A COST-EFFECTIVE SOLUTION FOR TRUCK PARKING BASED ON ARTIFICIAL INTELLIGENCE

For Western States Forum 2021

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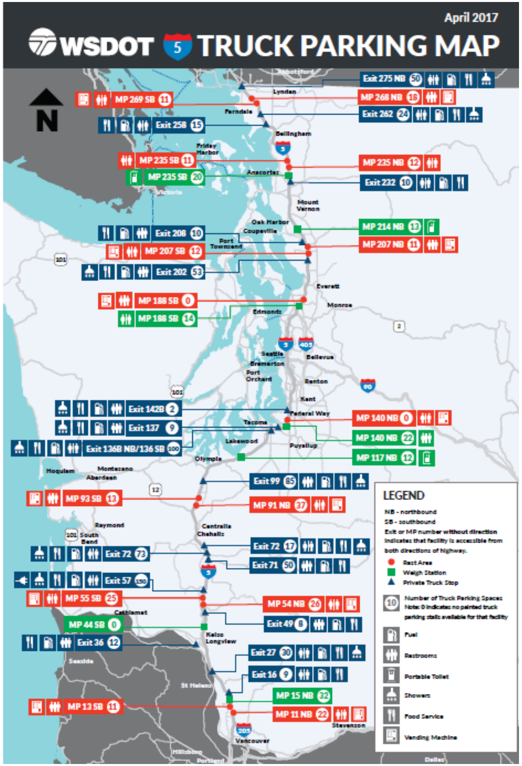
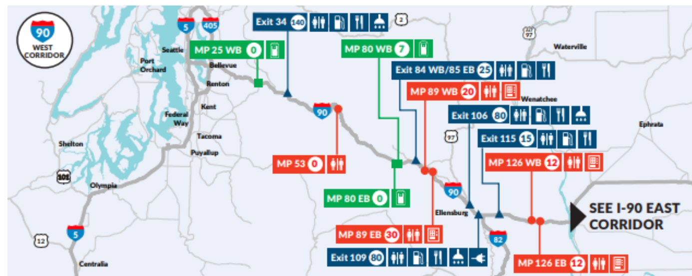
CONTENT

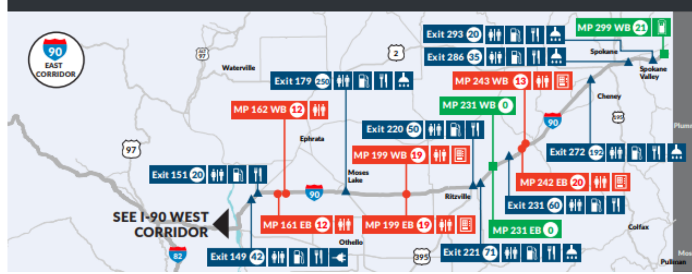
- Context
- Problem Statement & Literature Review
- What We Built – TPIMS in Washington
- What We Learned (Data, Pattern, Innovations)
- Pattern Analysis & Availability Prediction
- Findings
- Next Steps

WASHINGTON STATE TRUCK PARKING FACILITIES



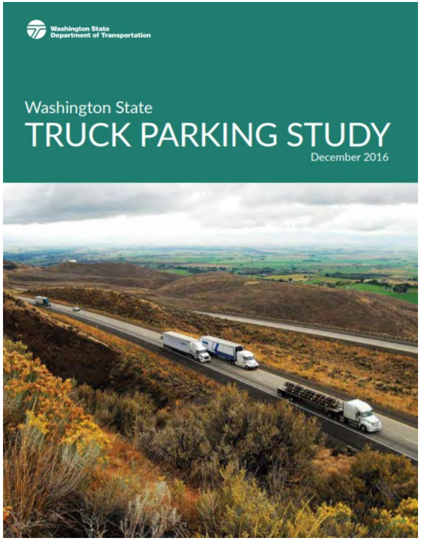
714 stalls
47 safety rest areas
14 weigh stations



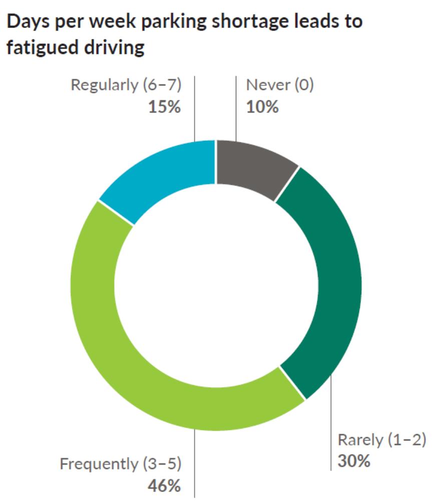


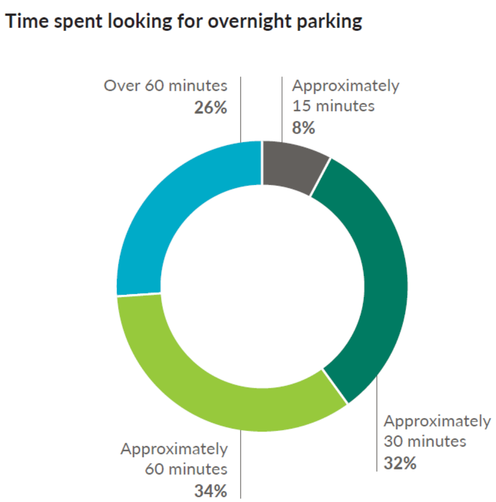
2016 TRUCK PARKING STUDY AND SURVEY

- Survey of over 1,000 truckers
- Identified truck parking issues
- Overview of potential solutions
- https://wsdot.wa.gov/freight/trucking



TRUCK PARKING SURVEY RESULTS



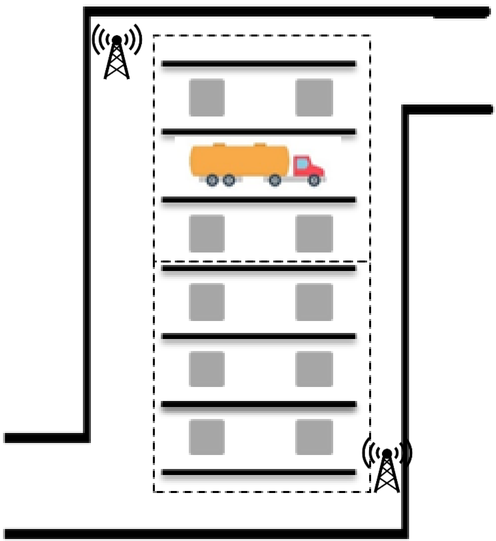


PROBLEM STATEMENT

- The supply of truck parking infrastructure does not meet today's demands
- The lack of parking spaces and real-time parking availability information increases the uncertainty of trips, and results in illegal and potentially dangerous parking or overtime driving
- While extensive research and development has focused on improving the utilization of parking facilities in urban areas, services are still limited and out-of-date for trucks

TRUCK PARKING DETECTION: SLOT-BASED SYSTEMS

- Current truck parking occupancy estimation systems can be divided into two approaches: slot-based and entry/exit-based [1] [3]
- In slot-based systems, sensors need to be mounted at each parking slot [1]
- This system is more accurate and reliable, but is usually expensive with a complex installation process



