Smart and Cooperative Truck Parking Information Management System (TPIMS)

Presented at the 21st Annual Western States Forum

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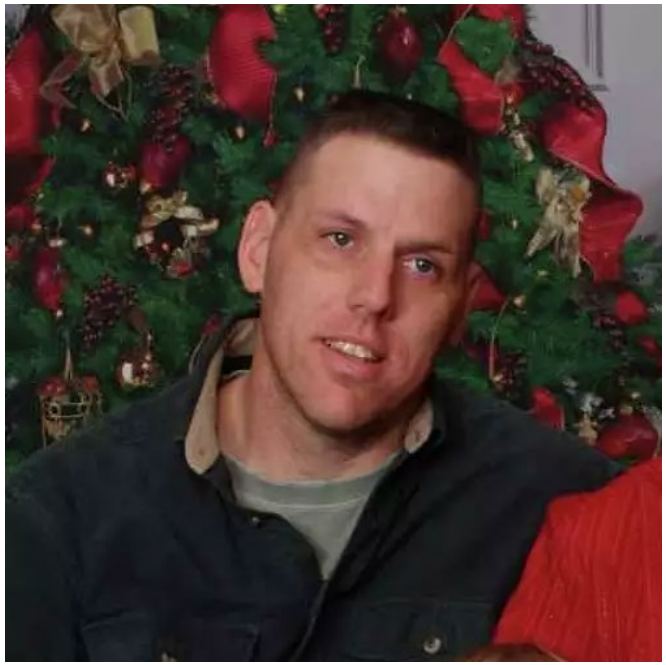
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Contents

- Truck Parking Problem and Project Motivation
- System Requirements and Implementation
- Prediction Model Development and Deployment
- Application Programming Interface (API) Design and User Interface
- Data Quality Improvement and Calibration
- Key Findings and Lessons Learned

Introduction



Jason's Law, enacted in 2012

The law set to addresses the shortage of safe truck parking facilities

Introduction

"WSDOT began exploring TPIMS in the 2018–2019 pilot observing trucks parked on shoulders and ramps"

This creating safety concerns for commercial carrier and the general motorist

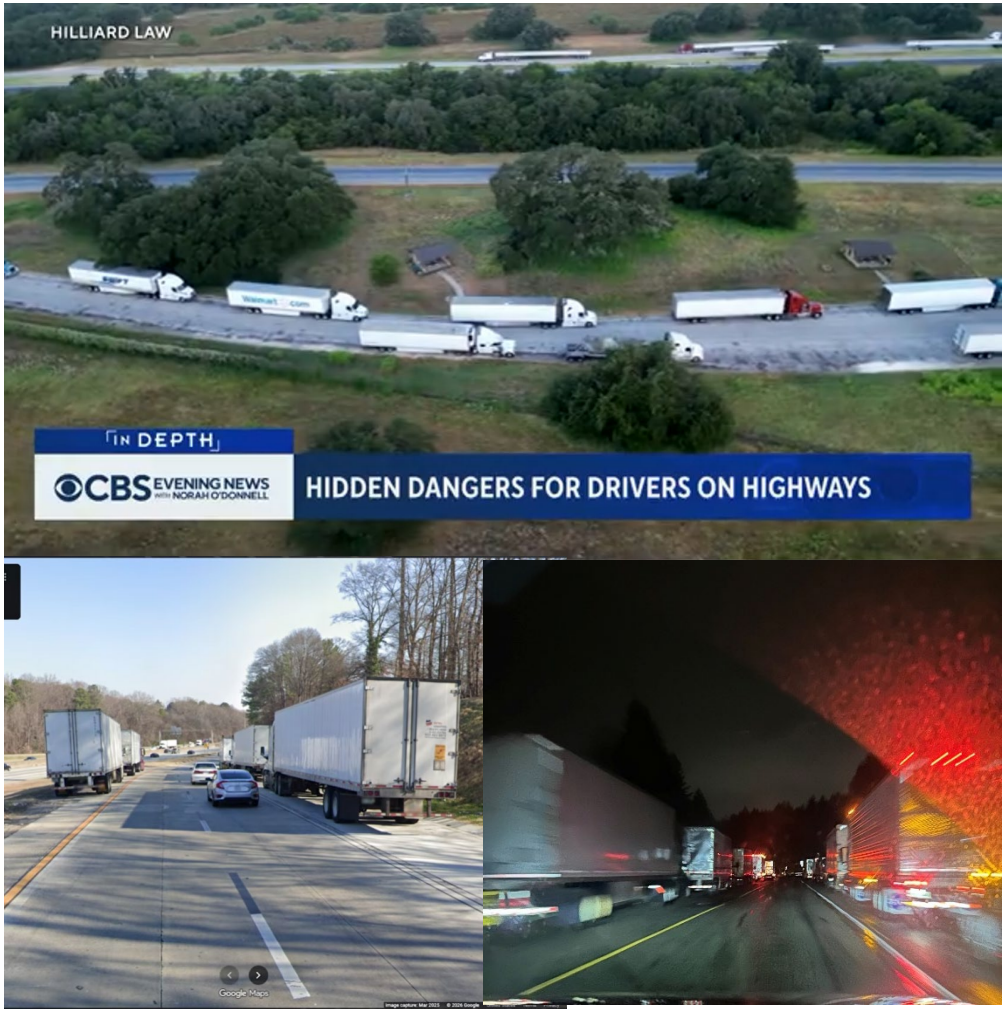
- Truck drivers face strict Hours-of-Service (HOS) limits, including a maximum of 11 hours of driving
  - The need to meet HOS requirements creates an urgency on the part of the driver and can lead to desperation



Examples of Washington rest areas reaching near-full or full occupancy overnight

Introduction

- There is **~1 rest area parking space for every 11 trucks**[1] on the road
  - Truck stops and Safety Rest Areas (SRAs) often reach capacity overnight
  - Drivers spend >56 minutes per day on average searching for safe parking[2]
- Parking shortages force trucks into unsafe locations, including:
  - shoulders, ramps, and other undesignated areas
- About 4,000 injury crashes each year are associated with trucks parked on ramps or along interstates[3]



Examples of trucks parked on highway ramps due to parking shortages (Top) News image of ramp parking[4] (bottom left) Ramp in Atlanta from Google Streetview (bottom right) Ramp in Washington

[1] American Transportation Research Institute. (2025). ATRI Research Focuses on Truck Parking at Public Rest Areas. https://truckingresearch.org/2025/04/atri-research-focuses-on-truck-parking-at-public-rest-areas/
[2] American Trucking Association. (2023). National Truck Parking Shortage: A Growing Safety Concern for All Motorists. https://www.trucking.org/news-insights/national-truck-parking-shortage-growing-safety-concern-all-motorists
[3] Federal Motor Carrier Safety Administration. (2020). Large Truck and Bus Crash Facts 2020. https://www.fmcsa.dot.gov/safety/data-and-statistics/large-truck-and-bus-crash-facts-2020
[4] Kris Van Cleave. (2023). Lack of parking for semi-trucks can have fatal consequences. CBS News. https://www.cbsnews.com/news/truck-parking-shortage-fatal-accidents/

Introduction

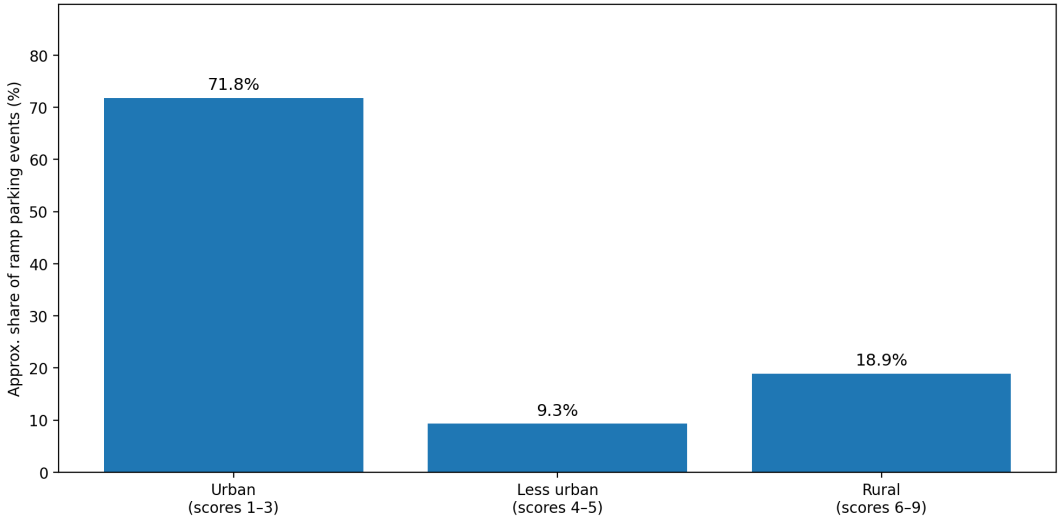
Truck parking shortages affect the entire highway system, *not just congested metropolitan regions*

A study from Altitude by Geotab and HNTB[5] (Data from November 1, 2024 to October 31, 2025)

- Over 2.2M parking events occur annually on U.S. highway ramps
- Top states: *Indiana, Illinois, Tennessee, California, Pennsylvania*
- ~30% of long-duration events* occur in counties with rural-urban score 4+**

* Long-duration events includes 9-12 hour of parking
** The US Department of Agriculture Rural-urban continuum score. Counties with a score of 1 correspond to metro areas with populations of 1 million or more, while counties with a score of 9 correspond to counties with urban populations of fewer than 5,000 that are not adjacent to a metro area.

Summary of ramp parking events across the rural-urban continuum in the United States[1]



[5] Altitude and HNTB. (2026). A nationwide study of interstate ramp parking. Altitude by Geotab.
https://altitude.geotab.com/insights-and-customer-stories/a-nationwide-study-of-truck-parking-on-interstate-ramps/

Introduction

Real-world Consequences of Truck Parking Shortages

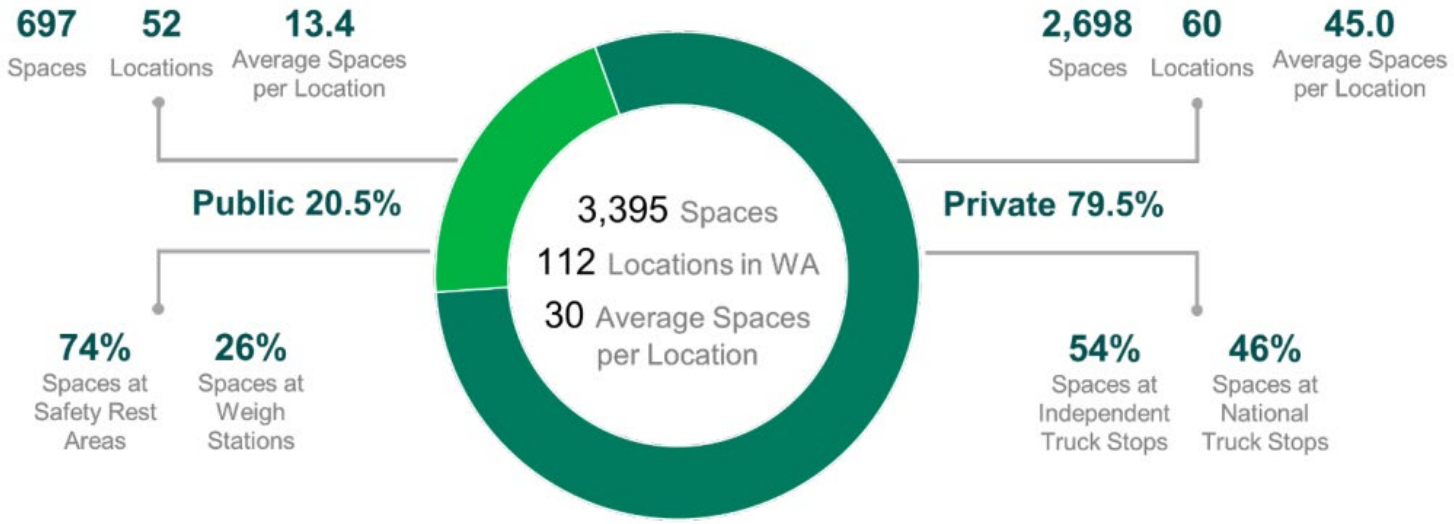
- **Safety:** Undesignated parking and fatigue-related driving risks
- **Economic:** Lost time, citations, and extra travel miles
- **Local:** Shoulder and ramp deterioration, idling impacts, and conflicts with nearby residential or commercial areas

*"Better use of parking data can **help drivers plan** routes and rest stops more safely and efficiently"*

Introduction

Washington State Truck Parking

60% of drivers spend over an hour just finding overnight parking[6], which impacts safety and compliance



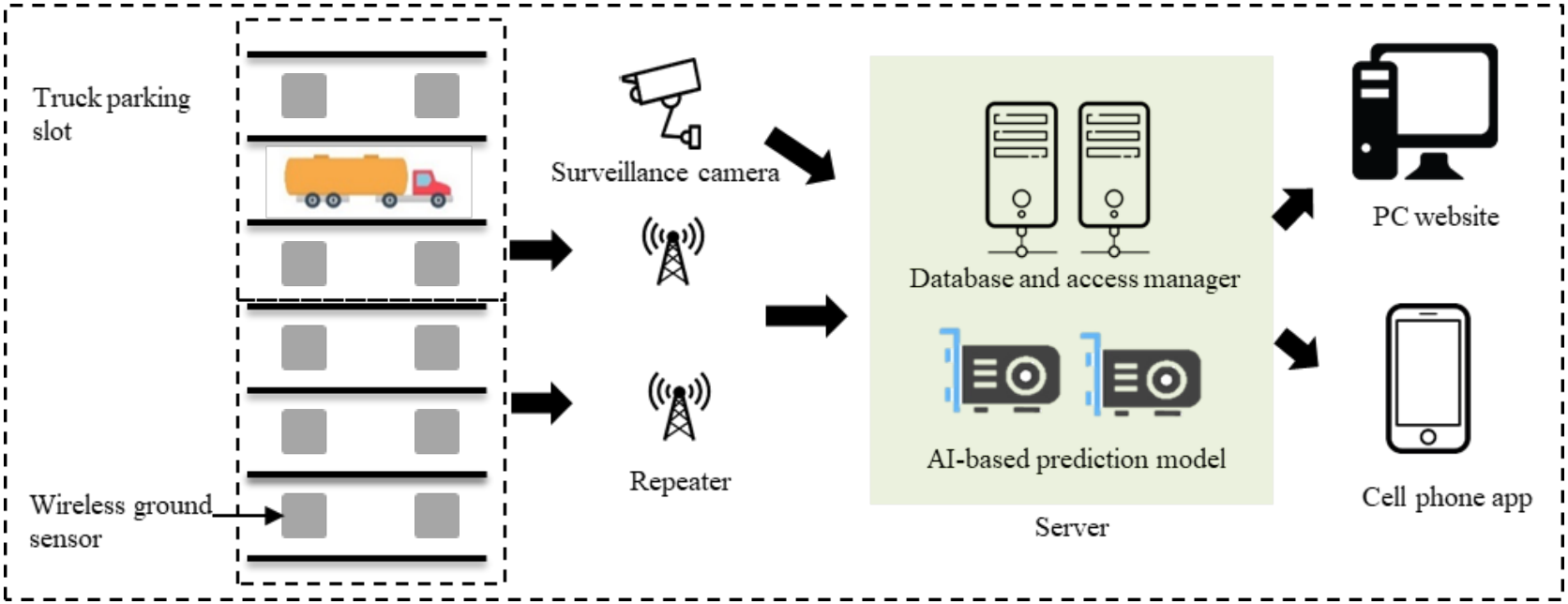
Truck Parking Space in Washington State[7]

Estimated daily parking space deficit in 2023: **700–870 spaces**[8]

Projected daily parking space deficit in 2035: **860–1,070 spaces**[8]

[6] WASHINGTON STATE DEPARTMENT OF TRANSPORTATION. (2016). Washington State Truck Parking Study.
[7] WASHINGTON STATE DEPARTMENT OF TRANSPORTATION. (2022). Appendix H: Washington Truck Parking Assessment (2022 Washington State Freight System Plan Update). https://wsdot.wa.gov/sites/default/files/2022-11/Appendix-H-FSP-Truck-Parking-Assessment_0.pdf
[8] Washington State Freight Mobility Strategic Investment Board. (2024). Washington State Truck Parking Implementation Plan. https://wsdot.wa.gov/sites/default/files/2024-12/Truck-Parking-Implementation-Plan-December2024.pdf

Pilot TPIMS in Washington (2022)



Pilot TPIMS architecture

[9] WASHINGTON STATE DEPARTMENT OF TRANSPORTATION. (2021). A COST-EFFECTIVE SOLUTION FOR TRUCK PARKING BASED ON ARTIFICIAL INTELLIGENCE. Western States Forum 2021. https://www.westernstatesforum.org/Documents/2021/Presentations/WSDOT_UW_MurthyYang_Final_TruckParkingPrediction.pdf

Pilot TPIMS in Washington (2022)

Pilot technology choice

- Limited commercial options were available at the time
- WSDOT used wireless ground sensors for stall-level occupancy detection



