with navigation systems such as Waze. [4]

Iowa DOT implemented a centralized data center for the work zone to streamline data collection and sharing between jurisdictions, improving operational efficiency and safety. [4]

Florida DOT got involved in CWZ standardization efforts to allow vehicle- to-infrastructure (V2I) communication, such as dynamic speed adjustments and queue warnings in work zones. [7]

Transition to Connected Work Zones (CWZ)

- The CWZ Standard Committee (including representatives from one.network, USDOT, and state DOTs) is refining WZDx into a static specification by 2025 to encourage broader adoption. [8]- Ver-Mac and one.network provide hardware/software solutions that push WZDx-compliant data to navigation apps (e.g., Waze) and connected vehicles. [10]- Key enhancements in CWZ include: 1) Worker presence detection: Sharing confidence levels about worker locations; 2) Smart work zone devices: Integrating data from arrow boards, cameras, and dynamic message signs. [4]

The rest of this report is organized as follows.

- Section 2 reviews the CAMP tool for work zones and explains why we ended up not using it.- Section 3 gives a high-level description of the software developed in the current project, introducing two major components: the Work Zone Server and the Mapping Tool.- Section 4 describes the Work Zone Server.- Section 5 presents the Mapping Tool.- Section 6 offers recommendations to Caltrans on the accuracy of the reporting of WZ information.- Section 7 concludes the report.

The source code developed for this project can be found here [2]: https://github.com/ucbtrans/ucbwzdx.

2 CAMP Tool and its Relationship to Current Project

The CAMP tool in the context of work zones refers to software developed by Crash Avoidance Metrics Partners (CAMP) LLC in collaboration with the Federal Highway Administration (FHWA). This tool, also known as the RSZW / Work Zone Software Toolchain, is designed to assist state and local Departments of Transportation (DOTs) in generating and managing digital information about work zone lane configurations and related changes for connected vehicle (CV) environments. [3]

The relationship of the CAMP tool to the WZ information is as follows:

- Purpose: The CAMP toolchain enables the creation of standardized digital descriptions of work zones, including lane closures, speed reductions, and lane drops. This information is critical for supporting infrastructure-to-vehicle (I2V) communications, which broadcast real-time work zone data to connected vehicles.- Functionality: The tool helps agencies populate messages that can be broadcast on the road to vehicle systems, providing drivers with timely warnings and information on upcoming work zones and their specific configurations.- Deployment: The toolchain is available for agencies to download and use, with the goal of broad testing and feedback to refine its capabilities. It is not a final commercial product, but an evolving resource that aims to improve the quality and consistency of work zone data for connected and automated transportation systems.- Target users: State and local DOTs, researchers, consultants, and vendors working in cooperative automated transportation and connected work zone management.

Originally, we planned to integrate our mapping tool used for the boundary refinement of the work zone with the CAMP tool. However, after a subsequent evaluation of the CAMP tool, we found a series of limitations that made us decide against such integration. Specifically,

- Manual data entry and human dependency: The tool relies on users to manually draw lane closures and input metadata, increasing the potential for human error, inconsistent data quality, and delayed updates.- Limited real-time capabilities: It lacks native support for dynamic or mobile work zones. There is no integration with real-time data sources, such as Global Positioning System (GPS) from maintenance vehicles or smart cones.- Usability and interface design: The user interface is not intuitive for nontechnical users. Basic operations often require training, and the tool has limited mobile friendliness for field use.

- Inadequate geospatial precision: The geometry of the work zone may be imprecisely drawn and is not snapped to a known base map. Lane-level accuracy, which is critical for connected vehicle applications, is difficult to ensure.- Lack of integration with agency systems: The tool is not designed to integrate easily with existing transportation management or permit systems, which limits its operational use.- Prototype-level maturity: As a proof-of-concept, the tool lacks the scalability and reliability required for statewide or production deployments.- Absence of built-In quality assurance: The tool does not provide automatic validation of data against the WZDx schema or flag missing or incorrectly formed data fields, requiring external validation tools.- Lack of support: The CAMP tool has not been developed since 2019.

3 Smart Work Zone Application Overview

The functional diagram of the smart Work Zone (WZ) application is presented in Fig. 1.