REFERENCES

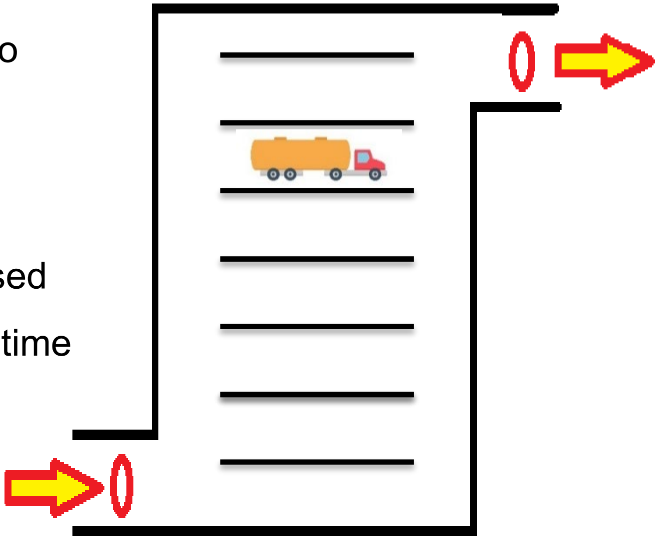
[1] Sun, W., Stoop, E. and Washburn, S.S., 2018. Evaluation of Commercial Truck Parking Detection for Rest Areas. *Transportation Research Record*, *2672*(9), pp.141-151.

[2] Morris, T., Henderson, T., Morellas, V. and Papanikolopoulos, N., 2018. A Real-Time Truck Availability System for the State of Wisconsin.

[3] Vital, F.D.A.A., Ioannou, P. and Gupta, A., 2020. Survey on Intelligent Truck Parking: Issues and Approaches. IEEE Intelligent Transportation Systems Magazine.

TRUCK PARKING DETECTION: FACILITY INGRESS/EGRESS SYSTEMS

- The facility ingress/egress algorithm implementation is cheap and easy to deploy but require high levels of calibration
- Error accumulation (caused by missed ingress/egress events) occurs over time [2] [3]



REFERENCES

[1] Sun, W., Stoop, E. and Washburn, S.S., 2018. Evaluation of Commercial Truck Parking Detection for Rest Areas. *Transportation Research Record*, *2672*(9), pp.141-151.

[2] Morris, T., Henderson, T., Morellas, V. and Papanikolopoulos, N., 2018. A Real-Time Truck Availability System for the State of Wisconsin.

[3] Vital, F.D.A.A., Ioannou, P. and Gupta, A., 2020. Survey on Intelligent Truck Parking: Issues and Approaches. IEEE Intelligent Transportation Systems Magazine.

TRUCK PARKING SENSOR REVIEW

FLIR TrafiCam x-stream video detection sensor [1]

SENSIT parking sensor based on magnetic and infrared [2]

Sensys microwave radar parking sensors [3]

REFERENCES
[1] https://www.flir.com/products/flir-traficam-x-stream/
[2] https://www.nedapidentification.com/products/sensit/
[3] https://www.sensysnetworks.com/products/flexradar

TRUCK PARKING DETECTION REVIEW

- Recently, many technologies and products have been deployed for truck parking detection: camera vision system, magnetic sensor, radar sensor, etc [3].
- In general, video-based detection is easy to install with rich information. However the reliability is not sufficient for 24/7 accurate detection since the detection result is highly impacted by occlusions, weather and lighting conditions [3]
- The radar sensor is the most accurate and reliable option. However, the system cost is high. Two sensors need to be installed on each truck parking slot [1] [2].

REFERENCES
[1] Sun, W., Stoop, E. and Washburn, S.S., 2018. Evaluation of Commercial Truck Parking Detection for Rest Areas. *Transportation Research Record*, *2672*(9), pp.141-151.
[2] Morris, T., Henderson, T., Morellas, V. and Papanikolopoulos, N., 2018. A Real-Time Truck Availability System for the State of Wisconsin.
[3] Vital, F.D.A.A., Ioannou, P. and Gupta, A., 2020. Survey on Intelligent Truck Parking: Issues and Approaches. IEEE Intelligent Transportation Systems Magazine.

LITERATURE REVIEW SUMMARY TABLE

Category	Data/Sensor Type	Checked features	Venue	Year	Ref
Truck Parking	Wireless ground sensors and cameras	Spatio-temporal features analysis	J. Transp. Eng.	2015	[1]
Urban Parking (Survey)	Smart parking management system	Information collection, system deployment and service dissemination	IEEETrans on ITS	2017	[2]
Truck Parking	GPS data	Utilization analysis	J. Transp. Eng.	2017	[3]
Truck Parking	Magnetic and radar-based sensor	Spatio-temporal features, parking event analysis, utilization analysis	TRR	2018	[4]
Truck Parking	Travel diary data	Driver demographics and behaviors analysis, unauthorized parking, parking search time	TRR	2018	[5]
Truck Parking (Survey)	Video, laser, GPS, magnetic, radar etc.	Spatio-temporal features analysis, curves similarity, classification analysis	IEEE ITS Magazine	2020	[6]

REFERENCES

[1] M. E. Bayraktar, F. Arif, H. Ozen, and G. Tuxen, “Smart parkingmanagement system for commercial vehicle parking at public rest areas,” *Journal of Transportation Engineering*, vol. 141, no. 5, p. 04014094, 2015.

[2] T. Lin, H. Rivano, and F. Le Mouel, “A survey of smart parking¨ solutions,” *IEEE Transactions on Intelligent Transportation Systems*, vol. 18, no. 12, pp. 3229–3253, 2017.

[3] K. Haque, S. Mishra, R. Paleti, M. M. Golias, A. A. Sarker, and K. Pujats, “Truck parking utilization analysis using gps data,” *Journal of Transportation Engineering, Part A: Systems*, vol. 143, no. 9, p. 04017045, 2017.

[4] W. Sun, E. Stoop, and S. S. Washburn, “Evaluation of commercial truck parking detection for rest areas,” Transportation Research Record, vol. 2672, no. 9, pp. 141–151, 2018.

[5] C. Boris and R. Brewster, “A comparative analysis of truck parking travel diary data,” *Transportation Research Record*, vol. 2672, no. 9, pp. 242–248, 2018.

[6] D. J. Sun, X.-Y. Ni, and L.-H. Zhang, “A discriminated release strategy for parking variable message sign display problem using agent-based simulation,” IEEE Transactions on Intelligent Transportation Systems, vol. 17, no. 1, pp. 38–47, 2015.