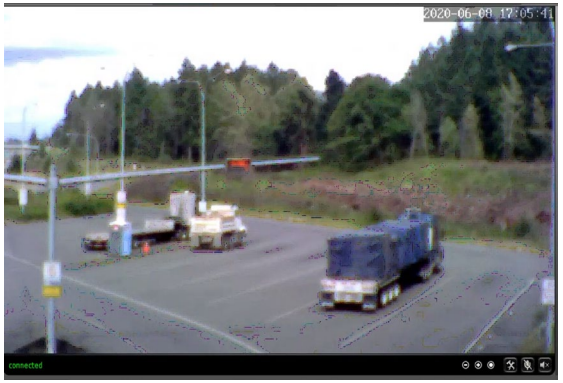


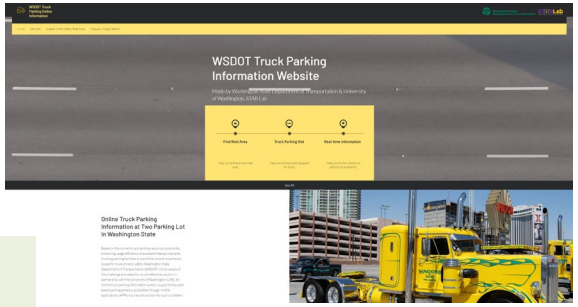
Magnetometers ground sensor



Repeater

Real-time video feed



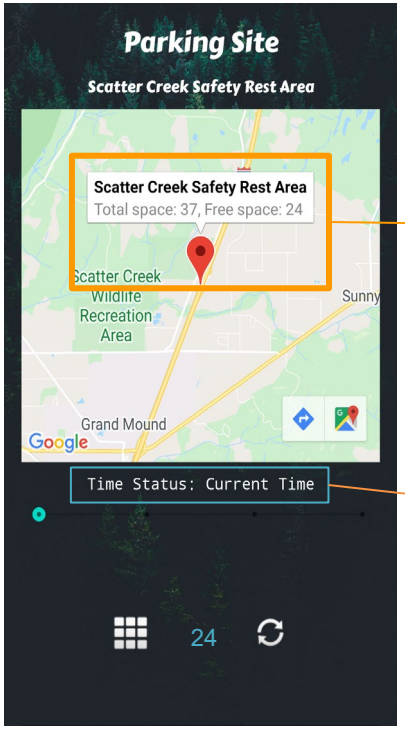


Web interface

Key lesson learned

- The system performed well from an accuracy standpoint
- However, it was not sustainable for large-scale deployment.
- It required many sensors, making deployment costly
- Sensor lifespan was shorter than expected, reducing long-term reliability

Pilot TPIMS in Washington (2022)

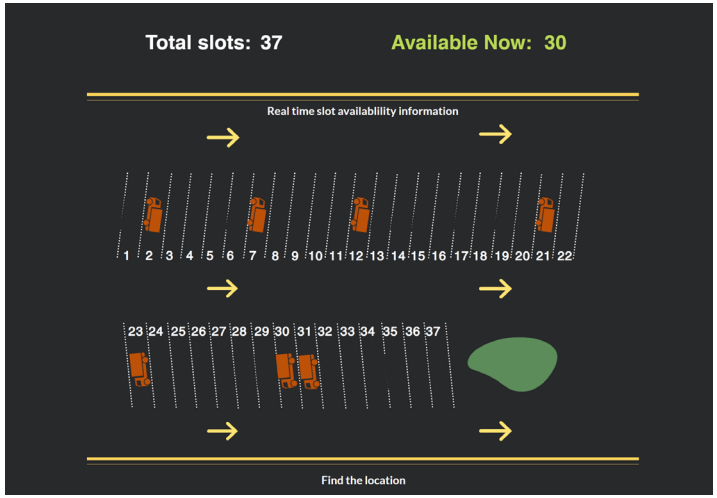


Real-time truck parking availability information

Move the slider to get the corresponding parking availability.

1. Current time
2. 10 min later
3. 30 min later
4. 1 hour later
5. 2 hours later
6. 4 hours later

Mobile App – Parking Availability



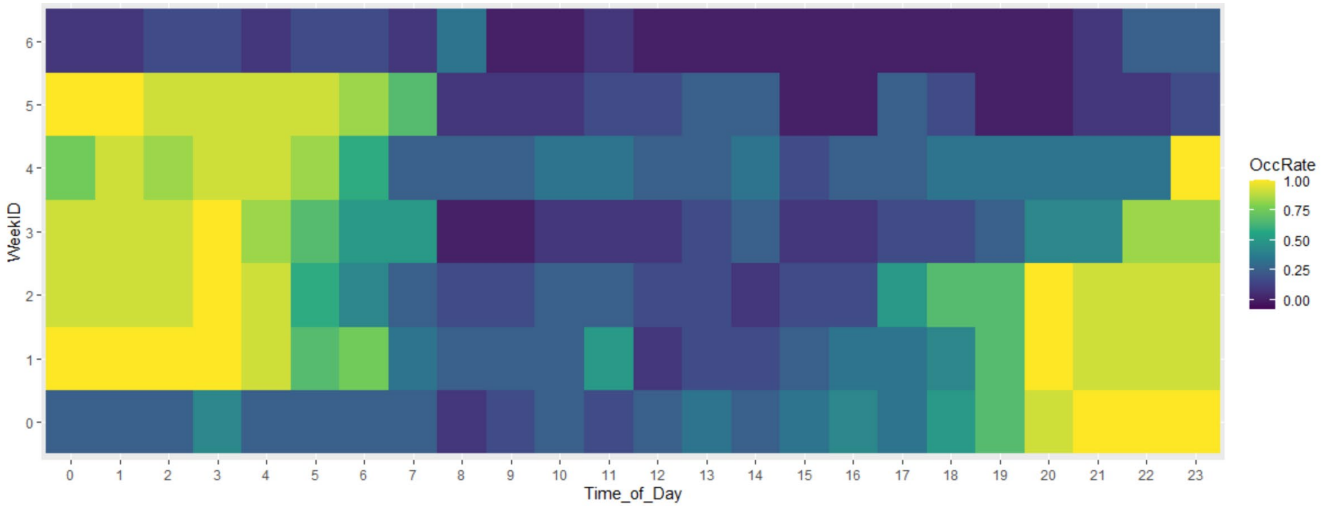


Real-time availability at (Top) at Scatter Creek Safety Rest Area and (Bottom) Nisqually Weigh Station on the Website (https://uwstarlab.wixsite.com/wsdotparking)

Pilot TPIMS in Washington (2022)

Truck Parking Occupancy Prediction (TPOP)

- A neural network was proposed to predict future occupancy levels at truck parking facilities
- Data were collected from two locations from January 1 to March 10 in 2020 and 2021
- A stacked long short-term memory (LSTM) neural network was used in the temporal feature learning component to improve prediction accuracy



Heat map of truck parking occupancy by time of day and day of week

For the day-of-week axis, 0 represents Sunday, and the remaining values follow the standard day-of-week index

Pilot TPIMS in Washington (2022)

Truck Parking Occupancy Prediction (TPOP)

- A neural network was proposed to predict future occupancy levels at truck parking facilities.
  - Data were collected from two locations from January 1 to March 10 in 2020 and 2021.
  - A stacked long short-term memory (LSTM) neural network was used for prediction.
- Mean Absolute Percentage Error (MAPE) was used for model validation.
- The prediction system achieved less than 12% error.

$$\mathcal{M}_{P_j} = \left|\frac{P_j - \hat{P}_j}{\hat{P}_j - \varepsilon}\right| * 100\%$$

MAPE formula

	10min	30min	1h	2h	3h	4h
MAPE	8.79%	9.01%	9.16%	9.47%	10.27%	11.34%

Prediction results across different forecast horizons

Pilot TPIMS in Washington (2022)

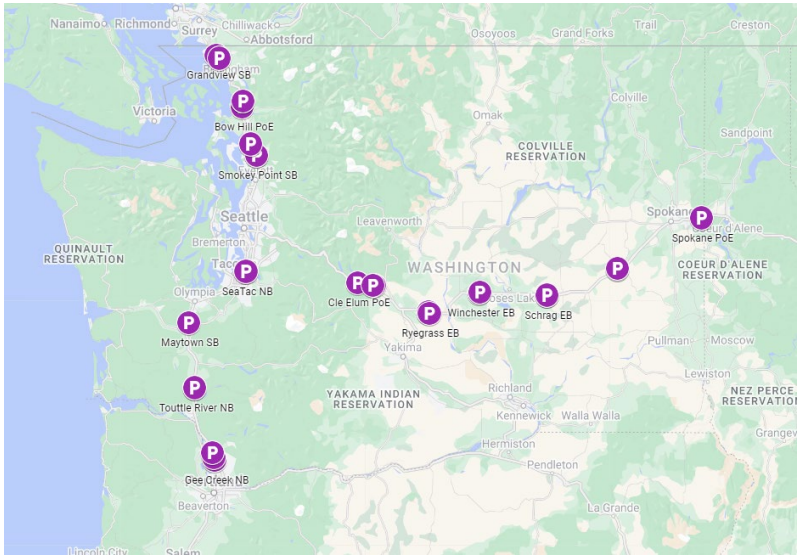
Pilot gaps / lessons learned

	Phase 1 (Pilot)	Phase 2
Technology	Magnetometer-based stall detection	Radar Sensor at entrance/exit & VDO-based
AI usage	AI forecasting was added to support advance parking predictions	Extended prediction horizons for longer-range forecasting
Coverage	Two locations	Expanded to more sites along the I-5 corridor
		Support for full operational deployment (i.e., APIs and website)

I-5 Truck Parking Information and Management System (TPIMS)

About the project:

- Provides truck drivers with real-time parking availability information:
  - A total of 273 truck parking stalls
  - Located along Interstate 5
  - Across 16 rest areas and weigh stations
- This information is available directly to truck drivers through in-cab systems, online applications, and websites
- A predictive parking availability feature provides expected truck parking spaces up to 8 hours in advance
- The I-5 system is intended to expand to additional high-volume freight corridors, with I-90 planned next
- Funding for the program is provided by the *Freight Motor Carrier Safety Administration (FMCSA) and the federal government*



Truck parking spots in WA

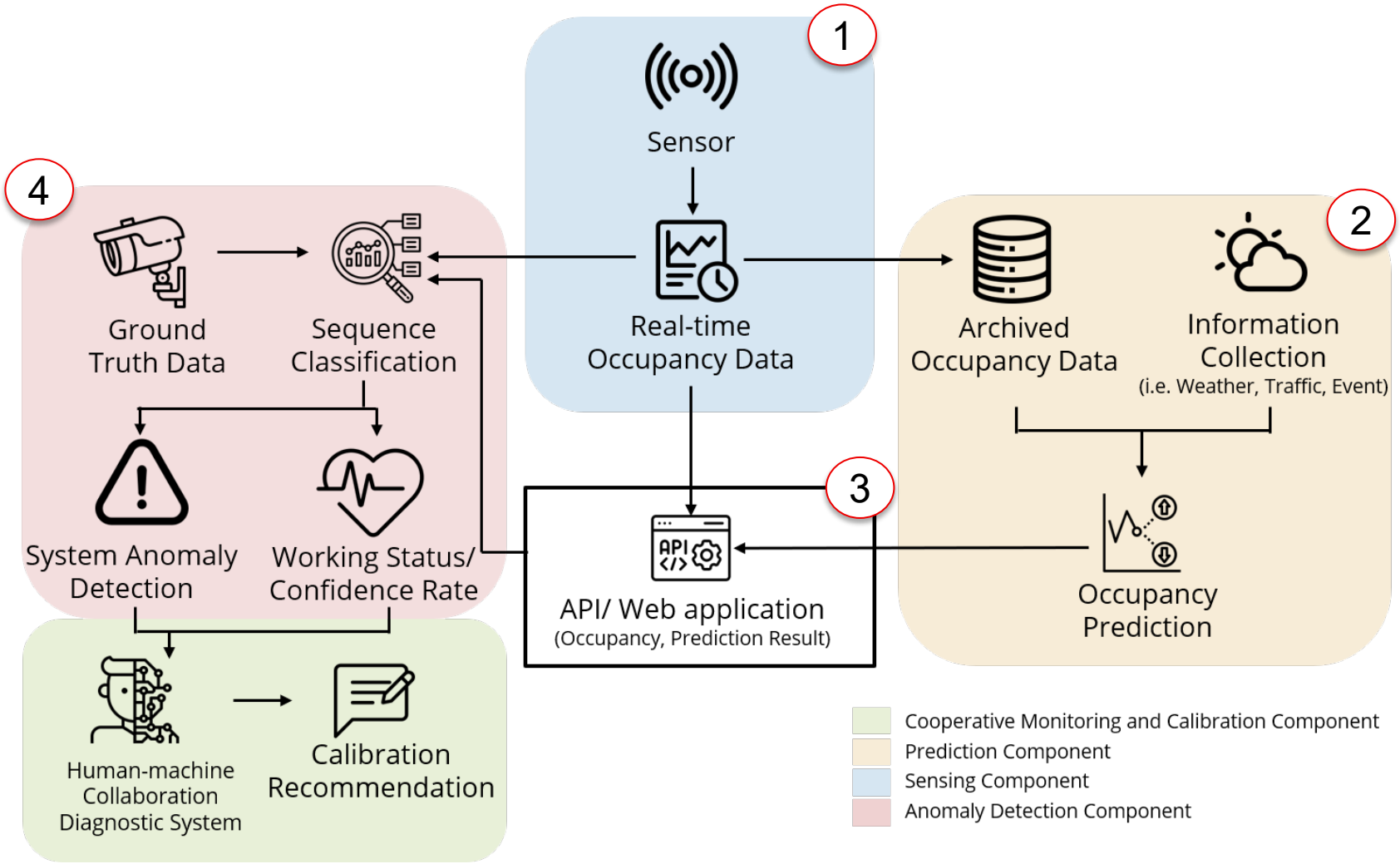
I-5 Truck Parking Information and Management System (TPIMS)

Expected outcome:

- Helps to address the high-priority I-5 corridor truck parking shortage
- Provides real-time truck parking availability information for approximately 100 spaces at weigh stations for the trucking community
- Improves use of existing parking spaces
- Enables long-haul truck drivers to plan stops more effectively along I-5
- Integrates with interstate TPIMS systems on I-5 in Oregon and California
- Allows WSDOT to access $2.3M in federal fund from an INFRA award

[10] Washington State Freight Mobility Strategic Investment Board. (2024). Washington State Truck Parking Implementation Plan. https://wsdot.wa.gov/sites/default/files/2024-12/Truck-Parking-Implementation-Plan-December2024.pdf

Truck Parking Information and Management System (TPIMS)



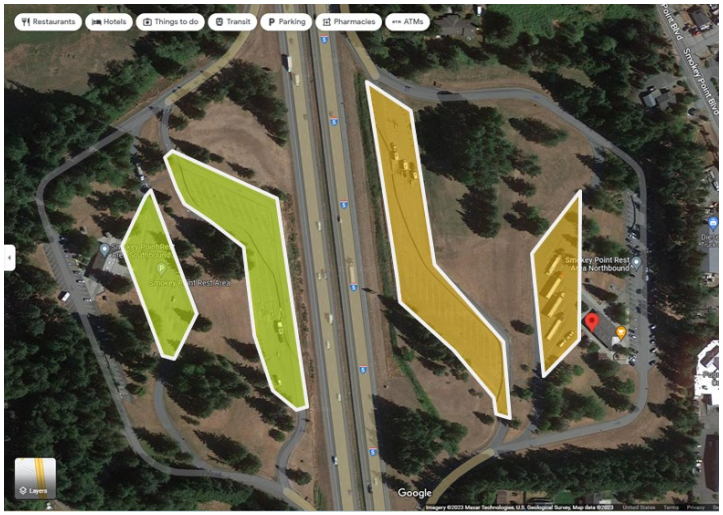
System Requirements and Implementation

Design Constraints



Shared entrances/exits with passenger vehicles at Schrag WB

If entry/exit sensors are used, they must reliably distinguish trucks from passenger vehicles

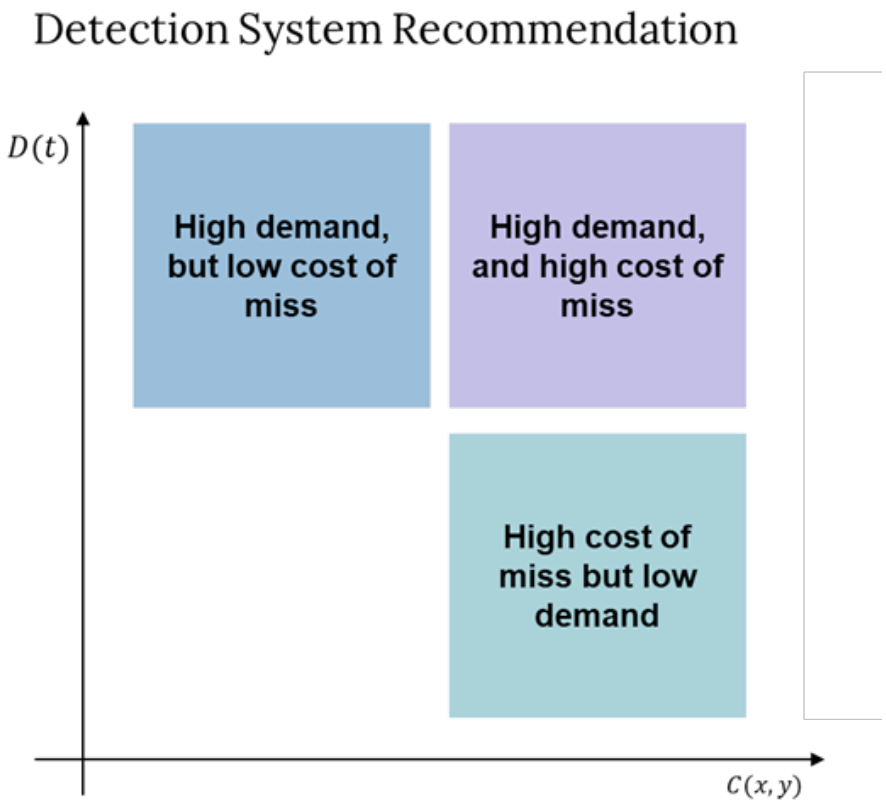


Separate truck and RV parking areas at Smokey Point NB and Smokey Point SB

Camera-based detection may be less cost-efficient when multiple cameras are needed to cover separated or irregular parking areas