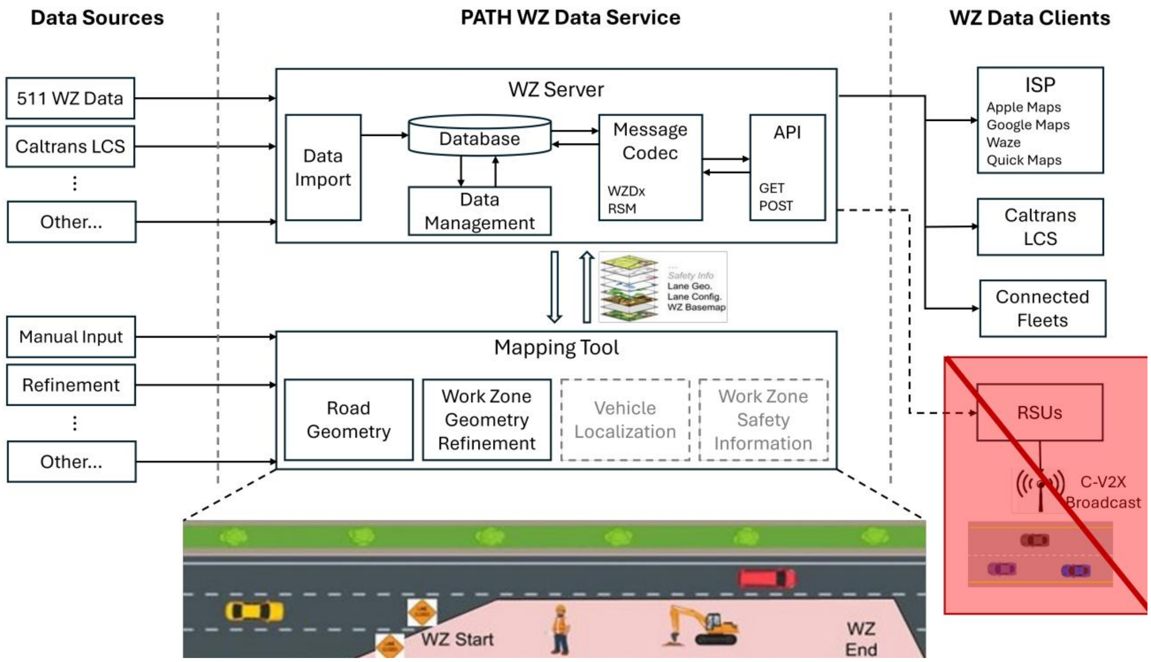

Fig. 1. Smart Work Zone application functional diagram.

The system has two major components:

1. WZ Server - responsible for collecting, storing, updating, and serving the WZ data.

2. Mapping Tool - responsible for refining the geometry of WZs and for augmenting WZ data with available safety information.

Originally, the WZ server was intended to upload Road Safety Messages (RSMs) [1] with information about nearby WZs to available Roadside Units (RSUs) with the idea in mind that these RSUs would then broadcast these messages and connected vehicles driving by them would receive this information. However, in the course of the project, it was decided not to implement this part of the WZ server as it would have very limited use due to the shortage of the required road infrastructure. From conversations with vehicle manufacturers, we learned that they do not intend to rely on roadside infrastructure, but rather expect to

have an online service that can be polled for information about available WZ and then distribute this information to their vehicles through the cloud using cellular communication. The online service in question would share the WZ information in WZ Data Exchange (WZDx) format.

The development of the Mapping Tool was motivated by the critical need to improve safety and support reliable navigation in and around active work zones. Ensuring the safety of both road users and construction workers requires precise and timely information about lane- level geometry, access restrictions, and traffic control layouts. As modern vehicles increasingly rely on advanced driver- assistance systems (ADAS) and fully automated driving capabilities, accurate lane- level representations of work zones are essential for safe operation, particularly in dynamic and constrained environments.

In addition, the presence of occlusion zones, areas where visibility is limited by equipment, barriers, or ongoing work, must be properly identified and encoded to support safe and informed decision- making by both human drivers and autonomous systems. Effective trip planning, including destination access, parking availability, and route selection, depends on the temporal accuracy of the work zone information. Commercial navigation and mapping providers often avoid integrating unreliable or low- quality data, underscoring the need for a refined, verified, and standardized work zone dataset. The mapping tool addresses these needs by providing geometry refinement and augmentation of safety attributes, thus improving both data reliability and its utility for downstream applications.

4 Work Zone Server

The WZ Server consists of the following modules:

The WZ Server consists of the following modules:- The database stores information about active work zones.- Message codec is a coder/decoder of the WZ data - data from the database are encoded into the WZDx version 4.2 format; or decoded from WZDx and proprietary formats to be inserted into the database.- The data import module is a collection of data ingestion routines that processes available WZ data feeds using the message codec and inserts the processed information into the database.- The data management module is responsible for data cleanup - ensuring that data are current and there are no duplicate records; and for pushing current WZ data to registered roadside units (RSUs).- The application programming interface (API) is the interface between the WZ Server and the Mapping Tool as well as the outside world, that is, the clients of the WZ data.