LITERATURE REVIEW SUMMARY TABLE

Category	Features/Model	Performance Evaluation	Venue	Year	Ref
Urban Parking	Long short-term memory (LSTM) Neural Network for stochastic prediction	MAE/MAPE/RMSE/RRSE	International Conference on GCP	2018	[1]
Urban Parking	Customized deep neural network based on Graph-Convolutional Neural Networks (GCNN) and LongShort Term Memory (LSTM)	MAE/MAPE	Transportation Research Part C	2019	[2]
Urban Parking	Long short-term memory (LSTM) Neural Network	Customized evaluation method (α value)	Neural Computing and Applications	2019	[3]
Truck Parking (Survey)	Non-Homogeneous Poisson Model, Multivariate Spatio-temporal Model, Classification Model and etc.	sensitivity and specificity	IEEE ITS Magazine	2020	[4]
City-Wide Parking	Deep learning, Hierarchical Recurrent Graph Neural Network	MAE/RMSE	AAAI Conference	2020	[5]
Short-Term Urban Parking	Poisson distribution model based on arriving and leaving distribution, Classification Model and etc.	Occupancy accuracy evaluation	IEEE Access	2020	[6]
Truck Parking	Static Regular Model, Trend Switching Model, Trend Shifting Model, Hybrid Model and Neural Network	MAPE/RMSE	J. Transp. Eng.	2020	[7]
Urban Parking	Linear Regression, ARIMA, SVM, Back- Propagation Neural Networks	MAE/RMSE	J. Adv. Transp.	2020	[8]

Literature review on truck parking prediction

REFERENCES

[1] W. Shao, Y. Zhang, B. Guo, K. Qin, J. Chan, and F. D. Salim, "Parking availability prediction with long short term memory model," in *International Conference on Green, Pervasive, and Cloud Computing*. Springer, 2018, pp. 124–137.

[2] S. Yang, W. Ma, X. Pi, and S. Qian, "A deep learning approach to real-time parking occupancy prediction in transportation networks incorporating multiple spatio-temporal data sources," Transportation Research Part C: Emerging Technologies, vol. 107, pp. 248–265, 2019.

[3] T. Anagnostopoulos, P. Fedchenkov, N. Tsotsolas, K. Ntalianis, A. Zaslavsky, and I. Salmon, "Distributed modeling of smart parking system using lstm with stochastic periodic predictions," Neural Computing and Applications, pp. 1–14, 2019.

[4] F. d. A. A. Vital, P. Ioannou, and A. Gupta, "Survey on intelligent truck parking: Issues and approaches," IEEE Intelligent Transportation Systems Magazine, 2020.

[5] W. Zhang, H. Liu, Y. Liu, J. Zhou, and H. Xiong, "Semi-supervised hierarchical recurrent graph neural network for city-wide parking availability prediction," in Proceedings of the AAAI Conference on Artificial Intelligence, vol. 34, no. 01, 2020, pp. 1186–1193.

[6] L. Zheng, X. Xiao, B. Sun, D. Mei, and B. Peng, "Short-term parking demand prediction method based on variable prediction interval," IEEE Access, vol. 8, pp. 58594–58602, 2020.

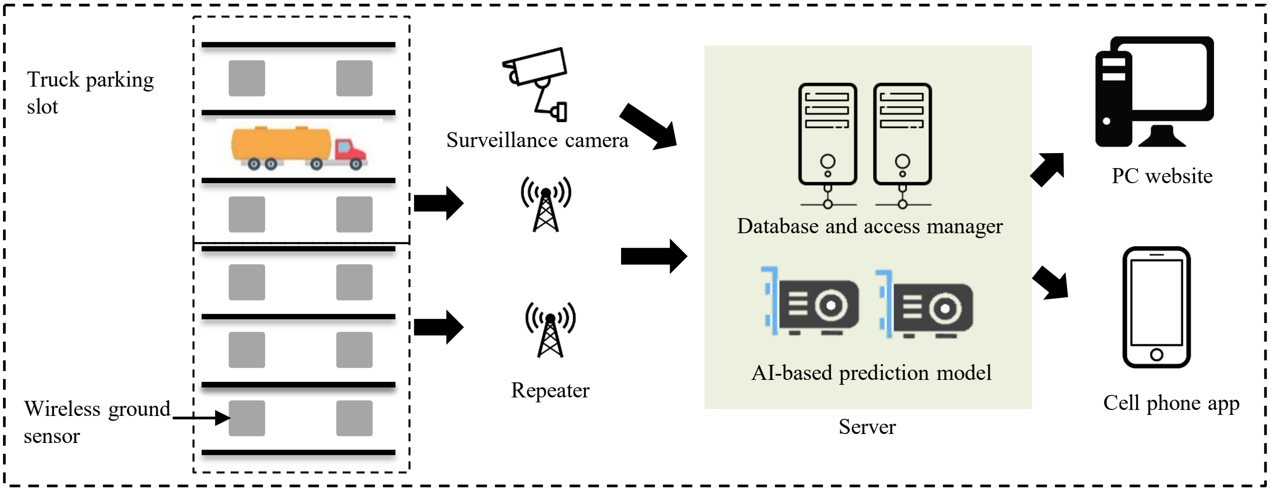
[7] B. A. Sadek, E. W. Martin, and S. A. Shaheen, "Forecasting truck parking using fourier transformations," Journal of Transportation Engineering, Part A: Systems, vol. 146, no. 8, p. 05020006, 2020.

[8] Z. Zhao and Y. Zhang, "A comparative study of parking occupancy prediction methods considering parking type and parking scale," Journal of Advanced Transportation, vol. 2020, 2020.

LITERATURE REVIEW FINDINGS

- Detailed truck parking pattern analysis requires a large amount of high-quality truck parking data
- Parking pattern and prediction algorithms have focused on urban parking instead of truck parking
- Parking availability prediction can be divided into two categories
  - Traditional approach: static and regression analysis (linear regression, ARIMA etc.)
  - Machine learning approach: sequence-based prediction model including RNN and LSTM
- With the limited parking status information and attribute factors, current models used in truck parking studies are always based on the traditional parametric approach
- Previous research shows that AI models, especially Recurrent Neural Networks (RNN) perform better than the traditional approach because it utilizes additional attributes that impact truck parking behavior

PILOT TPIMS IN WASHINGTON



Pilot TPIMS architecture

TPIMS IN WASHINGTON – SENSOR

VSN240-MP-2 MicroRadar® Sensor for Parking

Key Technological Highlights by Sensys Network, 2021:

- Ultra-low power, patented 6.3GHZ radar for bicycle, pedestrian and parking applications
- Flexible sampling rate: 1-8Hz
- Flexible detection range
- Reliable 2-way radio communications with Sensys Networks gateways

TPIMS IN WASHINGTON – REPEATER

FLEX-RP-B-LL-2 Repeater

Extension of range and coverage of the access point

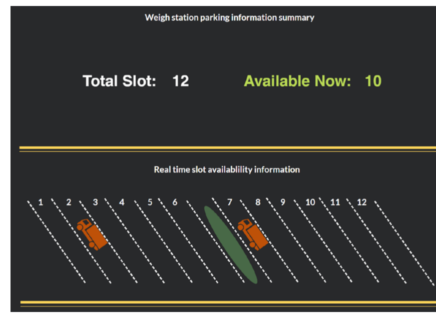
- Supports operating in two directions with one repeater; its supported sensors communicate with the access point
- Maximum single-hop range of ~2000 feet (610 meters) from supporting access point or repeater
- Maximum single-hop range of ~300 feet (91 meters) from sensors with Long Range External Antenna
- Fully wireless operation – no cable connections