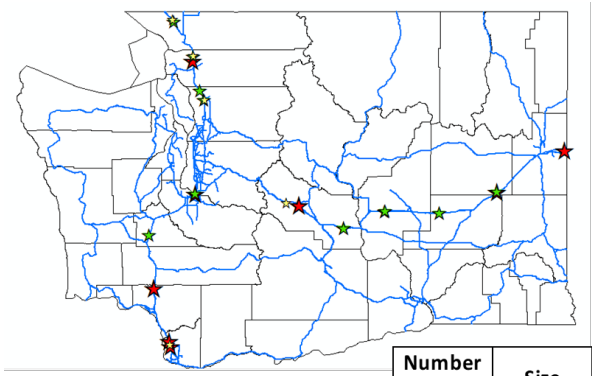
Site Evaluation

Assign a detection technology based on the level of precision required



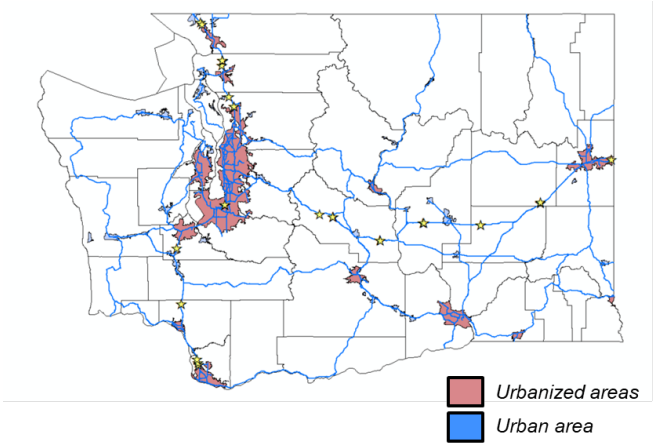
Framework for determining appropriate detection technology based on demand and cost-of-miss detection

Parking lot area



Number of Stall	Size	Count
<= 11	S	5
12-19	M	13
>= 20	L	10

Area Type



Data from WSDOT Geospatial Open Data Portal (0). Access on Oct 5, 2022

Site Evaluation

Comparison of Detection Systems

	Slot-by-slot (Magnetic/Radar-based)	Slot-by-slot (VDO)	In/out counting (With camera calibration)
Level of Precision	• High • Low error accumulate	• Moderate • Error can accumulate	• Moderate • Higher accuracy with the camera calibration
Conduit availability	Require	Require	Not required
Maintenance needs	Require at each detector	Require at each detector	Require at radar unit
Installation	In pavement (lot configuration changes may affect performance)	A location that can capture most of the parking area	At the entrance/exit of the parking lot
Demand	High parking demand	High to low parking demand	Low parking demand (can support higher demand with camera calibration)
Cost of miss	High cost of missed detection	High to low cost of missed detection	Low cost of missed detection(higher with camera calibration)

Selected Detection System

Radar-based entrance/exit counting sensor



Omnisight HD3D Radar & Video AI Fusion Sensor

Sensor Information Summarized

Parking sensor type/name	Omnisight Fusion Sensor V5
Detection accuracy	~90% (99% with data truthing)
Detection principle	Radar/Video Edge Detection
In-lot communication component and protocol	CAT6 - TCP/IP
Lot-to-server communication component and protocol	HTTPS
Communication distance	Wired; up to 1 km with an extender
Power supply of sensor/communication components	PoE Switch or PoE injector
Installation requirement	No controllers required
Maintenance frequency/costs/requirements	$50 / month / radar unit
Internet connectivity requirement/costs	Internet connection required
Input voltage requirement	48 VDC PoE switch
Power access point distance requirement (~ ft)	None
Installation needs for sensing components	Simple single-wire connection; RAM mounts included with device

Selected Detection System

Radar-based entrance/exit counting sensor

System Information Summary

Clear view of the entire sensing area for a truck parking lot	The radars can capture images/video of entry and exit events. A PTZ camera is used to support ground-truth verification of sensor accuracy and site status.
System components	Omnisight Fusion Sensor units operate without a controller. They require only power and internet connectivity.
Power supply requirements / voltage for different components (excluding sensor)	PoE 802.3at
Data type and volume (per day)	Real-time vehicle count and classification.
Communication cost (per month)	Internet service costs
Communication bandwidth requirements	Edge detection requires very little internet bandwidth. Sensors can also be configured to transmit 24/7 video, which would require more bandwidth, but this is not enabled by default



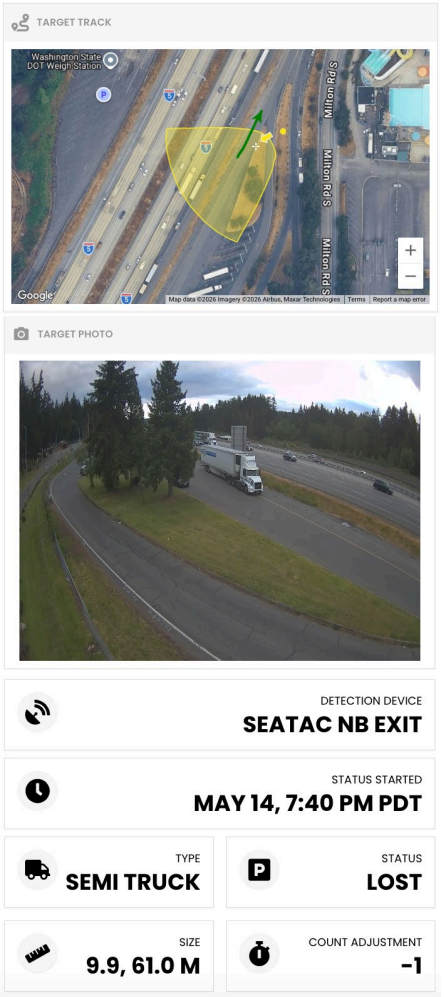
Sensor installation

Selected Detection System

Radar-based entrance/exit counting sensor



Virtual Screenline for Radar Detection at SeaTac Rest Area



Detection Detail

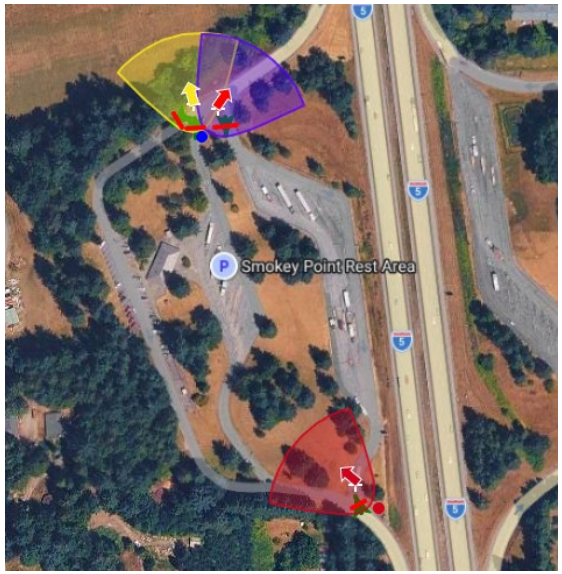
Selected Detection System

Cost for Radar-based entrance/exit counting sensor

- Radar-based entrance/exit counting requires two sensors: one for entry and one for exit
- Some sites may require additional vehicle detection sensors, depending on site configuration and number of access points
- Use all available sensing technologies (i.e. PTZ cameras, detection devices) for data truthing



Layout at Maytown Rest Area with one sensor at entrance and one at exit



Layout at Smokey Point SB with two sensors at entrance and one at exit

Selected Detection System

Cost for Radar-based entrance/exit counting sensor

- Using existing infrastructure, a radar-based TPIMS costs approximately $65,000 per site.
- When installing new infrastructure, a radar-based truck parking monitoring system costs approximately $160,000-$200,000 per site.

Installation Costs:
- Detection hardware
- Communications and power-related components
- Installation labor and commissioning
- System configuration, testing, calibration, and initial support

Ongoing Costs:
- Communications service
- Operations/technical support
- Maintenance and field support
- Data "Truthing" *(internal or external resource cost)*

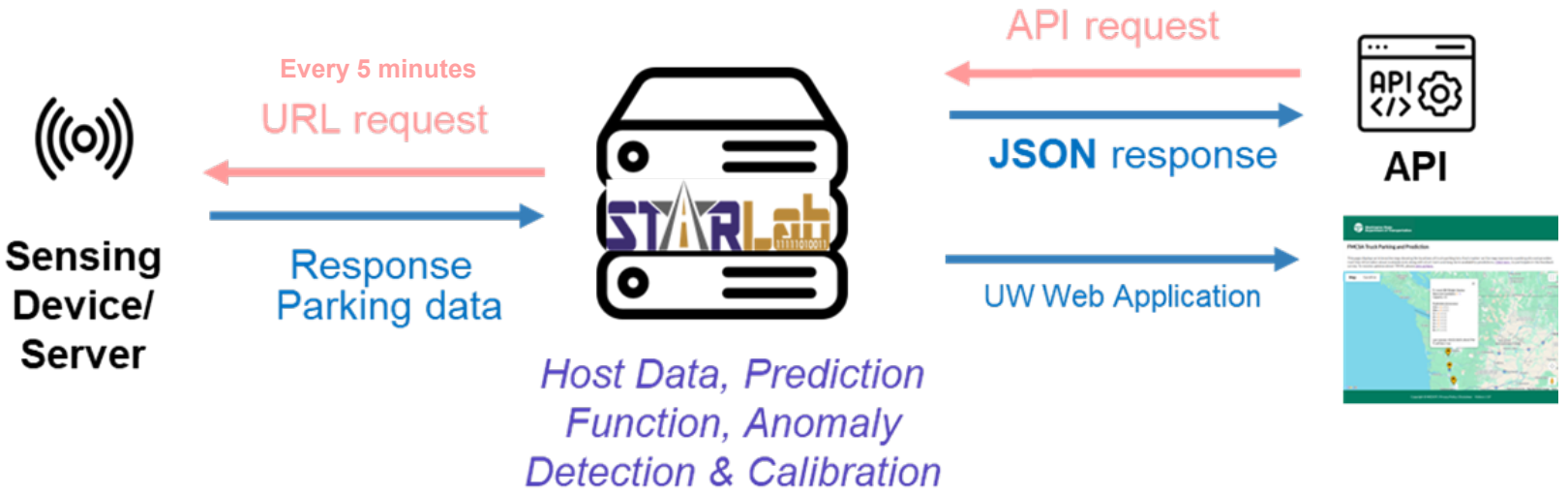
Variable Costs:
- Number of entry/exit points & required number of sensors
- Installing any required new poles, power, and communications connectivity
- Site-specific installation conditions

Selected Detection System

Cost breakdown for typical entry/exit Radar-based counting

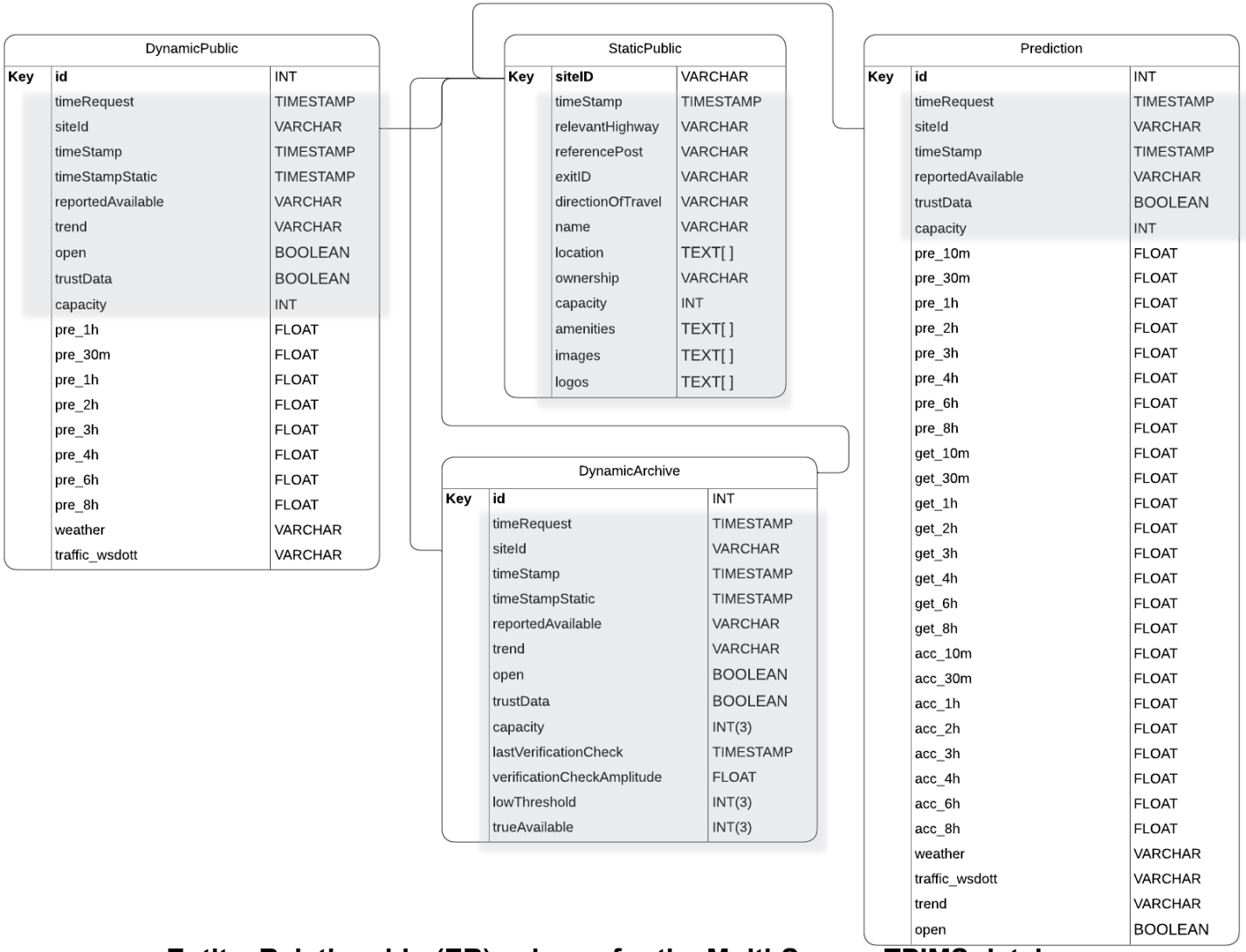
	Component	Description	Cost/Site (Round)
Hardware	Radar Sensor	Omnisight Fusion Sensor v5 ($6500/sensor)	$13,000
	Pole Cabinet Equipment	Pole Communications Cabinet Equipment: (1 per sensor, $6000/each)	$12,000
Installation	Installation-related Project Management services	On-site supervision, travel mobilization, engineering, and project management (IRD/Transpo Group)	$22,000
	Omnisight Calibration & 12 month prepay of Connect		$15,000
	TSIS Burn-In Testing, Onsite Support & Travel		$5,000
Total			**$67,000**
Infrastructure (Variable Cost)	Subcontractor physical installation	Field labor, conduit/wire, equipment installation, traffic control, and related installation work	$45,000
	New Pole purchase & installation		$50,000
Total			**$162,000**
Ongoing Monthly			
Software	TSIS Site Configurator & Management Portal	$250/month	$250
	TSIS Data Truthing (People cost for truthing.)	$500/month	$500

TPIMS Workflow



Workflow

Data Schema



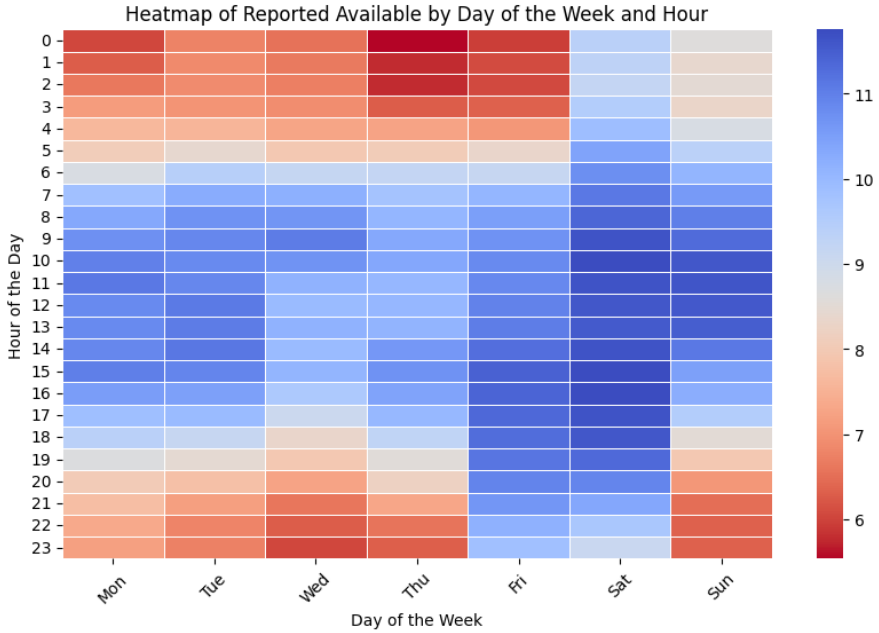
Entity–Relationship (ER) schema for the Multi-Source TPIMS database