4.1 Database

4.1 DatabaseThe database schema is in accordance with the WZDx version 4.2 format and is depicted in Fig. 2. [2]

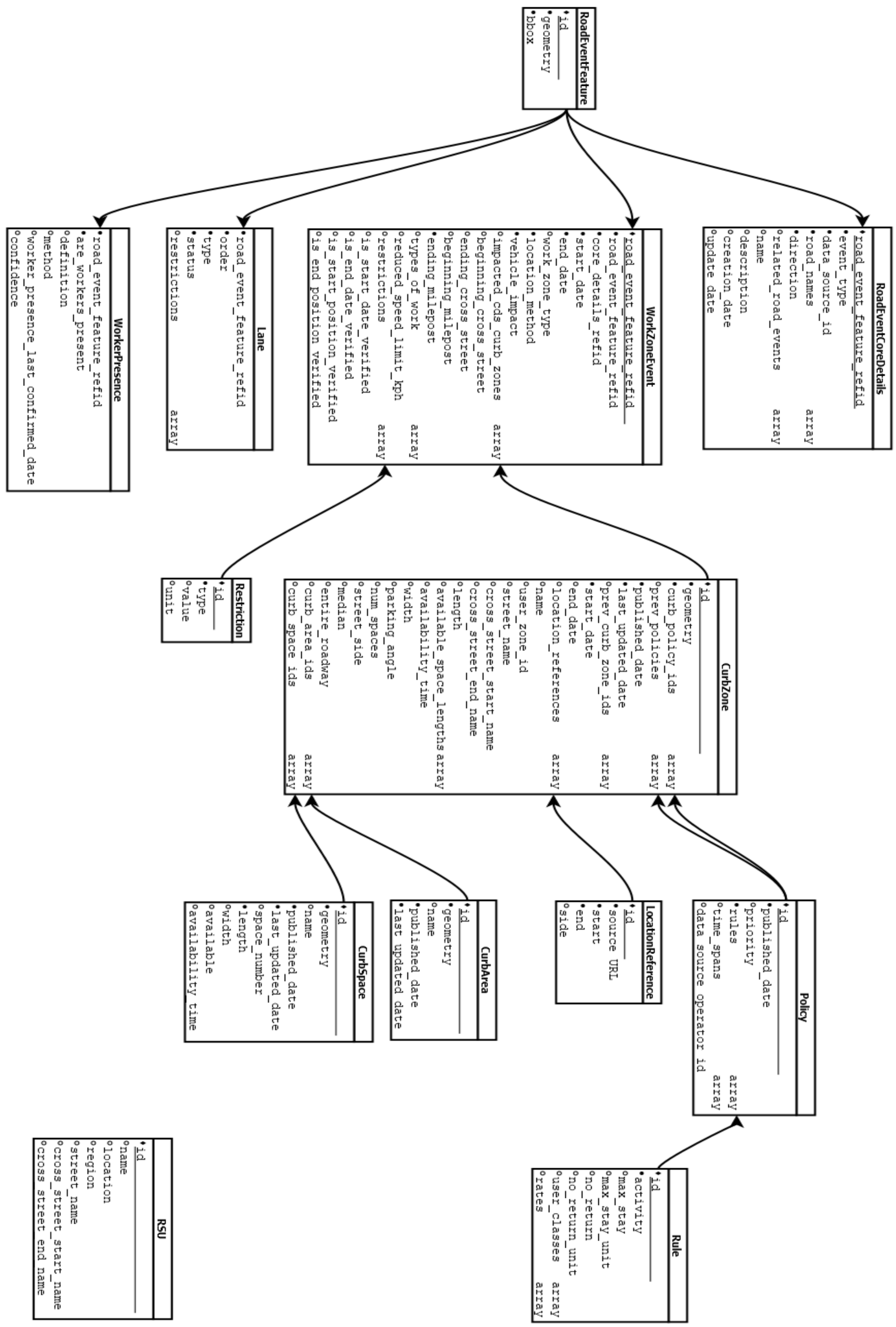

Fig. 2. Database schema. 9

4.2 Message CoDec

4.2 Message CoDecThe database schema in the previous section describes the internal data structure. The purpose of the codec module is to convert information from formats used by WZ data sources to the database structure and to convert the database structure to the WZDx version 4.2 format. The compatibility of the database structure; WZDx version 4.1, used by the MTC 511 WZ service; WZDx version 4.2; Caltrans Lane Closure System (LCS); and RSM parameters are summarized in Table 1.

Database	WZDx v.4.2	WZDx 4.1	LCS	RSM
Id	id	id	index	Event Identification
Type	type	type	-	-
geometry_type	geometry_type	geometry_type	-	Event Location Types
geometry_coordinates	geometry_coordinates	geometry_coordinates	beginLongitude, beginLatitude, endLongitude, endLatitude	Event Location
data_source_id	data_source_id	data_source_id	-	Data Source Authenticity, Data Source Authorization
event_type	types_of_work	event_type	-	Event Type
road_names	road_names	road_names	beginRoute, endRoute	Event Location
direction	direction	direction	beginDirection, endDirection, travelFlowDi-rection	Event Location Applicable Heading
related_road_eve	related_road_e	-	-	-