TPIMS IN WASHINGTON

Radar-based wireless ground sensor

Repeater

Real-time video



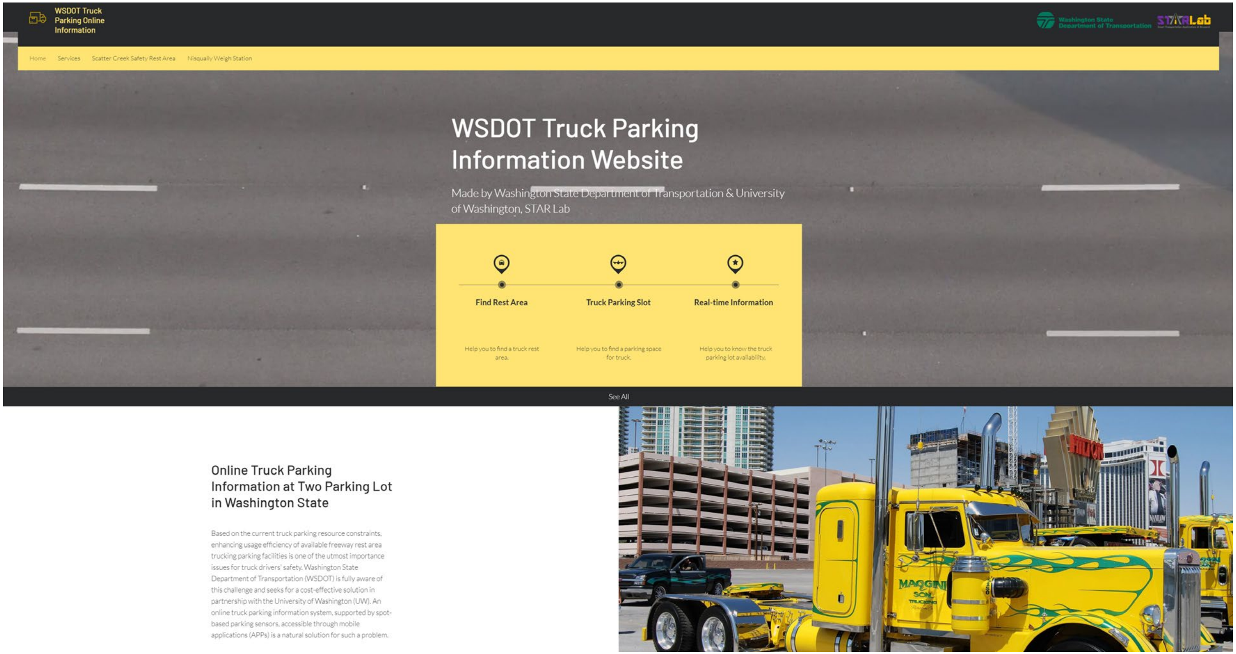
PC website

PILOT SITES IN WASHINGTON

Nisqually Weigh Station truck parking lot.

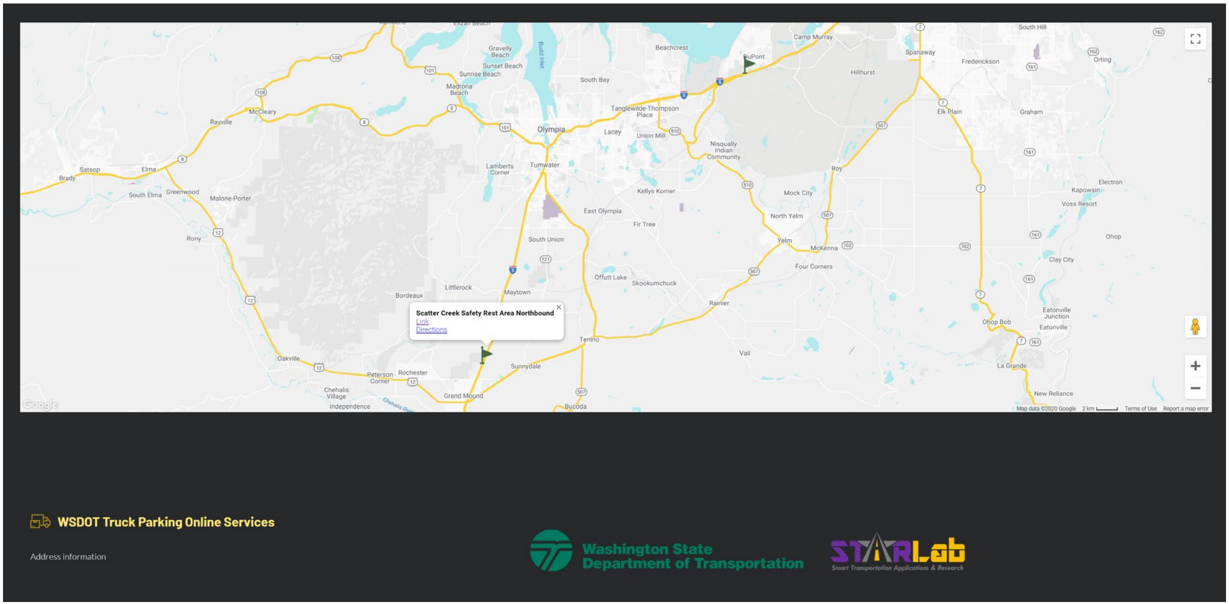
Scatter Creek Safety Rest Area truck parking lot

WEBSITE - MAIN PAGE



https://uwstarlab.wixsite.com/wsdotparking

WEBSITE - MAP PAGE

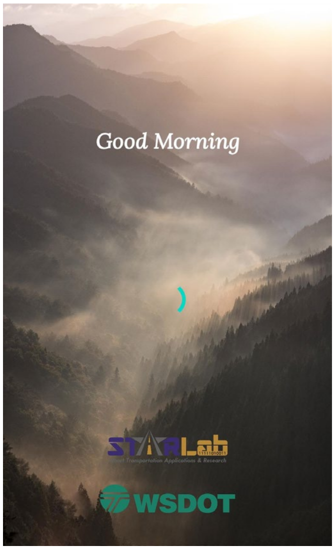


WEBSITE – PARKING AVAILABILITY

Real-time availability at Scatter Creek Safety Rest Area

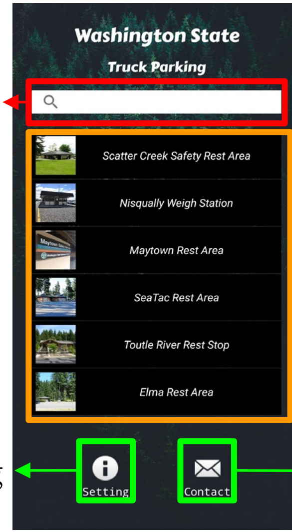
Real-time availability at Nisqually Weigh Station

MOBILE APP – HOME SCREEN



Splash Page

Search Parking Site Name



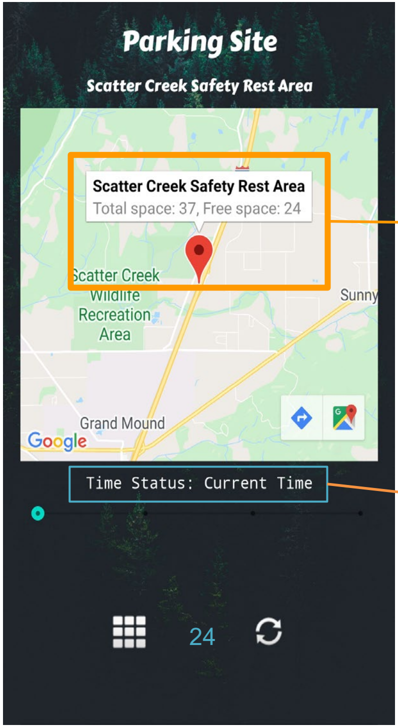
List All Parking Site Name

App Setting

Contact Information

Main Page

MOBILE APP – PARKING AVAILABILITY



Real-time truck parking availability information

Move the slider to get the corresponding parking availability.