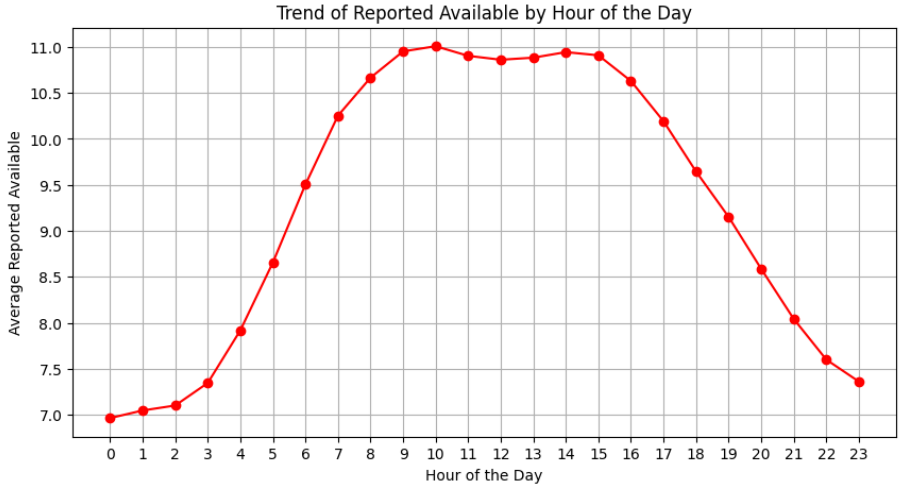
Prediction Model Development and Deployment

Prediction Algorithm

Why prediction is possible

- Historical parking data show recurring temporal patterns
- Availability changes by time of day, day of week, and site conditions
- *These patterns allow us to forecast future parking availability*



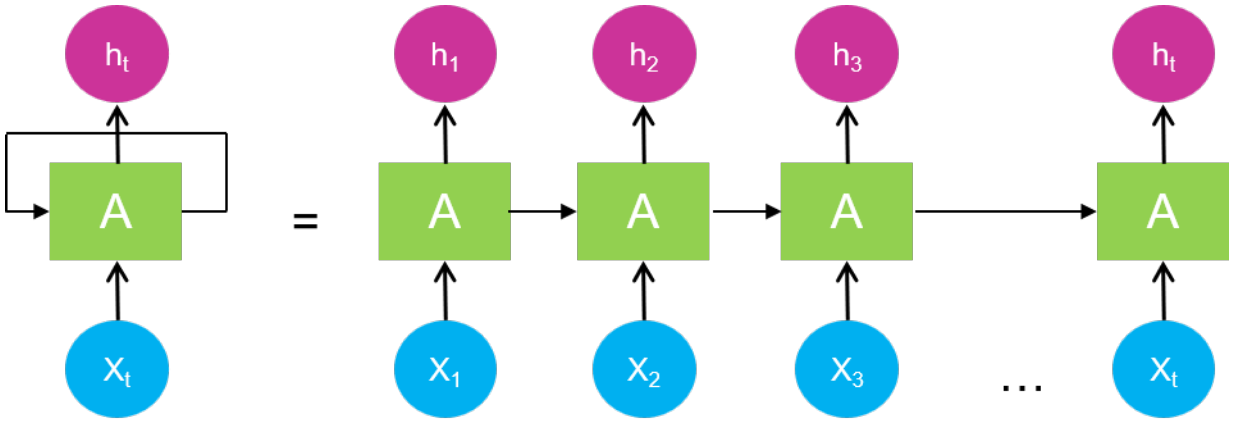


Data collected at Ft. Lewis every 5 minutes over 5 months (Aug 20, 2024 – Feb 13, 2025)

Prediction Algorithm

Recurrent neural network (RNN)

- Parking availability is **time-series data**
- **RNNs** are a class of neural networks designed to learn patterns from sequential observations
  - They use both the current input and information from previous time steps
  - This allows them to learn temporal dependencies and recurring patterns over time
- They use past conditions to predict future states

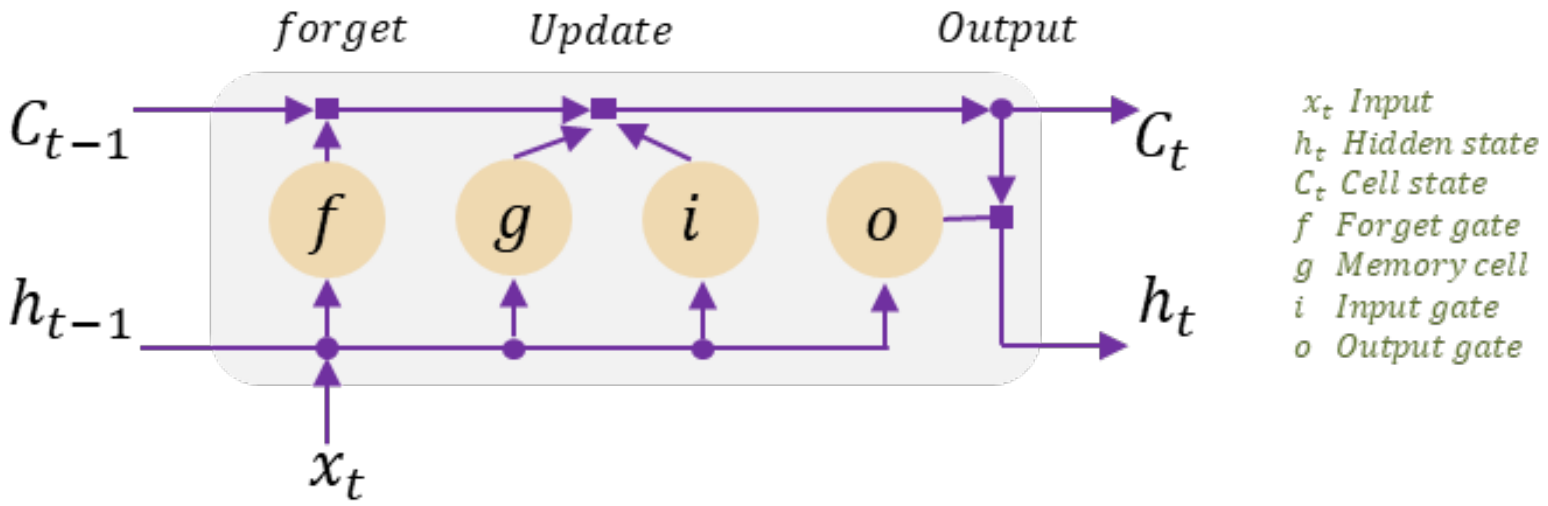


An unrolled recurrent neural network
(xt denotes the input at time step t, A is the recurrent neural network unit, and ht is the hidden state that carries information from previous time steps)

Prediction Algorithm

Long Short-Term Memory (LSTM) network

- LSTM is an advanced type of RNN
- It is better at learning longer-term temporal dependencies
- It is suitable for capturing changing parking patterns over time



Long Short-Term Memory (LSTM) architecture

Prediction Algorithm

Experiment

- Inputs: 5-minute parking availability and time features
- Features:
  - time (minute, hour, day of week)
  - *traffic (WSDOT Traveler Information API)*
    0 = Unknown, 1 = WideOpen, 2 = Moderate, 3 = Heavy, 4 = StopAndGo, 5 = NoData
  - weather (OpenWeather API)
    drizzle, rain, snow, clear, etc.
- Model: 2-layer LSTM with 64 hidden units/layer
- Window length: equal to prediction horizon
  - Example: use 1 hour of prior data to predict 1 hour ahead
- Output: multi-horizon forecasts
  - 10 min, 30 min, 1, 2, 3, 4, 6, and 8 hours ahead

Prediction Algorithm

Experiment

- Train period: 6 months, test period: last 2 weeks
- The model was trained using PyTorch 2.5.1 on a workstation equipped with NVIDIA GeForce GTX 1080 Ti GPUs with CUDA 12.3
- Metrics:
  - **Mean Absolute Percentage Error (MAPE):** quantifies the average magnitude of prediction error as a percentage of the actual value

$$\text{MAPE} = \frac{1}{n}\sum_{t=1}^{n} \left| \frac{A_t - P_t}{A_t} \right| \times 100$$

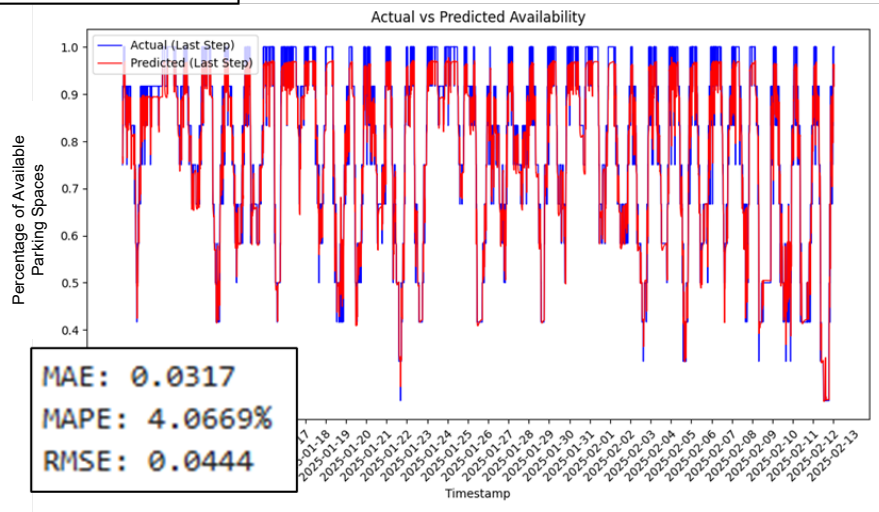
A_t= actual available spaces at time t
P_t= predicted available spaces
n= number of time points

  - **Accuracy=1-MAPE**

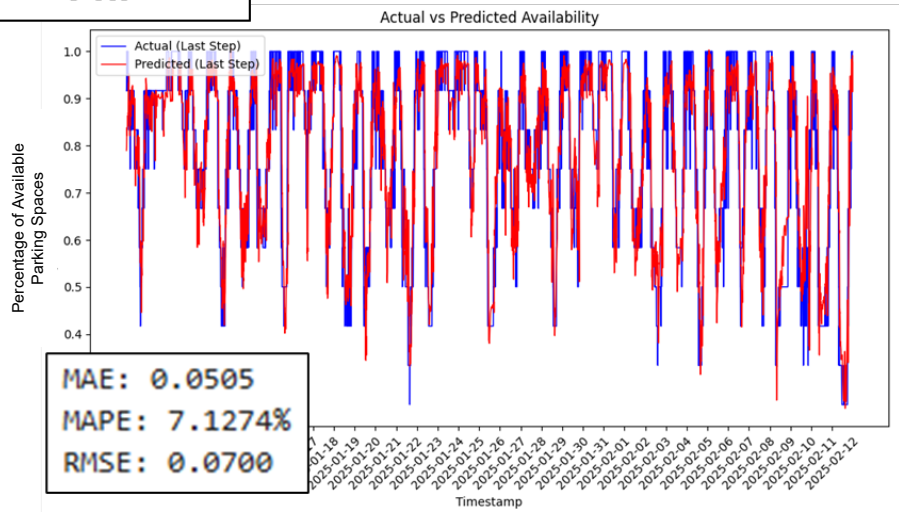
Prediction Algorithm

	10min	30min	1h	2h	3h	4h	6h	8h
MAPE	4.07%	4.82%	7.13%	11.29%	12.16%	15.10%	16.81%	18.19%
Accuracy	95.93%	95.18%	92.87%	88.71%	87.84%	84.9%	83.19%%	81.81

10 min



1 hr

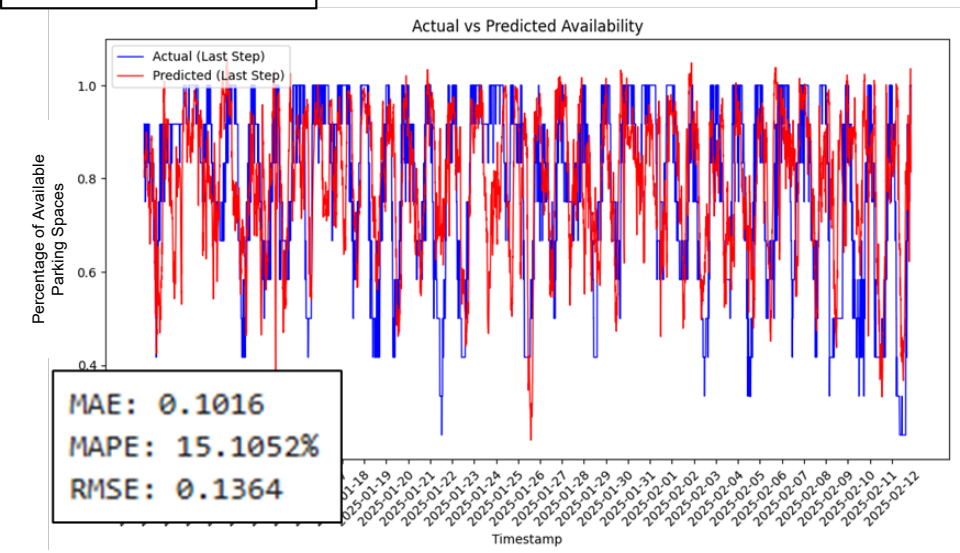


Prediction Result at 10 min and 1 hour

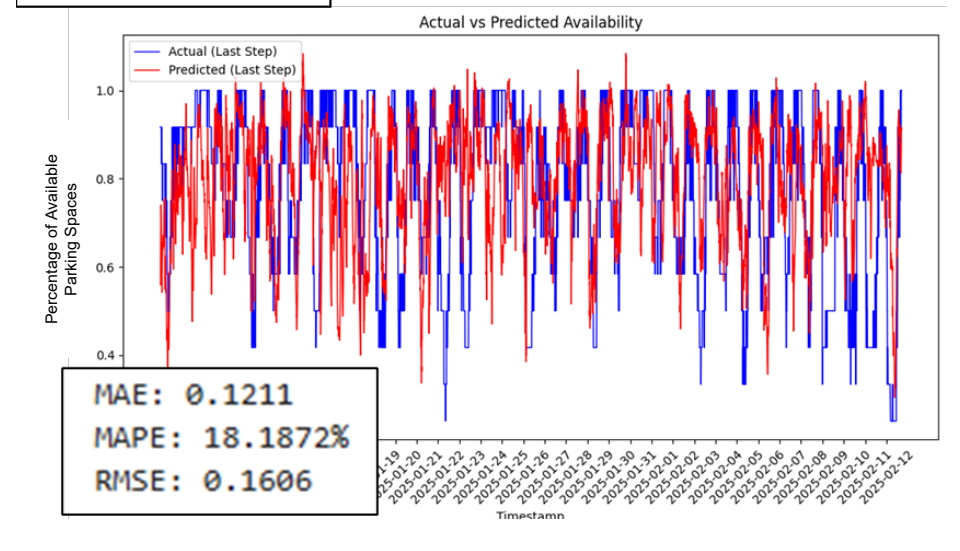
Prediction Algorithm

	10min	30min	1h	2h	3h	4h	6h	8h
MAPE	4.07%	4.82%	7.13%	11.29%	12.16%	15.10%	16.81%	18.19%
Accuracy	95.93%	95.18%	92.87%	88.71%	87.84%	84.9%	83.19%%	81.81

4 hr



8 hr



Prediction Result at 4 hr and 8 hr

Prediction Algorithm

Summary

- Prediction performance varies by forecast horizon. Short-term predictions are stronger, while longer-horizon predictions are more challenging
- The reported 80% prediction accuracy is based on MAPE and reflects performance at the longest horizon (up to 8 hours ahead)
- Shorter-horizon forecasts perform better:
  - reaching about 96% at 10 minutes ahead and 95% at 30 minutes ahead
- Even at longer horizons, the model can still provide useful planning guidance, often with only a small difference in estimated available spaces
- We are continuing to improve the model, with a goal of reaching at least 90% accuracy

API Design and User Interface

API Design

- The API follows the Mid America Association of State Transportation Officials (**MAASTO**) Data Exchange Specification
  - All services adopt standard HTTP RESTful conventions, with responses provided in JavaScript Object Notation (JSON)
  - Each API request requires an authentication key issued to trusted partners, such as MAFC or state DOTs
- Three categories of datasets:
  1. **Dynamic Public Feed:** Real-time availability and operational status for all TPIMS truck parking sites
  2. **Static Public Feed:** Site characteristics and location descriptors
  3. **Dynamic Archive-Only Feed**: Accessible only to trusted partners