nts	vents			
description	description	description	-	Common Message Header
creation_date	creation_date	creation_date	recordDate, recordTime	Event Time (Event Start Time)
update_date	update_date	update_date	-	Event Updates
start_date	start_date	start_date	closureStartDate	Event Time (Event Start Time)
end_date	end_date	end_date	closureEndDate	Event Time (Event End Time)
work_zone_type	-	-	typeOfClosure	-
event_status	event_status	event_status	isClosureEnd Indefinite	Event Updates, Event Cancellation
is_start_dateverified	is_start_date _verified	start_date _accuracy	-	-
is_end_dateverified	is_end_date _verified	end_date _accuracy	-	-
is_start_position _verified	is_start_position _verified	beginning _accuracy	-	Event Location Uncertainty
is_end_position _verified	is_end_position _verified	ending_accuracy	-	Event Location Uncertainty
location_method	location_method	location_method	-	Event Location Definition
vehicle_impact	vehicle_impact	vehicle_impact	-	Affected Vehicles
beginning_cross_street	beginning_cross _street	beginning _cross_street	beginLocation Name	Event Location
ending_cross_street	ending_cross _street	ending_cross _street	endLocation Name	Event Location
beginning_milepost	-	-	beginMilepost	-

ending_milepost	-	-	endMilepost	-
types_of_work	type_name	type_name	typeOfWork	Event Type
are_workers_present	are_workers_present	are_workers_present	-	Provide Indication of People Present
worker_present_definition	worker_present_definition	worker_present _definition	-	Provide Obstacle Indication
worker_present_confidence	worker_present_confidence	worker_present _confidence	-	Provide Obstacle Indication
worker_present_last _confirmed_date	worker_present_lastConfirmed date	worker_present_lastConfirmed date	-	Provide Obstacle Indication
impacted_cds_curb _zones	impacted_cds_curb Zones	-	-	-
lanes_order	lanes_order	-	-	Lane Closure Warning Needs
lanes_type	lanes_type	-	-	Lane Closure Warning Needs
isClosureEndIndefinite	lanes_status	-	-	Lane Closure Warning Needs
lanes_restrictions	lanes_restrictions	-	-	Lane Closure Warning Needs
reduced_speed_limit _kph	reduced_speed_limit_kph	-	-	Reduced Speed Zone Event
restrictions	restrictions	-	-	Lane Closure Warning Needs, Dynamic Traveler Information Needs

Table 1. Comparison of parameter sets of different WZ description formats.

4.3 Data Import

The data import module consists of routines that periodically poll the available data streams with WZ information, parse the input, convert it to the database structure using the message codec, and insert the resulting records into the database. The polling period can be 5 or 15 minutes. Currently, the WZ data are imported from the 511 work zone feed of the Metropolitan Transportation Commission (MTC). This feed contains information from the Caltrans LCS and a few cities - all within the region of the San Francisco Bay Area. This information is provided in WZDx version 4.1 format. The message codec is then used to translate it into the database structure.

4.4 Data Management

The data management module is responsible for maintaining data integrity, that is:

1. Ensure that there are no duplicate records of WZ events.

2. Remove outdated WZ records.

WZ server is NOT designed to store and analyze historic WZ data.

4.5 API

The WZ Server is accessed from the outer world via an API. The API has two methods: GET, which reads the data; and POST, which modifies the data. Tables 2 and 3 summarize the optional parameters of these two methods.

GET

Table 2. GET method parameters.

Parameter	Description
format	WZDx 4.2. In the future, other formats may become available.
version	For future use.
status	Active, Scheduled, or Closed.
severity	Major, Moderate, or Minor. OR queries are possible via a comma-separated list:?severity=Minor, Moderate.
bbox	Bounding box.
geography	Filtering near a point or linestring. The geography value should be provided as a WKT string in WGS84 latitude/longitude.

jurisdiction	District, City, County
event_type	Filter events using the event_type value list. Use a comma-separated list to perform OR queries.
created	Time when the message was created. This parameter can be preceded by one of the following operators: <, <=, >, >=.
updated	Last update. This parameter can be preceded by one of the following operators: <, <=, >, >=.
road_name	Shows only events containing a road with the provided name. Use a comma-separated list to form OR queries.
area	Bounding polygon.
limit	Max number of events to display.

POST

Parameter	Description
format	WZDx 4.2. In the future, other formats may become available.
version	For future use.
road_event_feature_id	Reference to the WZ event.
geometry	The WZ boundary represented as a multipolygon. The geography value should be provided as a Well-Known Text (WKT) string in WGS84 latitude/longitude.
lane_order	The position of a lane in sequence on the roadway. This value is used as an index to indicate the order of all lanes provided for a road event, starting with 1 for the leftmost lane.
lane_type	An indication of the type of lane or shoulder.
lane_status	Status of the lane for the traveling public.

Table 3. POST method parameters.

5 Mapping Tool

The purpose of the Mapping Tool is to refine the geometry of the WZ. This includes the WZ boundary provided in the form of a geo multipolygon and information about closed lanes. It interacts with the WZ server using the API defined above, as shown in Fig. 3 and Fig. 4, augmenting existing WZ event records by accurate geometry.