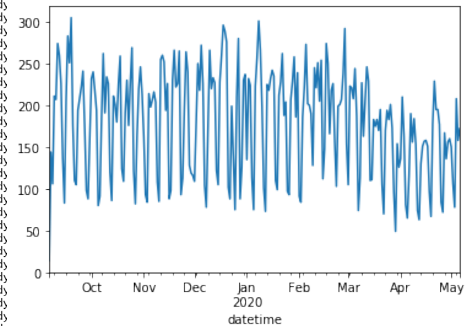
1. Current time
2. 10 min later
3. 30 min later
4. 1 hour later
5. 2 hours later
6. 4 hours later

DATA COLLECTION AND PRIMARY ANALYSIS

- Collected data from January 1st to March10th, 2020, 2021
- Data included:
  - Occupancy %
  - Number of available stalls
  - Date/Time
  - Weather
- Weather: sunny, cloudy, light rain, light snow, rain, snow, wintry mix and fog

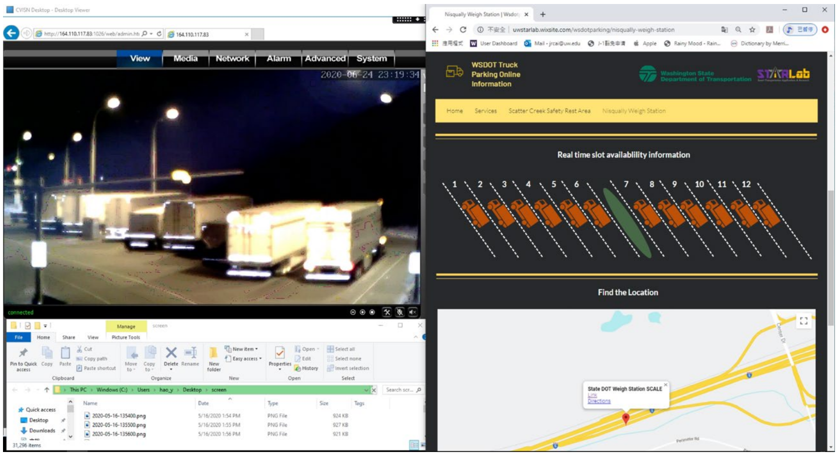
OverID	OccRate	AvSlot	YearID	X1ID	DateID	HourID	MinID	WeatherID
1	0.9459459	2	2020	1	10	0	0	Cloudy
2	0.9459459	2	2020	1	10	0	1	Cloudy
3	0.9459459	2	2020	1	10	0	2	Cloudy
4	0.9459459	2	2020	1	10	0	3	Cloudy
5	0.9459459	2	2020	1	10	0	4	Cloudy
6	0.9459459	2	2020	1	10	0	5	Cloudy
7	0.9459459	2	2020	1	10	0	6	Cloudy
8	0.9459459	2	2020	1	10	0	7	Cloudy
9	0.9459459	2	2020	1	10	0	8	Cloudy
10	0.9189189	3	2020	1	10	0	9	Cloudy
11	0.9189189	3	2020	1	10	0	10	Cloudy
12	0.9189189	3	2020	1	10	0	11	Cloudy
13	0.9189189	3	2020	1	10	0	12	Cloudy
14	0.9189189	3	2020	1	10	0	13	Cloudy
15	0.9189189	3	2020	1	10	0	14	Cloudy
16	0.8918919	4	2020	1	10	0	15	Cloudy
17	0.8918919	4	2020	1	10	0	16	Cloudy
18	0.8918919	4	2020	1	10	0	17	Cloudy
19	0.8918919	4	2020	1	10	0	18	Cloudy
20	0.9189189	3	2020	1	10	0	19	Cloudy
21	0.9189189	3	2020	1	10	0	20	Cloudy
22	0.9459459	2	2020	1	10	0	21	Cloudy
23	0.9459459	2	2020	1	10	0	22	Cloudy
24	0.9459459	2	2020	1	10	0	23	Cloudy
25	0.9459459	2	2020	1	10	0	24	Cloudy
26	0.9459459	2	2020	1	10	0	25	Cloudy
27	0.9459459	2	2020	1	10	0	26	Cloudy
28	0.9459459	2	2020	1	10	0	27	Cloudy
29	0.9459459	2	2020	1	10	0	28	Cloudy
30	0.9459459	2	2020	1	10	0	29	Cloudy
31	0.9459459	2	2020	1	10	0	30	Cloudy
32	0.9459459	2	2020	1	10	0	31	Cloudy
33	0.9459459	2	2020	1	10	0	32	Cloudy
34	0.9459459	2	2020	1	10	0	33	Cloudy
35	0.9459459	2	2020	1	10	0	34	Cloudy
36	0.9459459	2	2020	1	10	0	35	Cloudy
37	0.9459459	2	2020	1	10	0	36	Cloudy
38	0.9459459	2	2020	1	10	0	37	Cloudy
39	0.9459459	2	2020	1	10	0	38	Cloudy
40	0.9459459	2	2020	1	10	0	39	Cloudy

Data list



Daily Parking Events (Sep 2019 – May 2020)

RADAR SENSOR ACCURACY EVALUATION PROCESS



Realtime video and radar sensor status

Comparison data collection file

RADAR SENSOR ACCURACY EVALUATION FINDINGS

- Collected data over 28 days → 672 hours →40,320 images.
- Evaluated accuracy every minute. (60 figures)
- Recorded items including the error starting minute, slot id and duration time
- Analyzed the accuracy based on different time range and weather condition. (weather condition, time distribution)

$$Acc_{hourly} = \frac{F_{right}}{F_{total}}$$

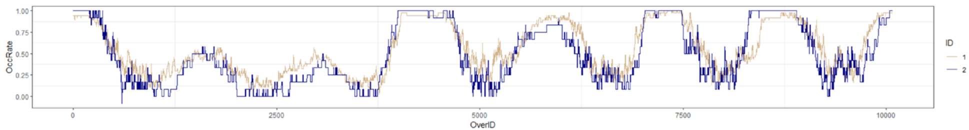
$$Acc_{all\_hour} = \frac{\sum_{hour} Acc_{hourly} * hour\_num}{F_{total}}$$