API Design


```
{
    "name": "Maytown SB Rest Area",
    "siteId": "WA00005IS0009300SMAYTOWNS",
    "timeStamp": "2025-05-12T23:06:57Z",
    "relevantHighway": "I-5",
    "exitID": "93",
    "referencePost": "93.0",
    "directionOfTravel": "S",
    "location": {
        "latitude": 46.871096,
        "longitude": -122.970358,
        "city": "Maytown",
        "zip": "",
        "streetAdr": "",
        "state": "WA",
        "timeZone": "Eastern"
    },
    "ownership": "PU",
    "capacity": 12,
    "images": [],
    "amenities": []
},
```


Static Public Feed


```
{
    "siteId": "WA00005IS0009300SMAYTOWRA",
    "timeStamp": "2026-04-14T16:00:03.032Z",
    "timeStampStatic": "2026-04-14T22:57:22.000Z",
    "reportedAvailable": "12",
    "trend": "STEADY",
    "open": true,
    "trustData": true,
    "capacity": 12,
    "predict_10m": 11.0,
    "predict_30m": 11.0,
    "predict_1hr": 11.0,
    "predict_2hr": 10.0,
    "predict_3hr": 7.0,
    "predict_4hr": 10.0,
    "predict_6hr": 8.0,
    "predict_8hr": 7.0,
    "acc_10m": 98.0,
    "acc_30m": 89.0,
    "acc_1hr": 95.0,
    "acc_2hr": 92.0,
    "acc_3hr": 75.0,
    "acc_4hr": 83.0,
    "acc_6hr": 57.0,
    "acc_8hr": 67.0
},
```


Additional from MAASTO Standard

$$Accuracy = 1 - \frac{|TruthValue - Predicted|}{TruthValue}$$

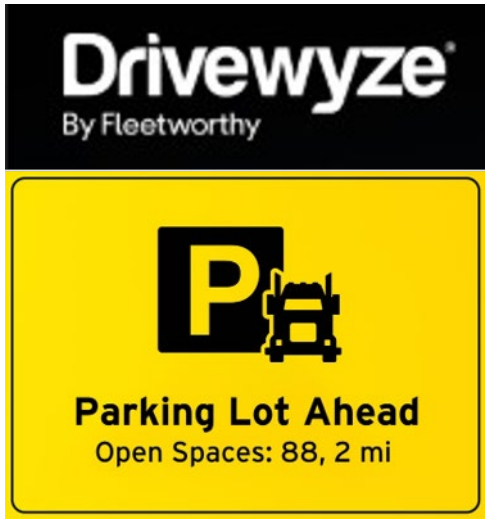
Dynamic Public Feed (modified)


```
{
    "siteId": "WA00005IS0009300SMAYTOWRA",
    "timeStamp": "2026-04-14T23:04:02.000Z",
    "timeStampStatic": "2025-10-31T00:19:46.000Z",
    "reportedAvailable": "12",
    "trend": "STEADY",
    "open": true,
    "trustData": true,
    "capacity": 12,
    "lastVerificationCheck": "2026-03-13T00:18:23.000Z",
    "verificationCheckAmplitude": 0.0,
    "lowThreshold": 1,
    "trueAvailable": 12
},
```