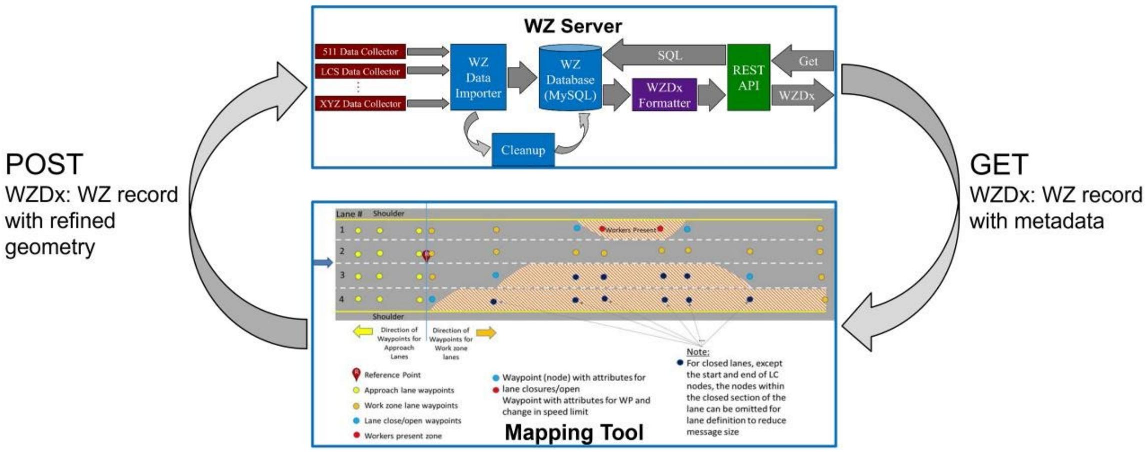

Fig. 3. Mapping Tool and its interaction with WZ server.

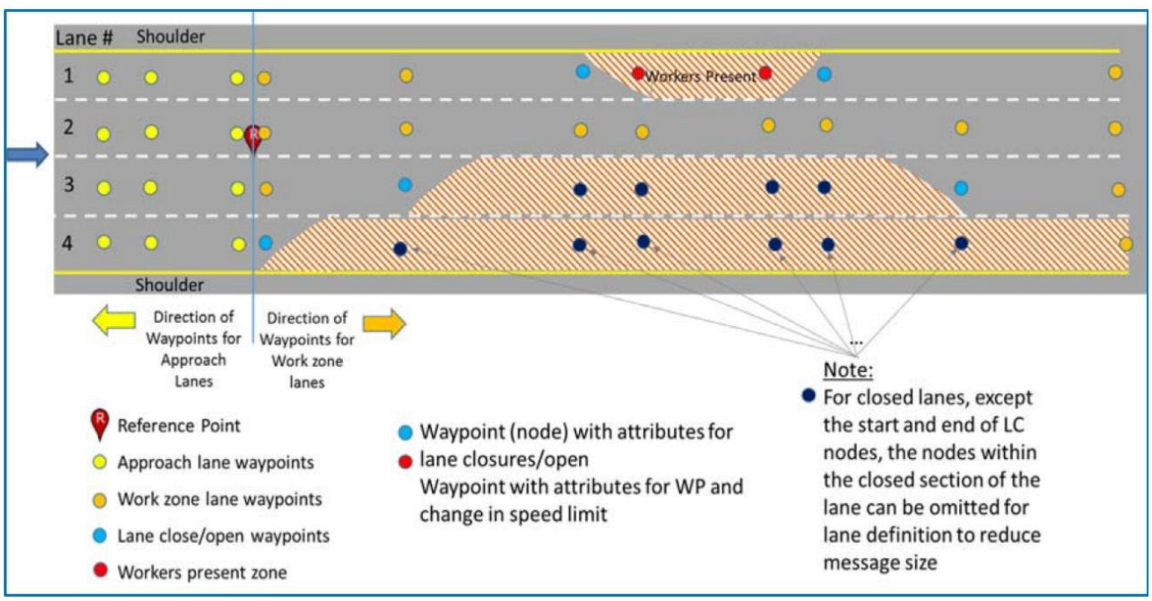

Fig. 4. Mapping Tool - zoomed in.

Geometry refinement is needed primarily because the original WZ information coming from sources, such as Caltrans LCS, is rather crude. The WZ geometry comes in one of two forms: 1) multi- point with begin and end points of the WZ; or 2) a linestring that corresponds to a centerline of the road. WZDx format supports the information about specific lanes that are closed. The internal LCS data model supports this information as well. However, data LCS data exposed to the public through Caltrans' Commercial Wholesale Web Portal (CWWP) [3] only indicate whether all or some lanes are closed. Moreover, on long road segments, where the work is planned to last several weeks or months, the corresponding WZ record in the LCS specifies the whole road segment as a single WZ, whereas in reality, the actual work is performed on small portions of this long segment, and these portions are different every day. Similarly, the start and end time of the WZ activity isn't always correctly reflected in the LCS. The accuracy of this information depends on a contractor working in a given WZ - thus, it is not guaranteed.