Accuracy is above 99%

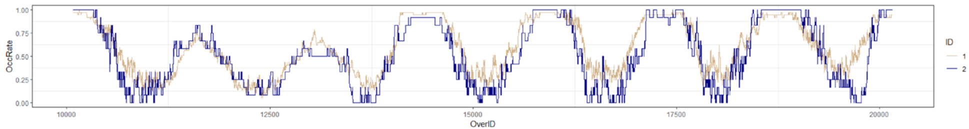
1	date	hour	error minute	slot id	slide num	accuracy	Weather
2	5/16/2020	14	28	1	2	0.966667	
3	5/16/2020	15	58	1	2	0.966667	
4	5/16/2020	16	53	2	1	0.983333	
5	5/16/2020	17				1	
6	5/16/2020	18	21	1	1	0.983333	
7	5/16/2020	19	8	2	1	0.983333	
8	5/16/2020	20				1	
9	5/16/2020	21				1	
10	5/16/2020	22				1	
11	5/16/2020	23				1	
12	5/17/2020	0				1	
13	5/17/2020	1				1	
14	5/17/2020	2				1	
15	5/17/2020	3	28	2	1	0.983333	
16	5/17/2020	4				1	
17	5/17/2020	5				1	
18	5/17/2020	6				1	
19	5/17/2020	7				1	
20	5/17/2020	8				1	
21	5/17/2020	9				1	
22	5/17/2020	10				1	
23	5/17/2020	11				1	
24	5/17/2020	12				1	
25	5/17/2020	13	20	1	1	0.983333	
26	5/17/2020	14				1	
27	5/17/2020	15	28	4	4	0.933333	
28	5/17/2020	16				1	
29	5/17/2020	17				1	
30	5/17/2020	18				1	
31	5/17/2020	19				1	
32	5/17/2020	20				1	
33	5/17/2020	21				1	
34	5/17/2020	22				1	
35	5/17/2020	23				1	
36	5/18/2020	0				1	
37	5/18/2020	1				1	
38	5/18/2020	2				1	
39	5/18/2020	3				1	

Acc_{hourly} evaluation table

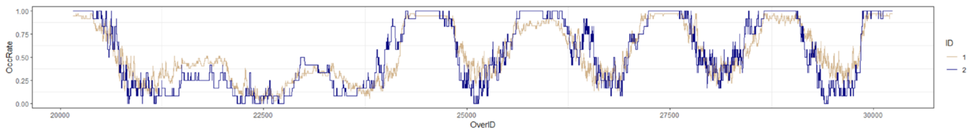
OCCUPANCY DATA VISUALIZATION



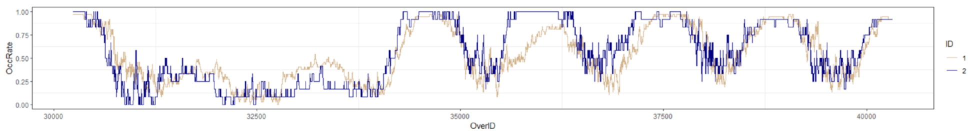
Jan 10th – Jan 16th occupancy rate changes per minute



Jan 17th – Jan 23rd occupancy rate changes per minute



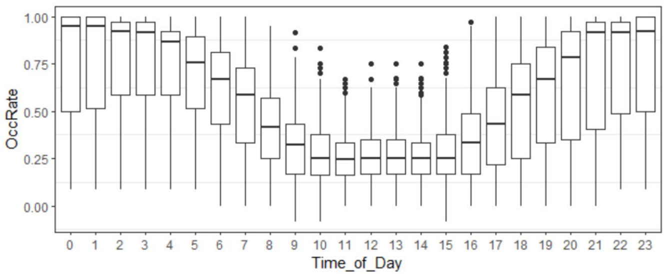
Jan 24th – Jan 30th occupancy rate changes per minute

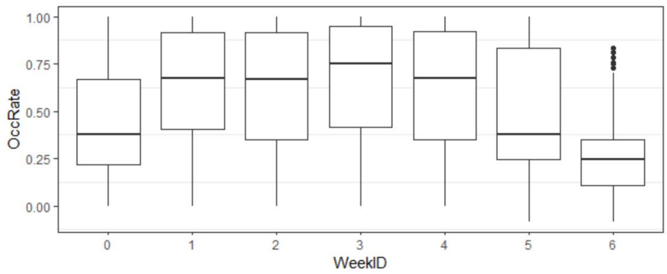


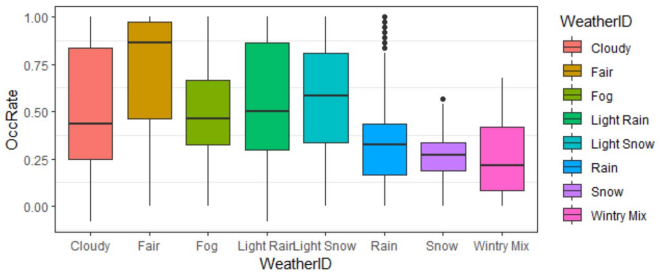
Jan 31th – Feb 16th occupancy rate changes per minute

ID 1 and 2 represent two different truck parking lots here.

OCCUPANCY DATA ANALYSIS



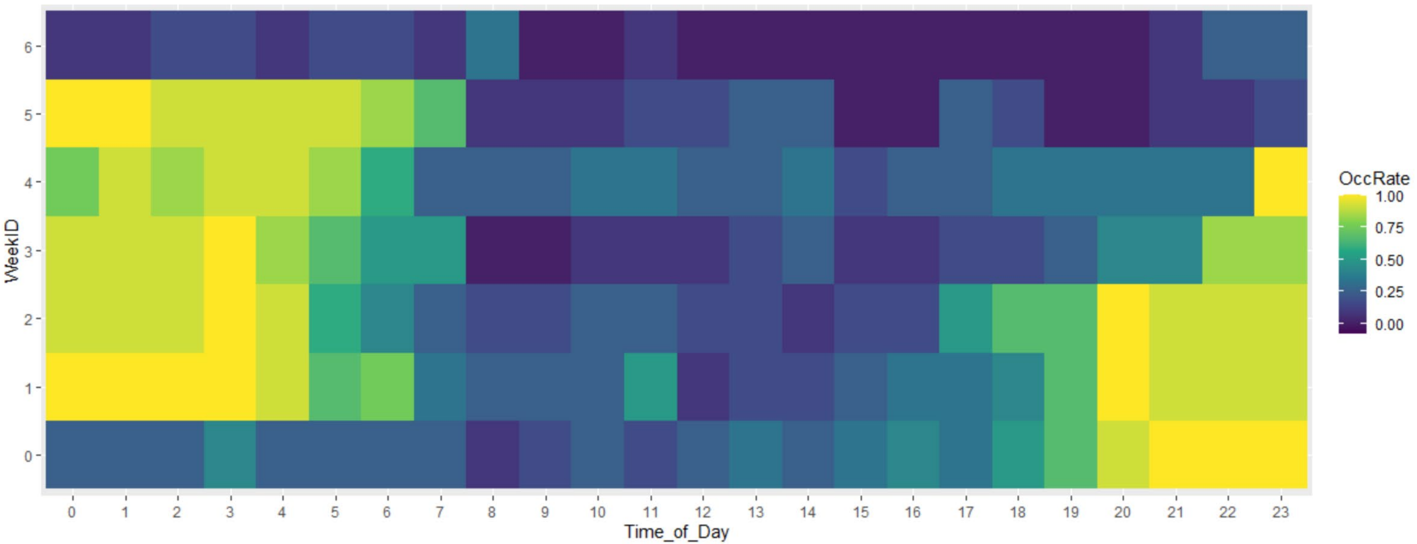




The box plot of truck parking occupancy rate for time of day, day of week and weather condition.

For day of week, 0 represents Sunday, 1 represents Monday, etc.

OCCUPANCY DATA ANALYSIS - CONTINUED



Time of a day and day of a week truck parking occupancy heat map visualization. For day of week, 0 represents Sunday and the rest are same as normal day of week index.