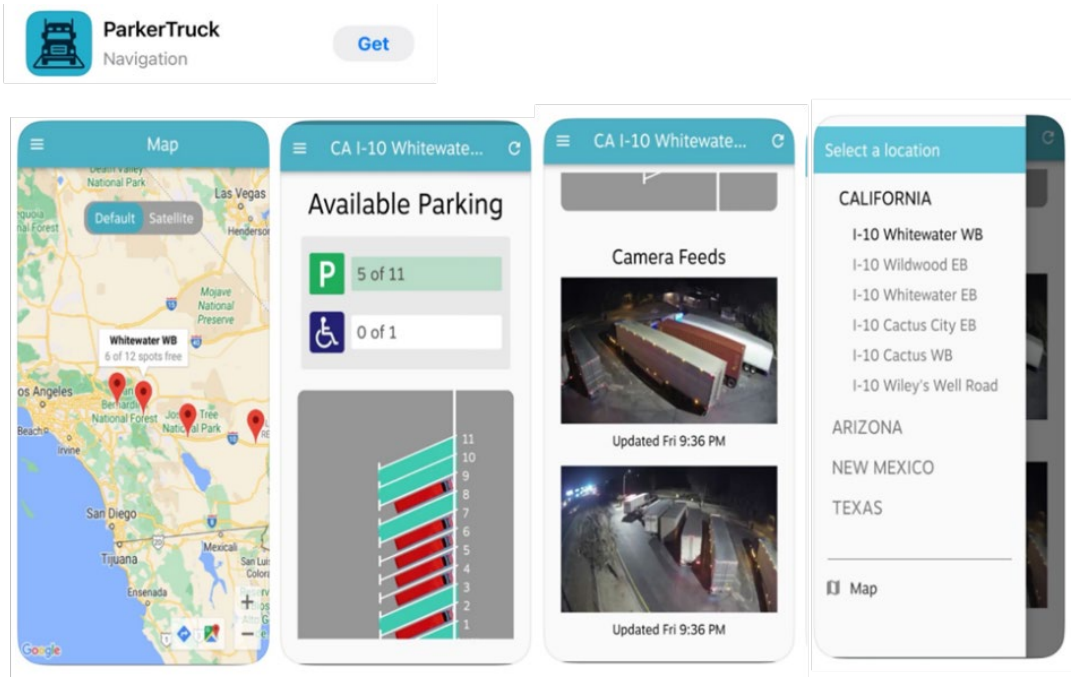

Dynamic Archive Feed

API Design

API Usage in Third-Party Applications

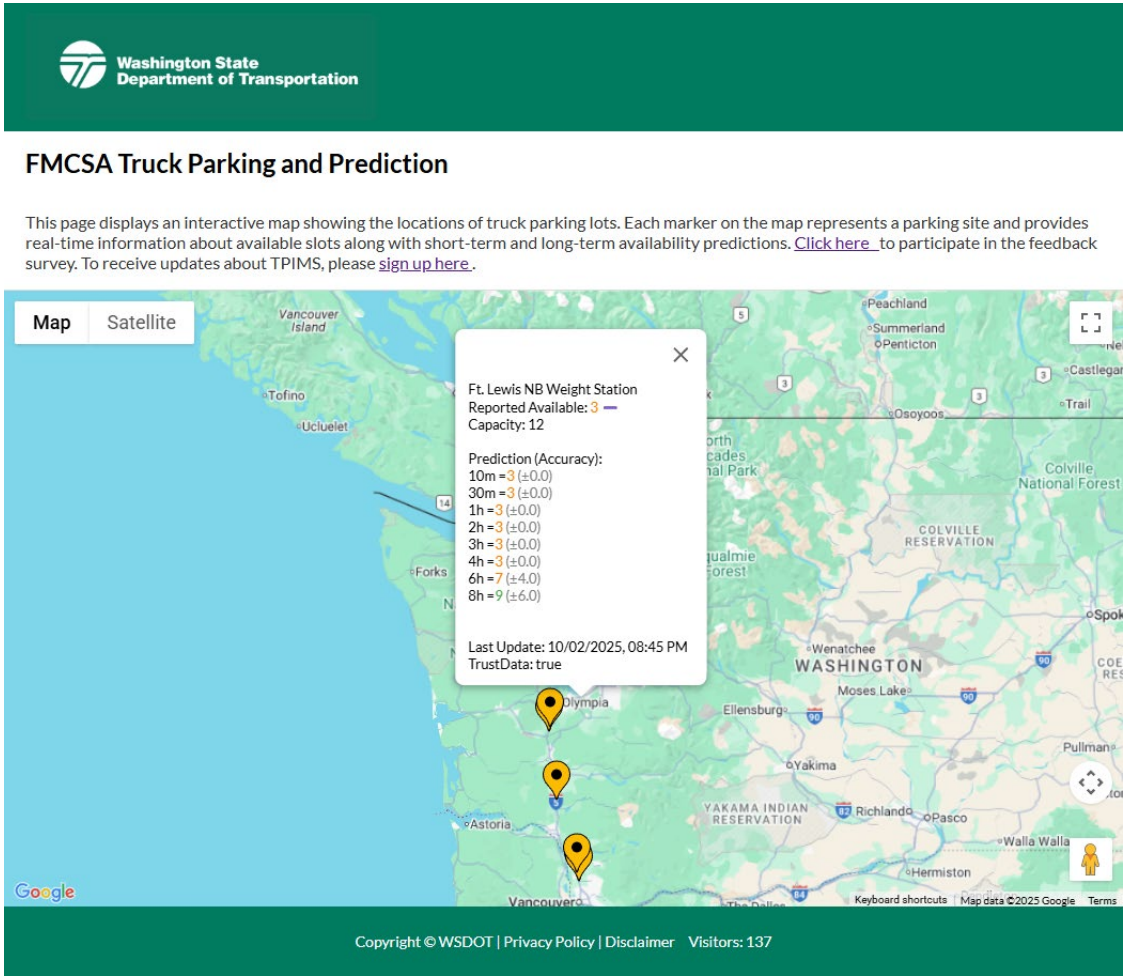


Drivewyze
Notifications to freight
Currently has Geofence



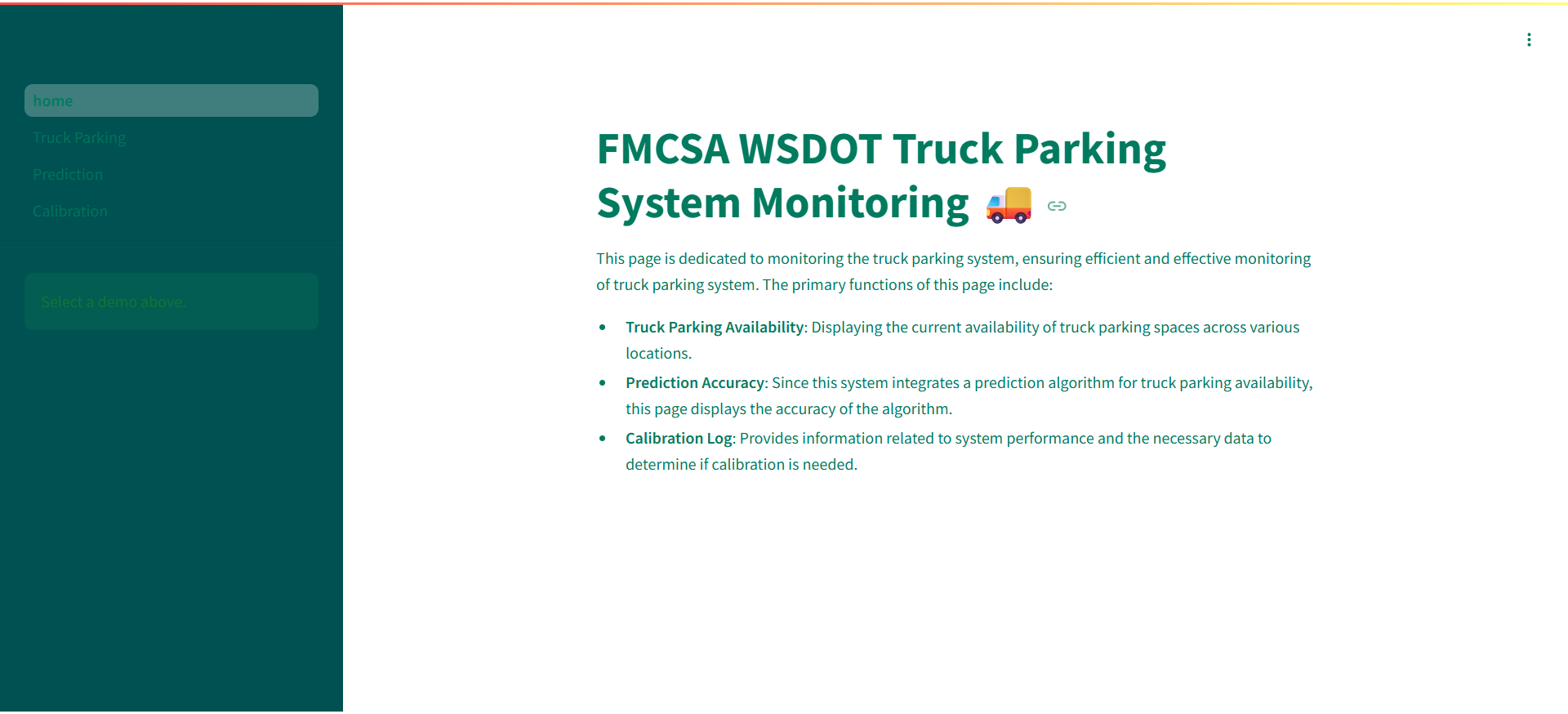
ParkerTruck

University of Washington (UW) TPIMS Dashboard



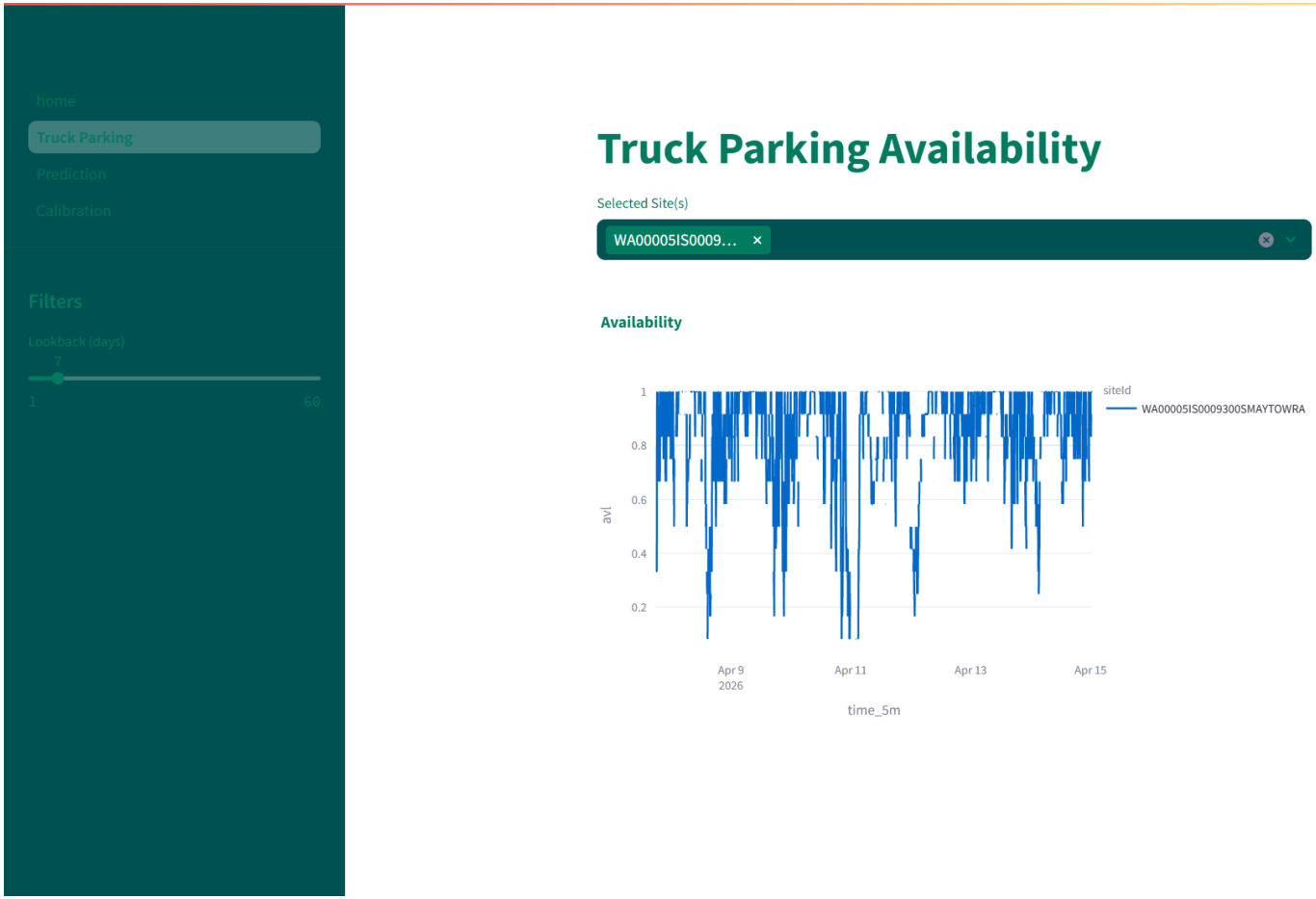
UW TPIMS Dashboard

System Monitoring Interface



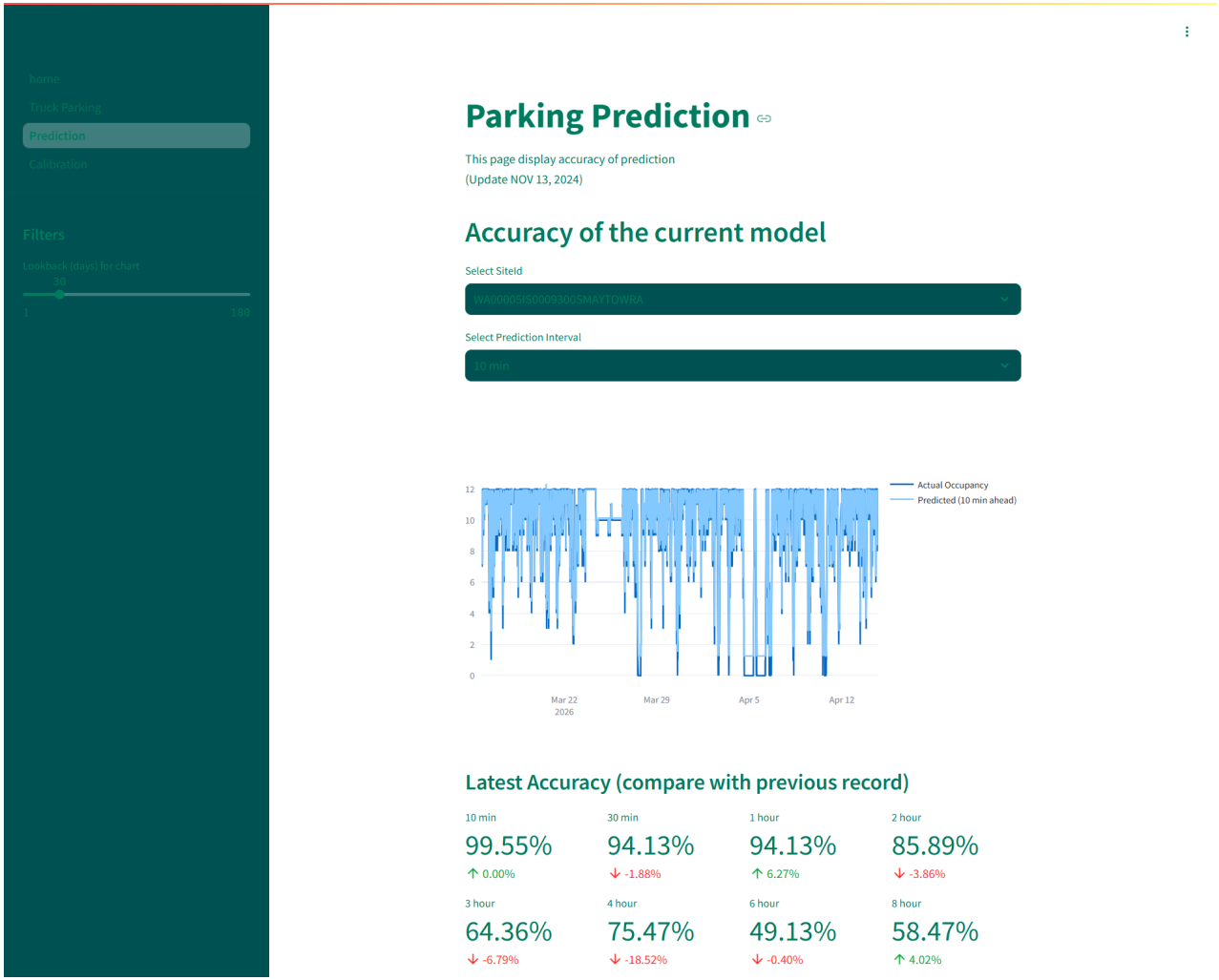
UW TPIMS Dashboard (Internal)
Homepage

System Monitoring Interface



UW TPIMS Dashboard (Internal)
Truck Parking Availability

System Monitoring Interface



UW TPIMS Dashboard (Internal)
Truck Parking Prediction

Data Quality Improvement and Calibration

Challenges with the Selected System

Validation Using CCTV Snapshots:

- Daily Validation (2 times/day)
- Weekly validation at designated hours over a 24-hour period

Real-world sensor errors are frequent, making manual checks impractical. Automated anomaly detection helps identify potential miscounts.



Example images from the SeaTac site showing synchronized views from four CCTV cameras covering all truck parking spaces

Challenges with the Selected System

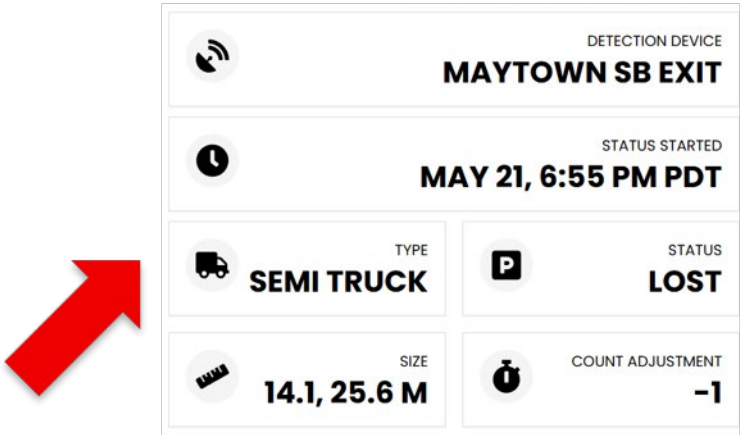
When can in/out radar sensors miscount vehicles? – **Wrong Classification**



Maytown site, where trucks share the entrance and exit with passenger vehicles; detection relies on vehicle classification







Example of misclassification at the Maytown SB exit

Challenges with the Selected System

When can in/out radar sensors miscount vehicles? – **Rare event**



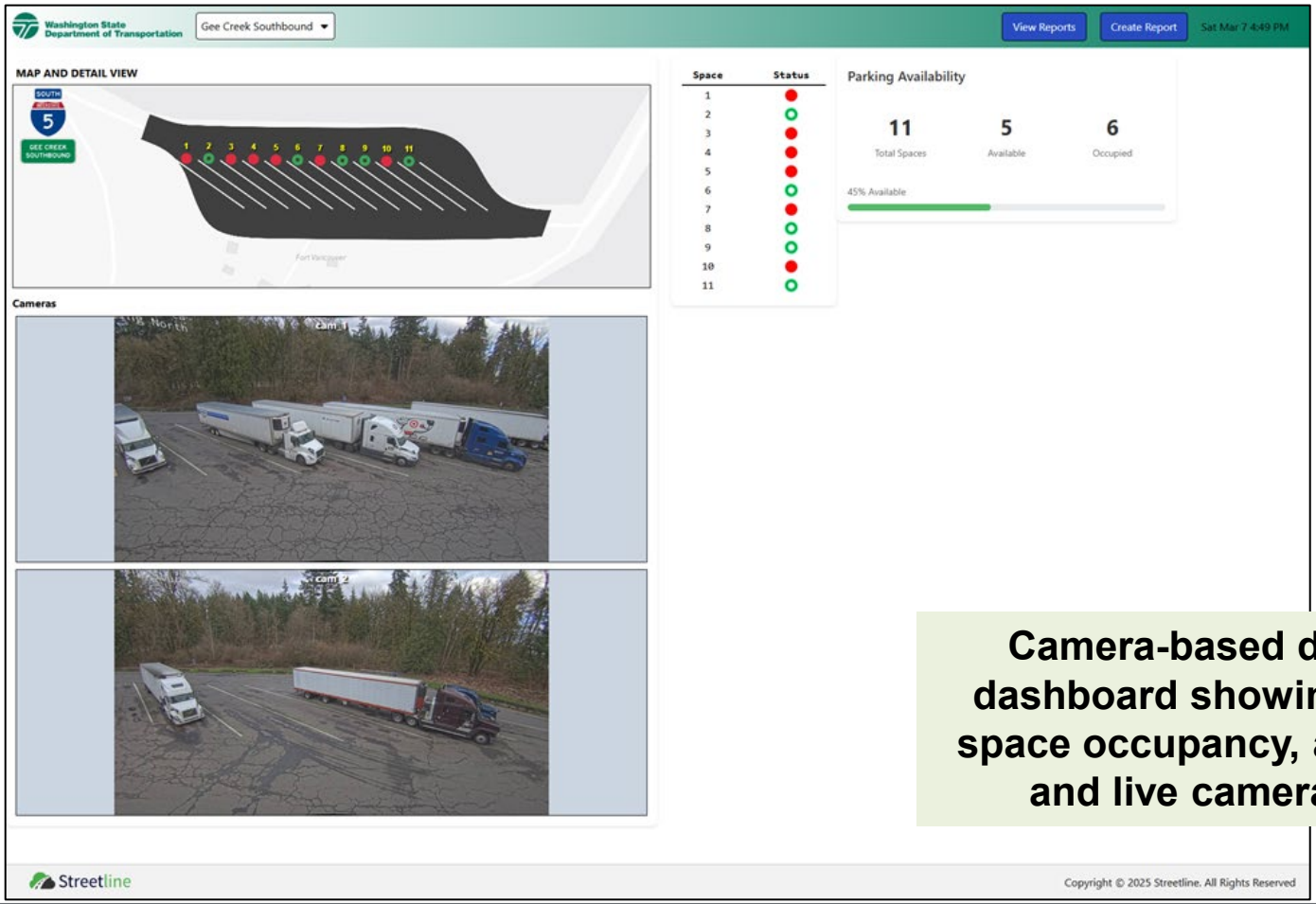
Missed detection at SeaTac due to a queue backup at the entrance



Drivers leave trailers in the lot

Challenges with the Selected System

Reference Sensor – Camera-based detection using CCTV images



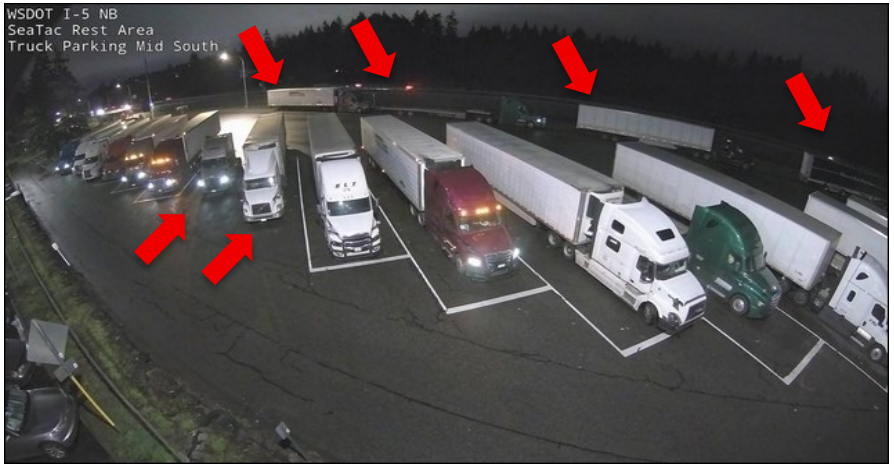
Camera-based detection dashboard showing parking space occupancy, availability, and live camera views

Challenges with the Selected System

When can a reference sensor (image detection) miscount vehicles?



Severe environmental conditions at Gee Creek NB (Top) and camera view obstruction caused by vegetation at Toutle River (Bottom)



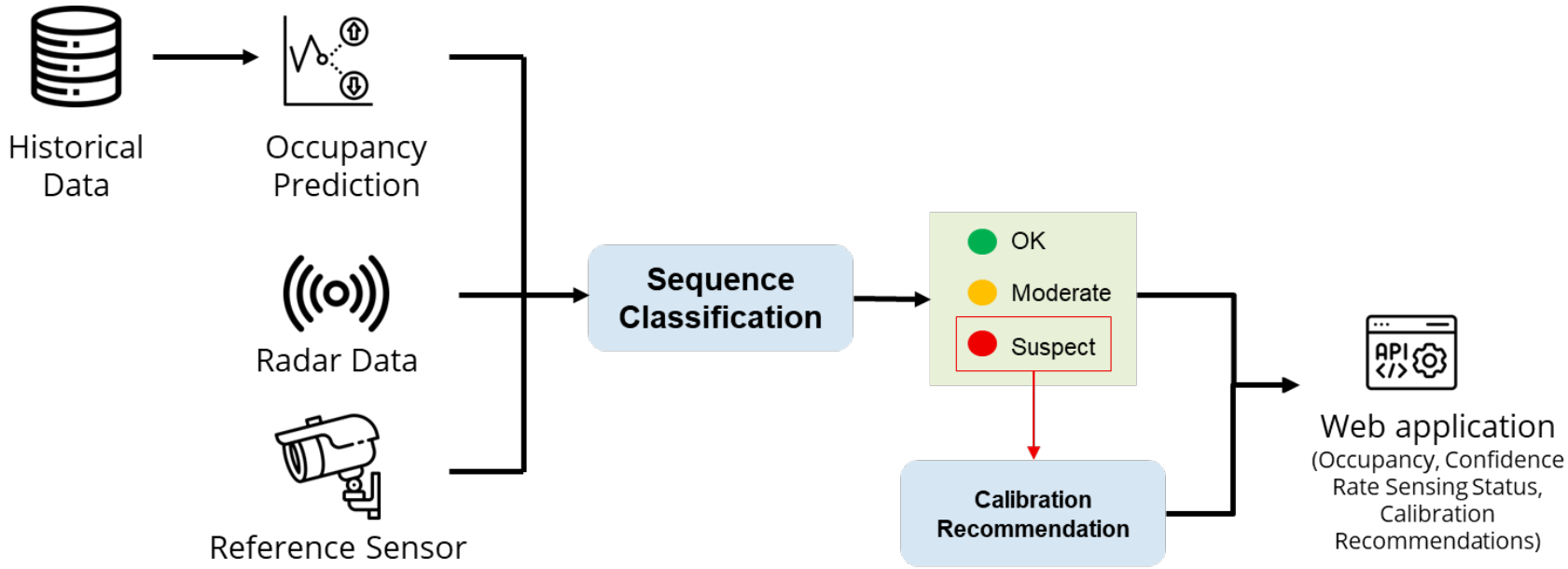
Example of trucks parked outside designated spaces at the SeaTac truck parking site (February 3, 2026, 00:00 AM)

"Relying on a single sensor type may not provide reliable measurements under all conditions"

Anomaly Detection

- Key concern of in/out counting system: **miscounts can accumulate over time**
  - *even a small detection error can gradually lead to large discrepancies*
- **Anomaly detection** helps identify observations or patterns that deviate from expected behavior
- Traditional anomaly detection techniques for time-series data are typically based on statistical methods
- Recent approaches rely on **predictive modeling**
  - A model trained on normal patterns should predict future observations accurately
  - Large prediction errors may indicate anomalous behavior
    - Forecasting-based methods use past data to predict future values and flag anomalies when error exceeds a threshold
    - Reconstruction-based methods learn to reconstruct normal time-series patterns. Large reconstruction errors suggest possible anomalies

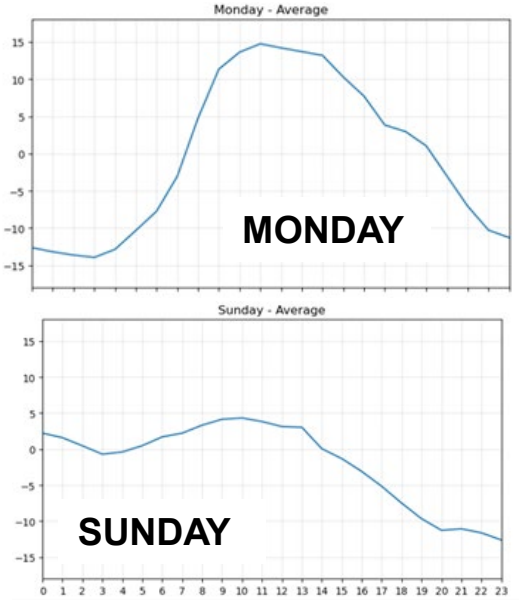
Anomaly Detection and Calibration Framework



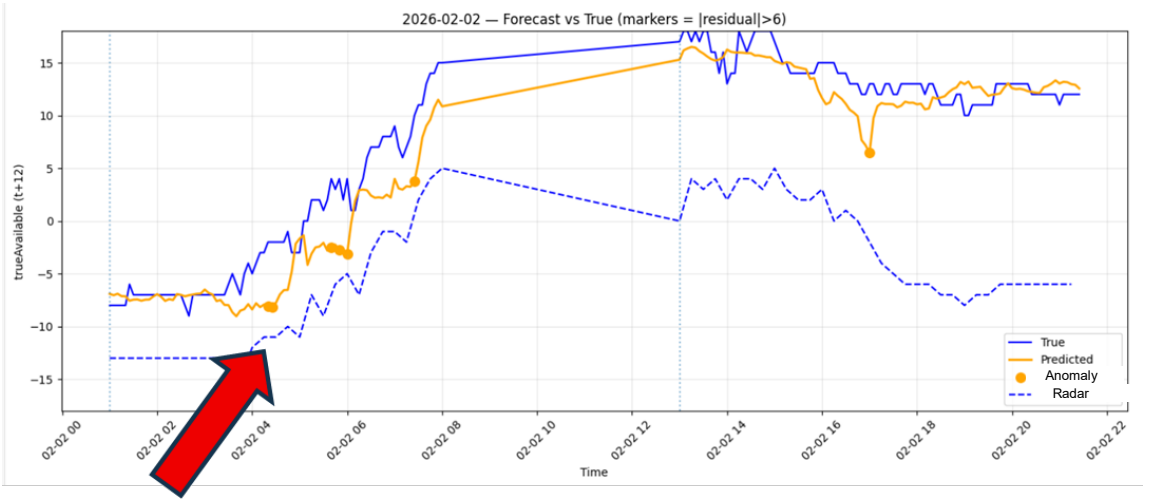
Overview of the anomaly detection and calibration framework