The Mapping Tool has three components:

1. Visualizer for displaying WZs on the map and WZ editor for manual editing of the WZ boundary.

2. Automatic WZ boundary refinement module for bulk boundary refinement of many WZs.

3. WZ boundary identification from dashcam video.

Next, we describe these components.

5.1 WZ Boundary Visualizer and Editor

The screenshot of the WZ visualizer and editor is shown in Fig. 5. The user can select a WZ of interest from the WZ drop- down list. The selected WZ is then displayed on the map. Each WZ must have at least two markers that denote the beginning and end of the WZ, while the WZ itself is a straight segment between these two markers. The user can add more markers, move or delete them to form a polygon representing the boundary of the WZ. The changes made by the user can be saved in the WZ database or rolled back.

Manual editing of WZ boundaries can be used on some selected WZs. It showcases a potential user interface to define the WZ by a contractor working on it. This approach does not scale to thousands of California WZs. For scalability, we must use the automatic WZ boundary refinement.

Fig. 5. WZ visualizer and editor.

5.2 Automatic WZ Boundary Refinement

For a given WZ, its record should contain the direction of travel on the road, as well as the types and numbers of the lane. If this information is present, it is relatively easy to obtain a geo- polygon representing the perimeter of the WZ starting from the original begin and end points of a segment or a polyline that denotes the centerline of the road. The calculation is performed based on the number of lanes extracted from OpenStreetMap (OSM) [4] , and on the width of the lane of a given road. The Federal Highway Administration (FHWA) adopts lane width standards primarily based on the American Association of State Highway and Transportation Officials (AASHTO) “Green Book”, with typical values varying by functional road class and context. [1]

5.3 WZ Boundary Identification from Dashcam Video

We solve the following problem. A vehicle is driving through the length of a traffic work zone. The vehicle is equipped with a dashcam with an integrated reasonably accurate GPS system. In our experiments, standard off- the- shelf GPS had a 1 Hz sampling rate and provided 15 significant digits of accuracy. As the vehicle drives down the road, traffic cones appear in view. They define the boundaries of the target work zone. To map these cones in the Mapping Tool, we need to obtain the geo-coordinates of the cones themselves.

Table 4. FHWA lane width standards by road class.

Roadway Class	Typical Lane Width (ft)	Notes
Interstates/freeways	12	Standard for high-speed, high-volume roads.
Rural arterials	12	11 ft may be used in constrained conditions.
Rural collectors	11–12	12 ft preferred; 11 ft allowed for lower volumes.
Rural local roads	9–11	10 ft minimum; 9 ft possible for very low-volume roads.
Urban arterials	10–12	11–12 ft typical; 10 ft allowed in low-speed, pedestrian-heavy areas.
Urban collectors	10–12	11 ft typical; 10 ft possible for low-speed, low-volume streets.
Urban local roads	9–11	10–11 ft typical; 9 ft possible for very low-speed, low-volume streets.

To detect WZs in a dashcam video, we use the YOLO v11 Nano, a pre- trained computer vision model widely used in industry applications.[5] The neural network uses a single- pass detection method with 24 convolutional layers and 2 fully connected layers.

Training YOLO on a publicly available dataset for traffic cones, we derived a model that performs with strong accuracy and average precision (AP) scores[6]. In dashcam videos, YOLO helps us recognize traffic cones (or other objects associated with WZ perimeter, e.g. fences).[7]

Now, we need to identify their position given the position of the dashcam. We take two adjacent frames, as shown in Fig. 7. In each frame, we compute the angle of the camera to the cone (more precisely, to the centroid of the bounding box created from the YOLO prediction). In the case of cone 1, this results in θ_1 and θ_2 for frame 1 and frame 2 respectively. We also know the distance traveled by the vehicle between the two frames. Normally, since we are working with lat/long coordinates, we would need to use the Haversine formula, described in the Appendix A to compute distances in meters.

Now we have all three key pieces of information known to us: the initial angle, the final angle, and the distance traveled. Therefore, we are able to create a triangle where each vertex is the vehicle's initial position, final position, and the cone's position. Using what we

Frame 1 Frame 2

Fig. 6. Two sequential frames with the same cones.

know, we are able to uniquely define all other side lengths and angles. This will allow us to precisely determine the position of the cone through triangulation.

Given are:

- θ_1 – angle of the vehicle to the cone in frame 1.- θ_2 – angle of the vehicle to the cone in frame 2.- Δx – distance traveled by the vehicle between frames 1 and 2 (in meters).

Define:

$$\begin{aligned} \theta_1' &= \frac{\pi}{2} - \theta_1, \\ \theta_2' &= \theta_2 + \frac{\pi}{2}. \end{aligned}$$

From the triangle property, we get:

$$\theta_3' = \pi - \theta_1' - \theta_2'.$$

Now, we get:

$$\frac{d_1}{\sin\theta_1'} = \frac{d_2}{\sin\theta_2'} = \frac{\Delta x}{\sin\theta_3'},$$

where d_1 is the distance from the dashcam to the cone in frame 1, and d_2 is the distance from the dashcam to the cone in frame 2.