DAILY SIMILARITY ANALYSIS

- The similarity pattern of a day is obvious, and a "cross X" pattern can be found. There are two high parallelism clusters aggregated for truck parking pattern.
- **"Daily off-peak hour":** From 8 AM to 4 PM. The occupancy rate of the truck parking lot is usually low (<40%), and the average parking time is relatively short (~20 minutes). The occupancy sequence similarity is very high (>51.05%), and the pattern is highly repetitive.
- **"Daily peak hour":** From 8 PM to 5 AM of next day (especially from 10 PM to 4 AM of next day). The parking lot occupancy rate is usually very high (>95%), the average parking time is long (>145 minutes).

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
0	1	0.8	0.9	0.9	0.6	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.5	0.7	0.9
1	0.8	1	0.9	0.8	0.4	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.3	0.6	0.7
2	0.9	0.9	1	0.9	0.6	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.4	0.7	0.9
3	0.9	0.8	0.9	1	0.7	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.5	0.8	0.9
4	0.6	0.4	0.6	0.7	1	0.6	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	0.8	0.8	0.7
5	0.2	0.1	0.1	0.2	0.6	1	0.5	0.1	0	0	0	0	0	0	0	0	0	0	0	0.2	0.7	0.7	0.4	0.3
6	0	0	0	0	0.1	0.5	1	0.4	0	0	0	0	0	0	0	0	0	0	0.1	0.7	0.6	0.2	0	0
7	0	0	0	0	0	0.1	0.4	1	0.2	0	0	0	0	0	0	0	0	0.1	0.4	0.6	0.2	0	0	0
8	0	0	0	0	0	0	0	0.2	1	0.3	0	0	0	0	0	0	0.3	0.5	0.4	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0.3	1	0.5	0.3	0.3	0.3	0.3	0.5	0.6	0.3	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0.5	1	0.9	0.8	0.8	0.8	0.8	0.4	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0.3	0.9	1	0.9	0.9	0.9	0.8	0.3	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0.3	0.8	0.9	1	0.9	0.9	0.8	0.2	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0.3	0.8	0.9	0.9	1	0.9	0.8	0.2	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0.3	0.8	0.9	0.9	0.9	1	0.8	0.3	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0.5	0.8	0.8	0.8	0.8	0.8	1	0.4	0.1	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0.3	0.6	0.4	0.3	0.2	0.2	0.3	0.4	1	0.4	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0.1	0.5	0.3	0	0	0	0	0	0.1	0.4	1	0.3	0	0	0	0	0
18	0	0	0	0	0	0	0.1	0.4	0.4	0	0	0	0	0	0	0	0	0.3	1	0.3	0	0	0	0
19	0	0	0	0	0	0.2	0.7	0.6	0	0	0	0	0	0	0	0	0	0	0.3	1	0.4	0.1	0	0
20	0.1	0.1	0.1	0.1	0.4	0.7	0.6	0.2	0	0	0	0	0	0	0	0	0	0	0	0.4	1	0.5	0.3	0.1
21	0.5	0.3	0.4	0.5	0.8	0.7	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.5	1	0.7	0.6
22	0.7	0.6	0.7	0.8	0.8	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.7	1	0.9
23	0.9	0.7	0.9	0.9	0.7	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.6	0.9	1

Daily similarity result

WEEKLY SIMILARITY ANALYSIS

- The truck parking pattern of every week can be divided into two clusters: working mode and off-working mode.

- "**Working mode**": From Sunday night until Friday evening. The parking sequence similarity is very high (>56%) and fits well with the daily "peak-hour" and "off-peak hour" pattern.

- "**Off-working mode**": the relax time of truck drivers usually starts on Friday night. On Saturday, Sunday or even sometimes Monday morning, the truck parking pattern similarity is low. Random and personalized parking events are relatively high.

	Sun	Mon	Tue	Wed	Thu	Fri	Sat
Sun	1	0.3	0.4	0.4	0.4	0.4	0.6
Mon	0.3	1	0.7	0.8	0.7	0.5	0.2
Tue	0.4	0.7	1	0.7	0.7	0.6	0.3
Wed	0.4	0.8	0.7	1	0.7	0.5	0.2
Thu	0.4	0.7	0.7	0.7	1	0.5	0.2
Fri	0.4	0.5	0.6	0.5	0.5	1	0.4
Sat	0.6	0.2	0.3	0.2	0.2	0.4	1

Weekly similarity result

PREDICTION METHODOLOGY

- With the development of the machine learning technology, parking occupancy prediction using neural networks is the top choice for the research team [1] [2] [3] [4].
- Through similarity analysis, researchers have an intuitive understanding of the truck parking pattern –attribute features, including time of day, day of week are significant factors.
- Sequence correlations are also important reference for predicting the future status.
  - Recurrent Neural Network (RNN) are necessary in prediction model to "memorize" the historical change in the processed sequence.
- In the project, we proposed a neural network – Truck Parking Occupancy Prediction (TPOP) neural network to predict the future occupancy level of each truck parking lots.
- Two types of features learning component – historical sequential features and attributes features are integrated into TPOP and shows promising result.

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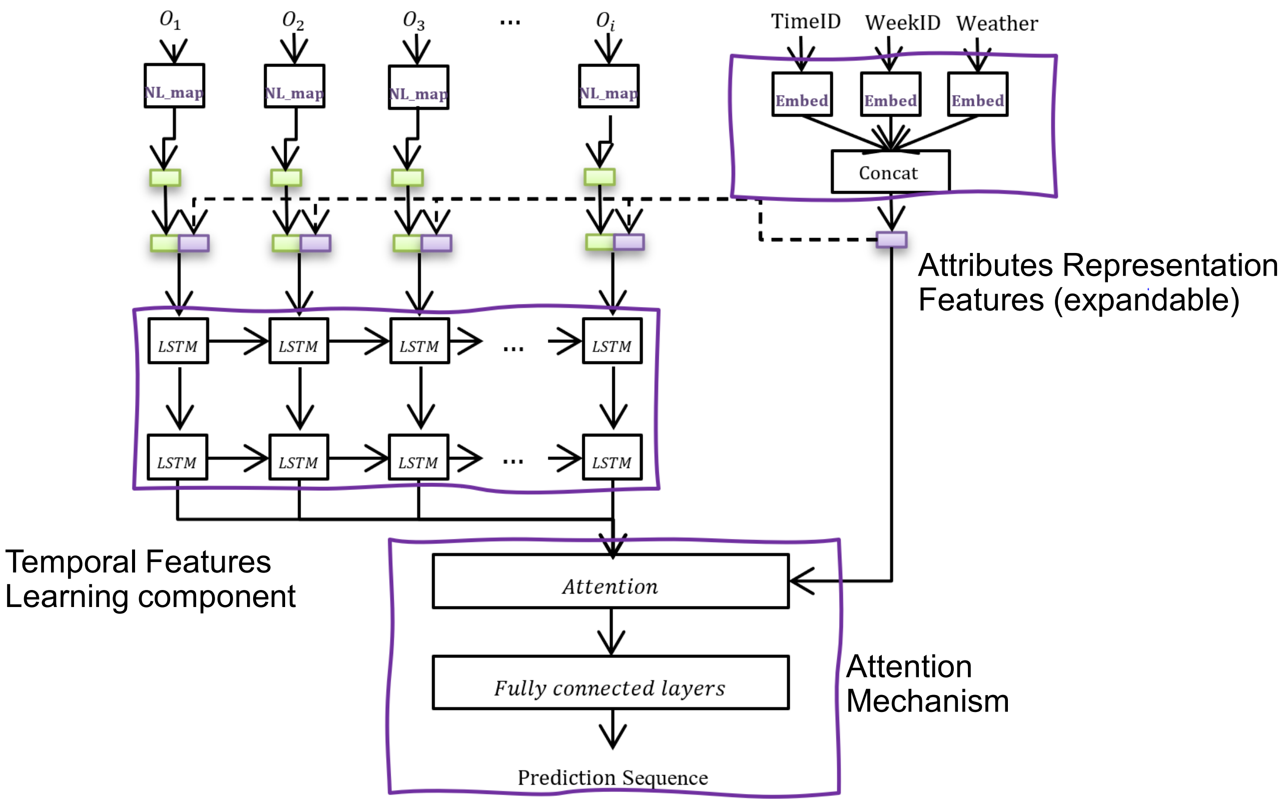
[2] S. Yang, W. Ma, X. Pi, and S. Qian, "A deep learning approach to real-time parking occupancy prediction in transportation networks incorporating multiple spatio-temporal data sources," Transportation Research Part C: Emerging Technologies, vol. 107, pp. 248–265, 2019.