Anomaly Detection and Calibration Framework

- Developed a **prediction-based anomaly detection framework**
- Trained the prediction model using two months of historical data
  - At each time step, the model predicts the expected parking occupancy
  - Computed the prediction residual (difference between predicted occupancy and observed radar occupancy)
- **Camera-based reference sensor data** to provide additional context



Temporal parking availability patterns at SeaTac (Dec 1, 2025 - Feb 5, 2026)



Prediction-assisted anomaly detection

Anomaly Detection and Calibration Framework

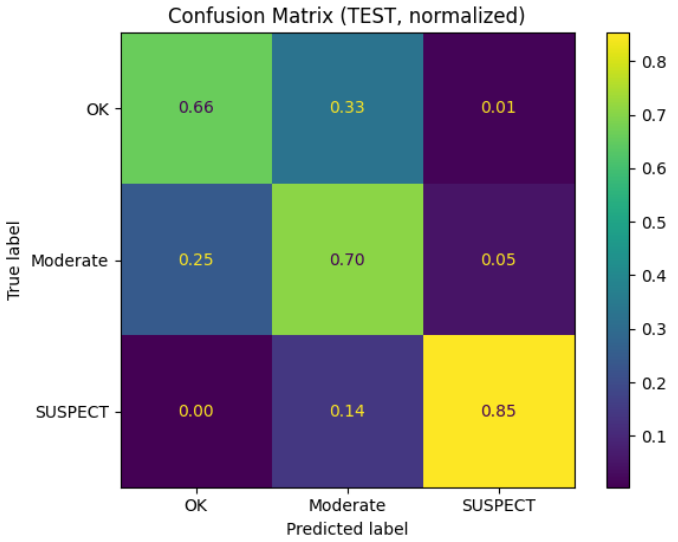
- Used a **sequence classification approach** instead of evaluating each point independently
- Created **rule-based labels**
- Trained an **InceptionTime sequence classification model** using a **48-step input window (4 hours)** and **30-minute prediction horizon**
- Achieved 74.5% overall classification accuracy on the test dataset Model performed:
  - best in identifying Suspect conditions
  - Confidence model was trained on ~600 manually verified observations

OK
- |Radar − Reference| ≤ 2
- Prediction supports a sensor

Moderate
- 2 < |Radar − Reference| < 8

Suspect
- |Radar − Reference| ≥ 8
- Possible sensor malfunction or accumulated counting error

Rule-based labels

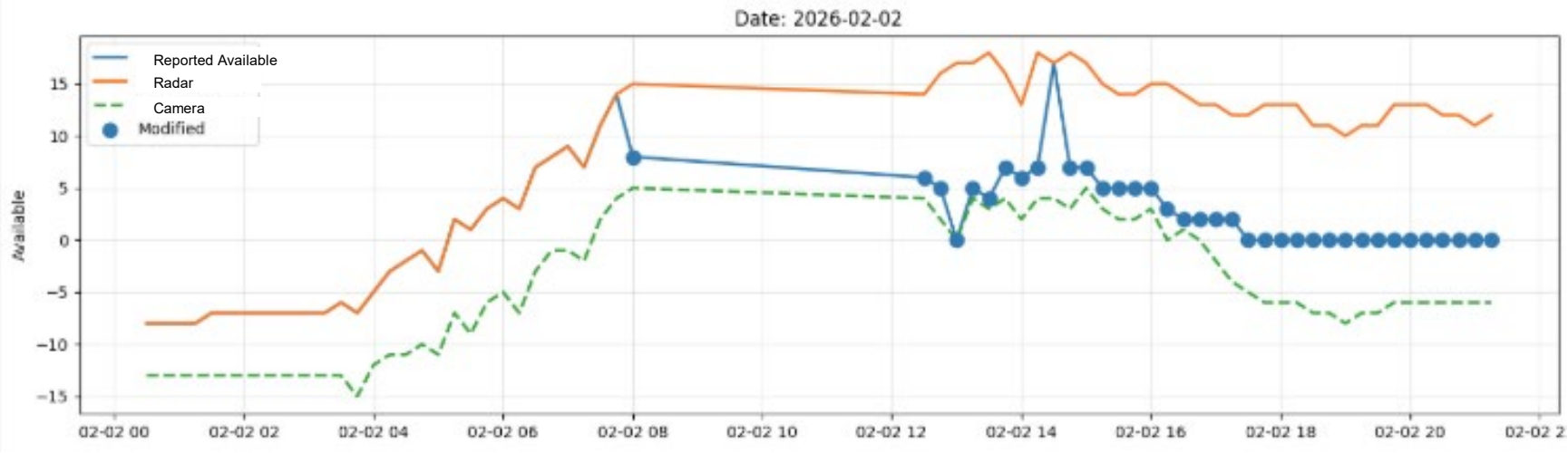


Normalized confusion matrix of the sequence classification model on the test dataset

Anomaly Detection and Calibration Framework

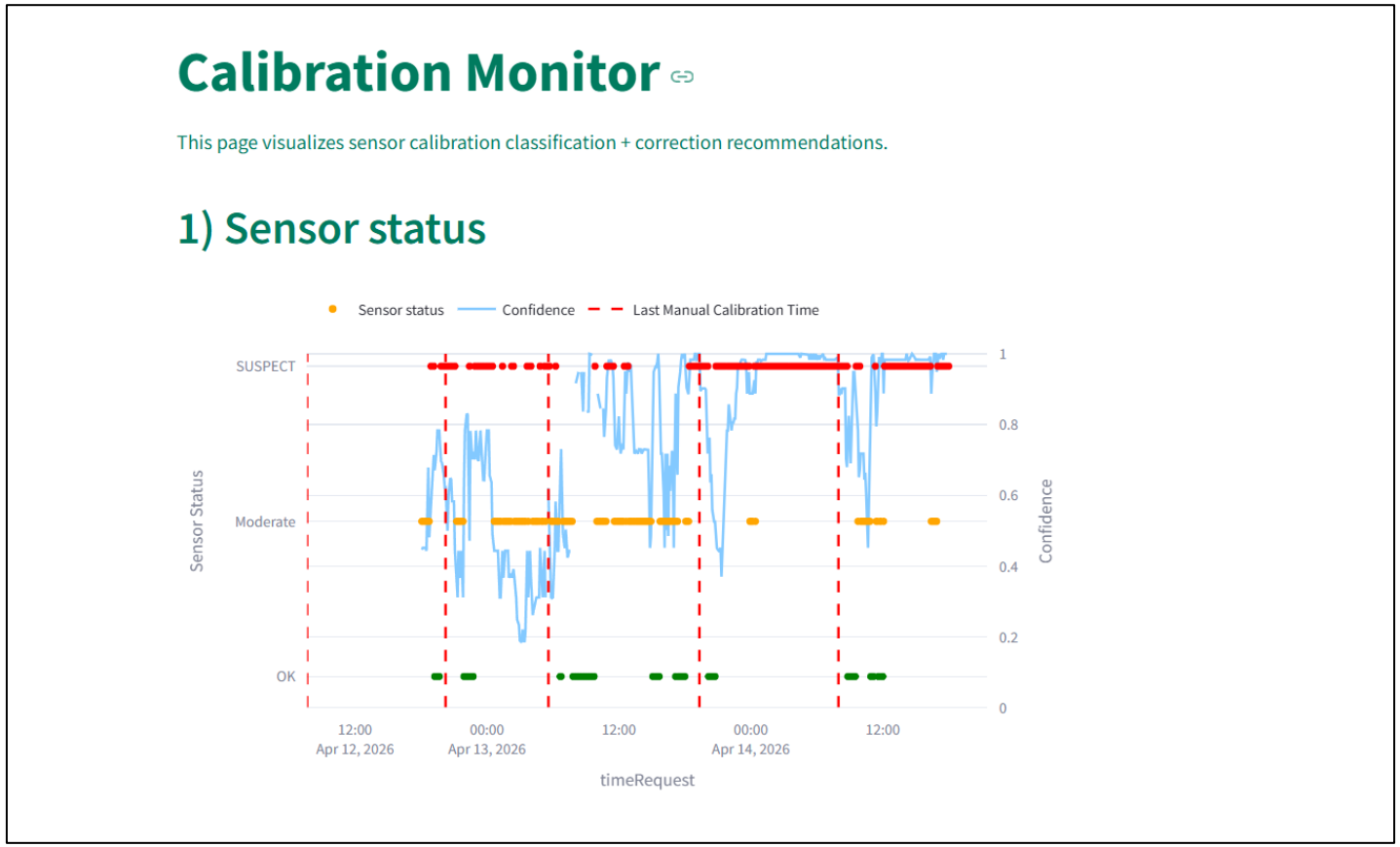
Calibration

- Detect anomalies → recommend calibration
- Apply correction when status = Suspect
- Use a camera-based reference sensor to correct radar estimate
- *Mean Absolute Error (MAE) reduced from 5.51 to 3.97*



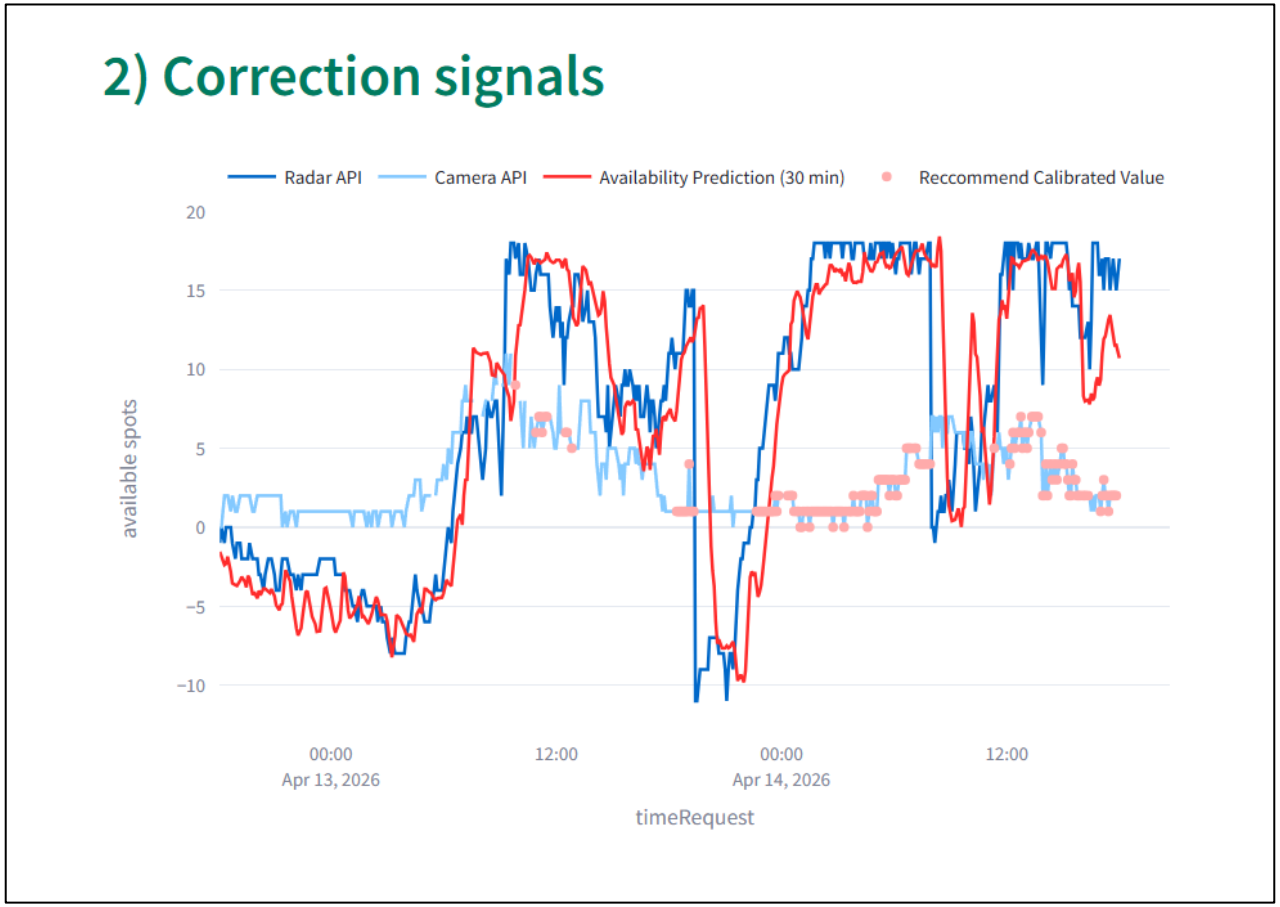
Example of automatic calibration using reference sensor data

Anomaly Detection and Calibration Framework



UW TPIMS Dashboard (Internal)
Sensor Status

Anomaly Detection and Calibration Framework



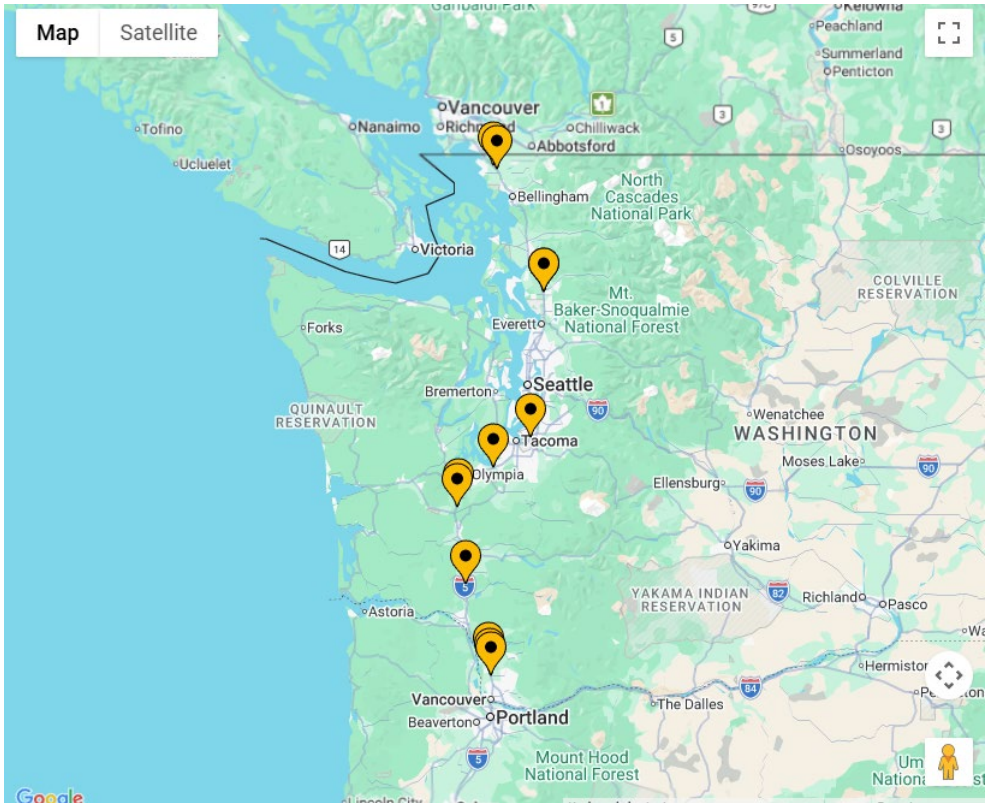
UW TPIMS Dashboard (Internal)
Calibration recommendation

Summary and Findings

Summary

Installed locations (April 2026)

No	Site	Radar	Camera
1	Gee Creek NB	✓	-
2	Gee Creek SB	✓	✓
3	Ridgefield	✓	-
4	Toutle River NB	✓	-
5	Maytown	✓	-
6	SeaTac WS	✓	✓
7	Smokey Point NB	✓	-
8	Smokey Point SB	✓	-
9	Custer NB	✓	-
10	Custer SB	✓	-
11	Ft. Lewis	✓	✓



Installed locations (April 2026)

Summary

Early market penetration (Dec 2025):

- Awareness promoted through WSDOT email outreach and QR-code posters
- Posted at rest areas and weigh stations to inform carriers of the new service
- Early results reflect the initial stage of adoption, with growth expected as awareness expands
  - 101 visitors / 186 views on the Drivewyze landing page
  - 51 landing-page views on Streetline,
  - 3,710 messages sent + 51 new TPIMS email subscribers from the WSDOT outreach campaign



WSDOT outreach poster promoting the new I-5 real-time truck parking information system

Summary

Market Penetration:

- WSDOT expanded its existing Drivewyze partnership to deliver in-cab truck parking availability alerts along the I-5 corridor, from Vancouver to the Canadian border
- This subscription-based service costs approximately $70,000 per year
- Drivewyze alerts generated strong early reach:
  - 120,000+ alerts since the July launch
  - Reaching an estimated 10–15% of I-5 corridor drivers



DriveWyze in-cab alert

Summary

System Performance

Predictive Algorithm

- Validated LSTM model with >80% accuracy across all horizons (10 min–8 hrs)
- Highest accuracy at short-term forecasts (90–95%)
- We continue to improve the AI forecasting tool, with the goal of increasing accuracy for predictions up to 10 hours ahead