Thus, distances d_1 and d_2 can be expressed as:

$$d_1 \quad = \quad \sin\theta_1' \frac{\Delta x}{\sin\theta_3'},$$

$$d_2 \quad = \quad \sin\theta_2' \frac{\Delta x}{\sin\theta_3'}.$$

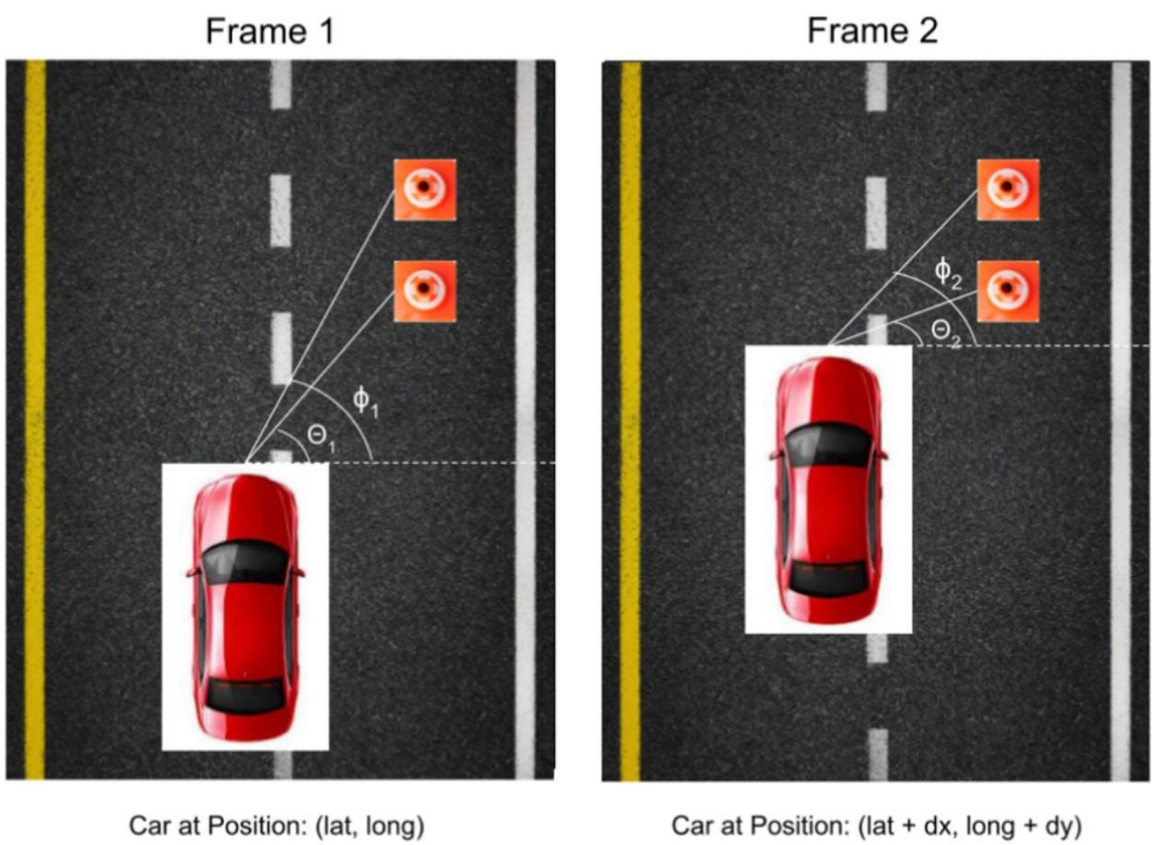

Fig. 7. Computing con positions from two sequential frames.

In conjunction with the positions of the dashcam in frames 1 and 2, these distances allow us to compute the position of the cone.

The detection and positioning of the cones, as well as the subsequent construction of the WZ boundary as a convex hull of the detected cones, are implemented in the Web app, shown in Fig. 8.

Fig. 8. WZ detection from the dashcam video in the web app.

6 Recommendations for Caltrans

To support safer and more effective WZ operations, it is essential for Caltrans to improve the precision, granularity, and timeliness of WZ data, particularly with regard to spatial boundaries, temporal information, and worker presence. The following recommendations summarize actionable strategies and best practices for improving WZ data quality and integration with the WZDx feed.

6.1 Accurate Work Zone Boundaries

The precise delineation of the geometry of the work zone is critical for automated vehicle navigation, occlusion analysis, and traveler information systems. Caltrans should prioritize the use of high- resolution spatial data derived from:

- LineString geometries with verified field coordinates.- Combined sources such as Lane Closure System (LCS) records, GPS traces, Internet of Things (IoT) devices, and contractor-supplied digital maps.- Real-time or near-real-time updates reflecting field conditions.

These measures will ensure that map- based systems, including commercial routing services,

can accurately reflect the evolving footprint of work zones.

6.2 Timely and Reliable Work Zone Timing

Static or outdated temporal information undermines the value of WZDx feeds. To ensure that time data reflect current field conditions:

- The start and end times of the work zone should be updated live, reflecting actual conditions rather than planned schedules.- A field-to-feed feedback loop should be implemented, where crews or field sensors provide real-time input directly into the WZDx system.- If real-time data are unavailable, the WZDx feed should explicitly reflect this via a confidence or verified field flag.

6.3 Representing Worker Presence

Information on whether workers are present within an active zone is crucial for dynamic speed enforcement and driver awareness. Caltrans is encouraged to:

- Use IoT devices and fleet AVL (automatic vehicle location) systems to detect and signal the presence of workers.- Provide field crews and contractors with easy-to-use mobile applications that allow real-time status updates.- Develop policy frameworks that require updates at the start and end of shifts to reflect when workers are active in the field.

6.4 Best Practices for High-Quality WZDx Feeds

To ensure Caltrans WZDx feeds meet both safety and operational goals, we recommend:

- Integration of multiple data sources (LCS, GPS, AVL, contractor input, IoT) to increase reliability.- Real-time updating capabilities to reduce latency between field conditions and digital feeds.
- Data augmentation strategies that include confidence scores or verification flags when high-fidelity data is not available.- Incentive structures for contractors and maintenance crews that tie data accuracy to safety metrics or performance evaluations.

By implementing these practices, Caltrans will help ensure that its work zone data supports emerging mobility technologies, improves safety for all road users, and complies with national data sharing standards such as WZDX.

7 Conclusion and Future Work

WZDx specification, developed by the US Department of Transportation (USDOT), has evolved into the Connected Work Zone (CWZ) standard under the stewardship of the Institute of Transportation Engineers (ITE), AASHTO and Society of Automotive Engineers (SAE). This transition aims to formalize the data sharing protocols of the work zone, improve interoperability, and improve the safety of workers and travelers. Below is an overview of state and regional DOT initiatives using WZDx/CWZ and related formats [9, 10].

Accurate geometry and timely updates on worker presence in work zones are essential to ensure road safety and operational efficiency. Geometry defines the physical layout of lane closures, shifts, and detours, while timeliness ensures that road users and systems respond to real- time conditions. If this information is incorrect or outdated, it can lead to dangerous driving decisions, delays, or failures in connected and automated vehicle (CAV) systems. The impacts span across many users and systems involved in transportation. Table 5 summarizes the users of this information and specifies why it is important to them.

Table 5. Users of WZ geometry and worker presence data.

Who uses	Why it's important
Drivers and travelers	Need accurate detour information and alerts about worker presence to drive safely and make informed route choices.
CAV and ADAS systems	Require high-precision, real-time lane-level geometry and up-to-date obstructions to plan safe paths and avoid dangerous maneuvers.
Navigation and routing apps	Depend on real-time updates to provide optimal route suggestions and avoid misleading or outdated directions.
Transportation agen-	Use this data for situational awareness, operational co-

cies (DOTs)	ordination, performance monitoring, and public commu-nication.
Traffic management centers (TMCS)	Integrate work zone updates into traffic control strate-gies, such as signal timing adjustments and dynamic message signs.
Emergency services	Rely on this information to reroute quickly, avoid haz-ards, and access incident scenes safely.
Freight and logistics companies	Use timely data to avoid delays, optimize routes, and ensure on-time deliveries.
Maintenance contrac-tors	Validate real-time location of crews, ensure compliance with permits, and coordinate safe field operations.

Future work on WZDx and CWZ data should prioritize mechanisms to provide timely updates on accurate work zone geometry and real- time worker presence. As road conditions

change dynamically during maintenance activities, ensuring that digital representations reflect current state is essential for both human drivers and automated systems. To enhance the fidelity and freshness of these data, emerging sources such as dashcam video streams from maintenance vehicles and smart cones equipped with location and status sensors should be explored. These technologies can serve as a valuable input to automatically verify, enrich, or update work zone feeds in near- real time, improving both situational awareness and roadway safety.

A Haversine Formula Explanation

Given two points on a sphere with geographic coordinates:

$$(\phi_1, \lambda_1), \quad (\phi_2, \lambda_2)$$

where:

ϕ is latitude in radians, λ is longitude in radians, R is the Earth's radius (mean value: 6,371 km).

The Haversine formula calculates the great- circle distance d between the two points:

$$\Delta\phi = \phi_2 - \phi_1, \quad \Delta\lambda = \lambda_2 - \lambda_1$$

$$a = \sin^2\left(\frac{\Delta\phi}{2}\right) + \cos(\phi_1) \cdot \cos(\phi_2) \cdot \sin^2\left(\frac{\Delta\lambda}{2}\right)$$

$$c = 2 \cdot \arcsin(\sqrt{a})$$

$$d = R \cdot c$$

This formula accounts for the curvature of the Earth and is widely used in navigation, GPS, and geographic distance calculations.

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