Uptime & Latency

- Streetline API reported 100% uptime
- No latency issues observed in data feeds

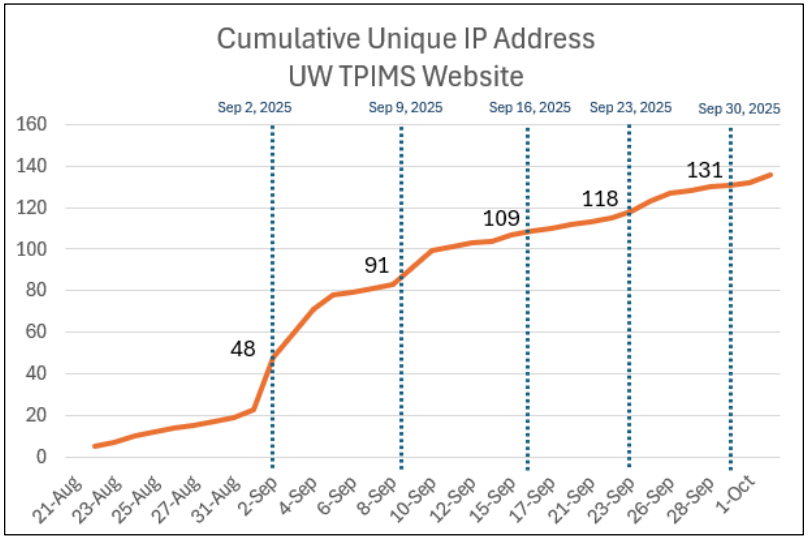
Technical Challenges

- Calibration and placement adjustments are critical for accuracy
- Communication backhaul gaps (fiber/cellular, e.g., Gee Creek)
- Power and cabinet constraints affected equipment reliability

Summary

Dashboard Engagement (Sept 2025)

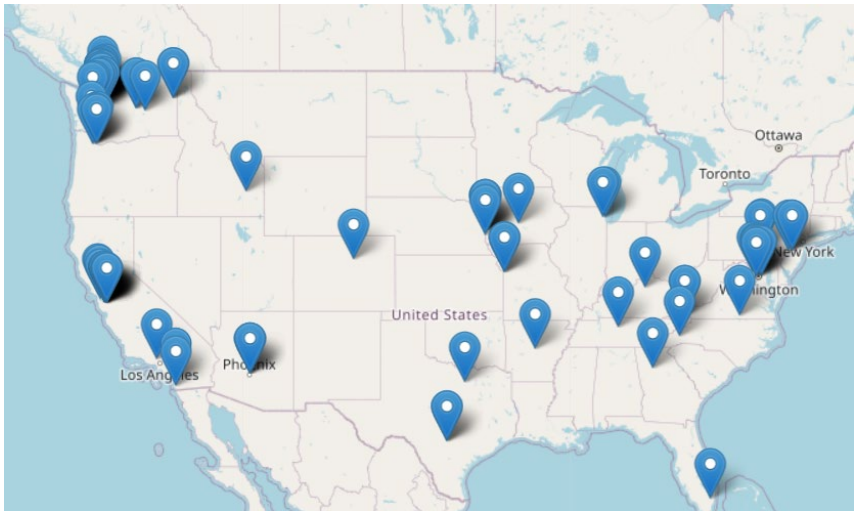
- Visitors: grew from 48 (pre-launch) → 131 (4 weeks post-launch)
- Google Analytics sample: 11 users, avg 34 sec
- Usage mainly desktop-based,



Cumulative of unique IP addresses in USA visiting the UW TPIMS website (Aug 21, 2025 – Oct 2, 2025)

Lessons Learned

- Predictive tool must be accessible and mobile-friendly
- Messaging and map clarity are essential

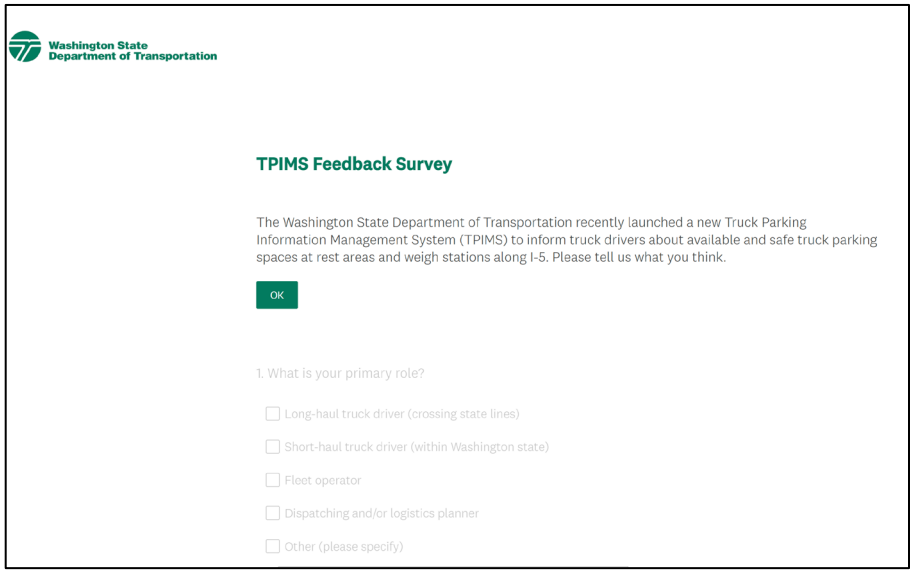


Distribution of IP addresses in USA visiting the UW TPIMS website (Aug 21, 2025 – Oct 2, 2025), based on data from https://www.showmyip.com

Summary

Initial Feedback

- Awareness beginning, engagement limited
- Access to maps/predictive tools must improve
- Messaging needs clarity and consistency
- Stakeholders see value, usability is critical
- Surveys may be insufficient and should be complemented with intercept interviews
- The pilot is building a foundation for broader participation and scale-up



Survey Platform

Findings

Operational Lessons

Equipment Placement

- Camera and sensor angles required adjustment
- Obstructions (trees, lighting) impacted detection reliability

Power & Cabinets

- To reduce installation cost, the system used existing illumination power where possible

Connectivity

- Existing ITS fiber was used when available
- Cellular modems were installed where fiber was unavailable
    - Adds recurring third-party service costs



Severe environmental conditions at Gee Creek NB (Top) and camera view obstruction caused by vegetation at Toutle River (Bottom).

Findings

Programmatic Lessons

Vendor-Neutral Approach

- Info through multiple platforms increased confidence
- Reduced reliance on a single vendor; showed interoperability

Data Validation

- Predictive feeds must be validated before dissemination
- Unvalidated data undermines trust and delays adoption

Evaluation Framework

- Technical metrics alone are not enough
- Must track adoption, satisfaction, and behavior changes

Implementation Process

- Installation and data transfer required coordination with vendors
- Better pre-procurement planning needed for equipment and integration

Future Directions

- WSDOT's Office of Transportation Operations Division is evaluating opportunities to expand truck parking at 24 safety rest areas and 18 vehicle inspection sites along I-5 and I-90. The total budget for analysis of these expansions is $1.2 million[13]
- Ongoing work to support TPIMS improvement

WSDOT Truck Parking 2026-2027 Continual Learning for Predicting Truck Parking Availability

1 Analyze data

Data Collection & Exploratory Analysis

2 Enhance prediction model

Continual/online Learning
Adaptation under non-stationary data

3 Implementation

Framework Development
+ Toolkit

System Configuration and Operational Enhancement of the Truck Parking Information Management System (TPIMS)

1 Support TPIMS software configuration and refinement

2 Support system verification and validation

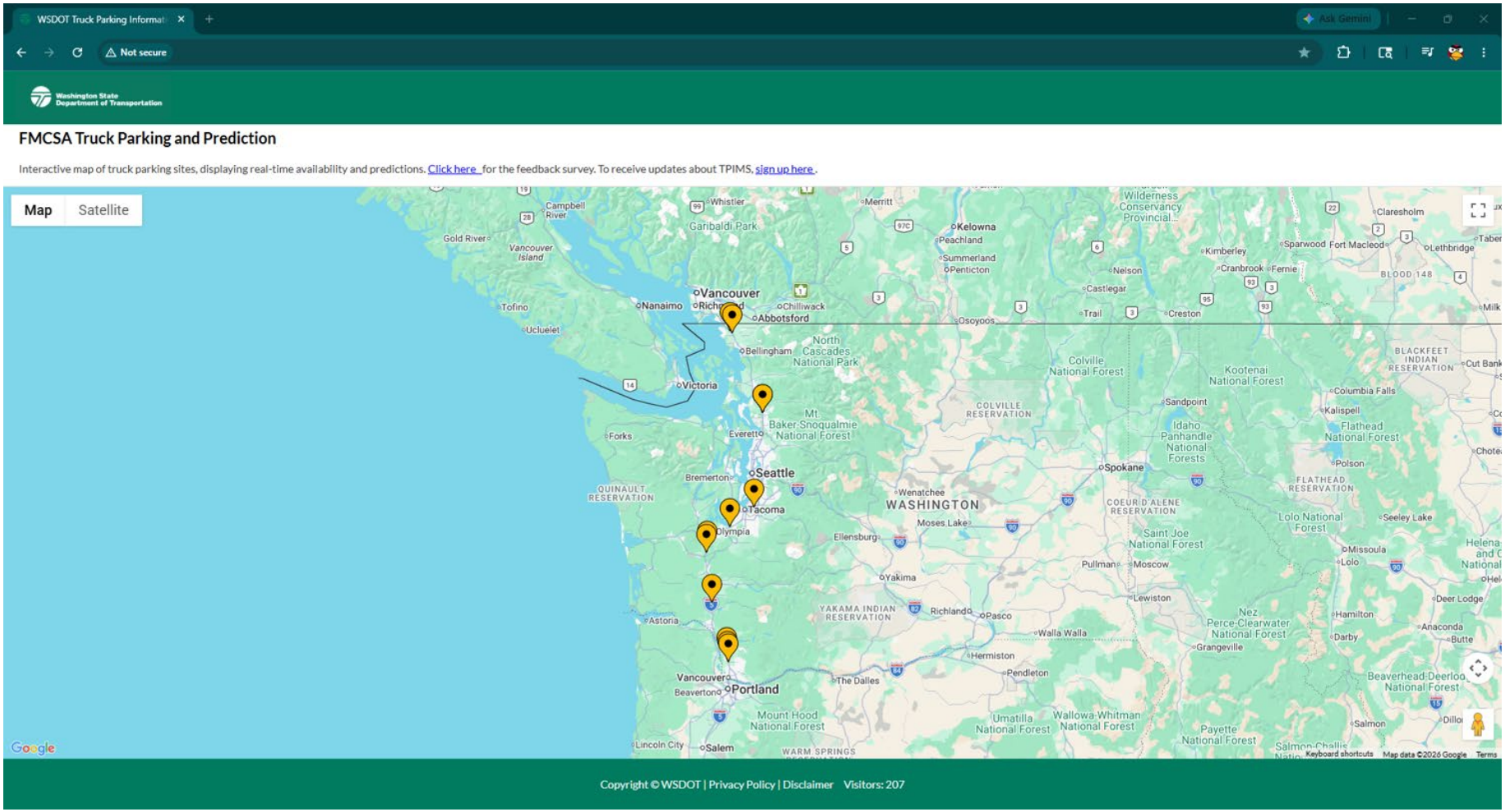
3 Align API standards with WSDOT and relevant stakeholders

4 Improve the WSDOT Traveler website and user interface

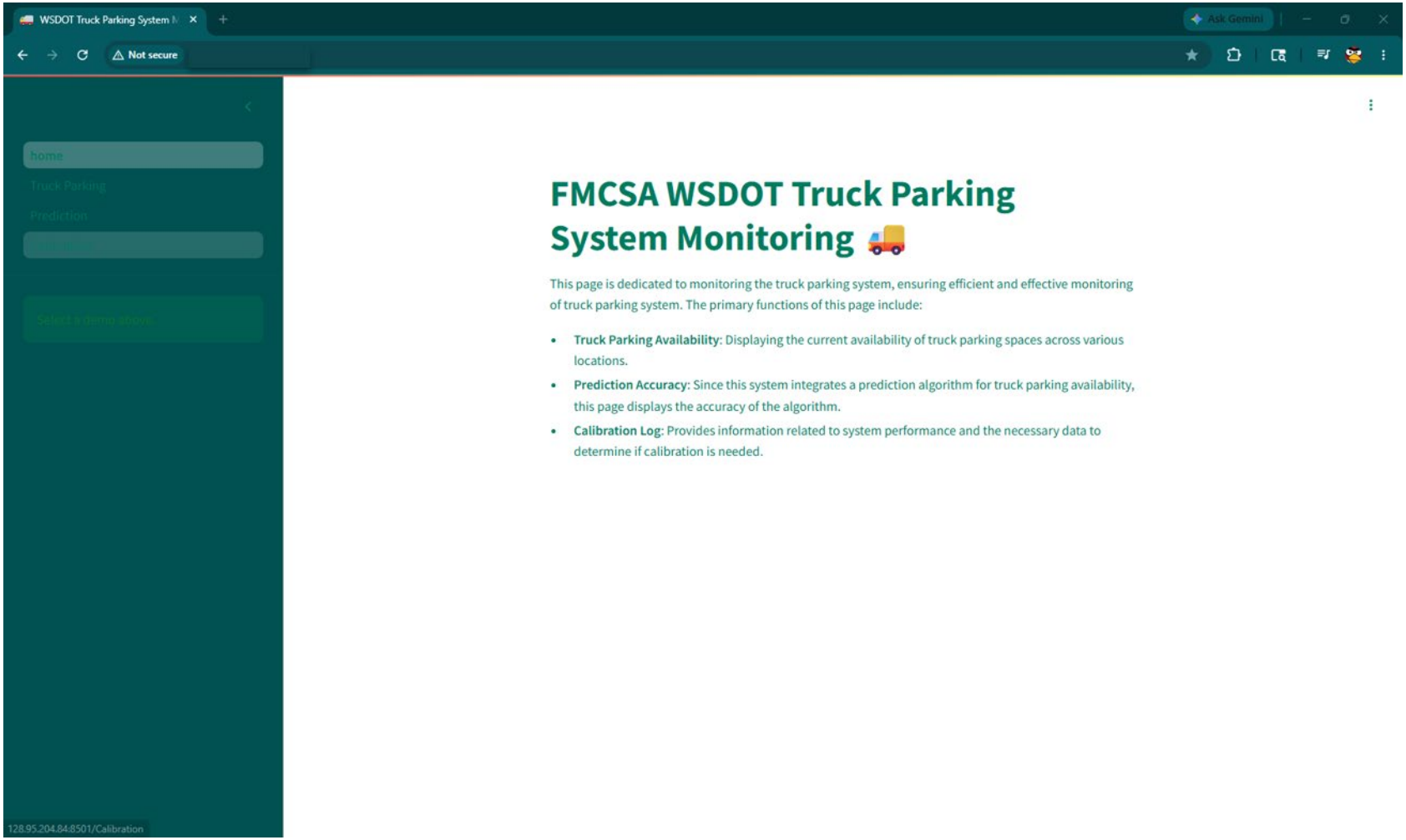
"Future work includes both infrastructure expansion and continued refinement of TPIMS algorithms, software, APIs, and user-facing tools"

[13] WSDOT. (2024). Truck parking plans. https://wsdot.wa.gov/construction-planning/statewide-plans/freight-plans/truck-parking-plans

DEMO


WSDOT Truck Parking Informat
Not secure
Ask Gemini
Washington State Department of Transportation
FMCSA Truck Parking and Prediction
Interactive map of truck parking sites, displaying real-time availability and predictions. Click here for the feedback survey. To receive updates about TPIMS, sign up here.
Map
Satellite
Vancouver
Abbotsford
Victoria
Seattle
Tacoma
Olympia
Spokane
WASHINGTON
Portland
Google
Copyright © WSDOT | Privacy Policy | Disclaimer Visitors: 207

DEMO


WSDOT Truck Parking System
Not secure
Ask Gemini
home
Truck Parking
Prediction
Select a demo above.
128.95.204.84:8501/Calibration
FMCSA WSDOT Truck Parking System Monitoring 🚚
This page is dedicated to monitoring the truck parking system, ensuring efficient and effective monitoring of truck parking system. The primary functions of this page include:
Truck Parking Availability: Displaying the current availability of truck parking spaces across various locations.
Prediction Accuracy: Since this system integrates a prediction algorithm for truck parking availability, this page displays the accuracy of the algorithm.
Calibration Log: Provides information related to system performance and the necessary data to determine if calibration is needed.

Acronyms

AI = Artificial Intelligence
BOOLEAN = True/False value
CAT6 = Category 6 Ethernet Cable
CCTV = Closed-Circuit Television
FLOAT = Floating-point number / decimal number
ft = feet
HTTPS = Hypertext Transfer Protocol Secure
ID = Identifier / Identification Number
INT = Integer
JSON = JavaScript Object Notation
L = Large
M = Medium
PoE = Power over Ethernet
PoE 802.3at = Power over Ethernet, IEEE 802.3at standard
PTZ camera = Pan-Tilt-Zoom camera
RAM = Random Access Memory
RV = Recreational Vehicle
S = Small
SB = Southbound
TCP/IP = Transmission Control Protocol / Internet Protocol
TEXT [ ] = Array of text values
TIMESTAMP = Date and time value
TPIMS = Truck Parking Information Management System
URL = Uniform Resource Locator; commonly, a web address used to access a page or online resource
UW = University of Washington
VARCHAR = Variable Character String
VDC = Volts Direct Current
WB = Westbound
WSDOT = Washington State Department of Transportation

Questions?

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Washington State Department of Transportation, Olympia, WA.

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University of Washington, Seattle, WA.

June 2026

Thanks a lot!