[3] T. Anagnostopoulos, P. Fedchenkov, N. Tsotsolas, K. Ntalianis, A. Zaslavsky, and I. Salmon, "Distributed modeling of smart parking system using lstm with stochastic periodic predictions," Neural Computing and Applications, pp. 1–14, 2019.

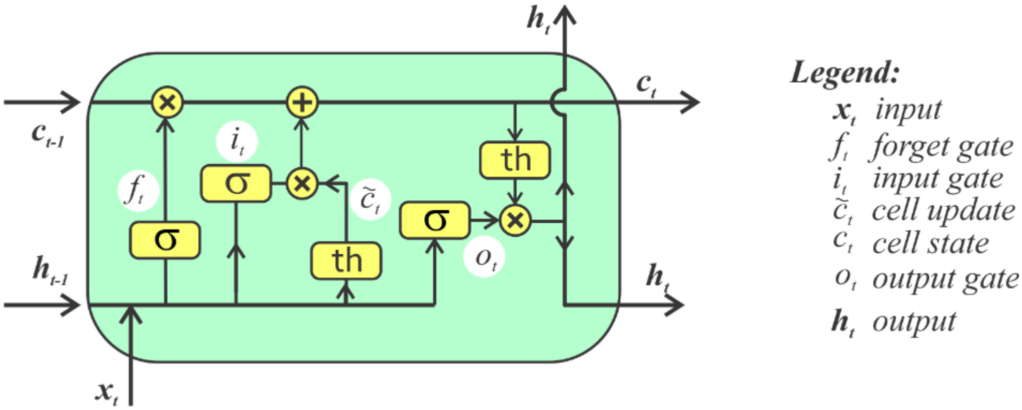
[4] F. d. A. A. Vital, P. Ioannou, and A. Gupta, "Survey on intelligent truck parking: Issues and approaches," IEEE Intelligent Transportation Systems Magazine, 2020.

PREDICTION METHODOLOGY - ARCHITECTURE



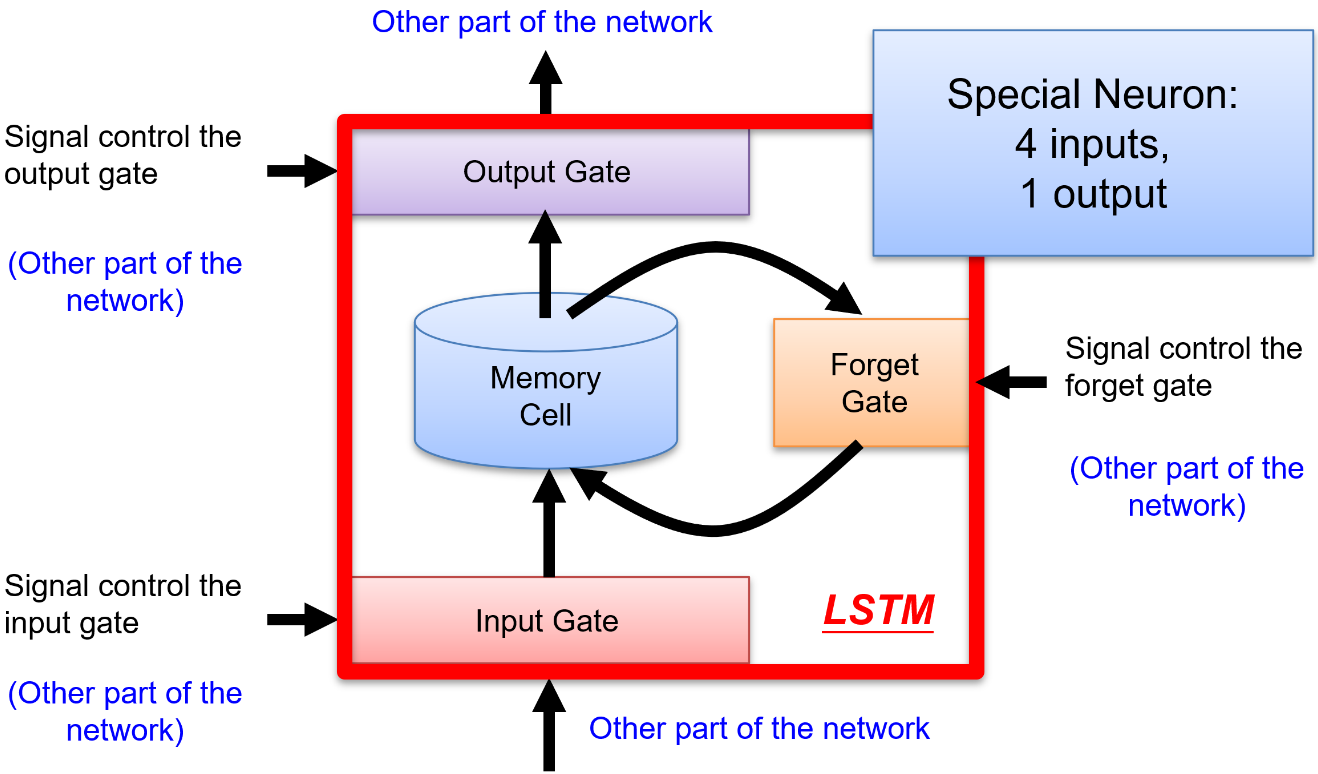
PREDICTION METHODOLOGY

- The TPOP was implemented with PyTorch 0.3.1. The workstation for training was equipped with a GPU (NVIDIA TITAN Xp) and the CPU is Intel Core i7 8700. The operation system is Linux Ubuntu 16.04.
- In the research, the team collected data from 49 truck parking slots in two locations from Jan 01 to Mar 10 of 2020 and 2021.
- A Stacked Long short-term memory (LSTM) neural network was used for high accuracy prediction result in the temporal features learning component.

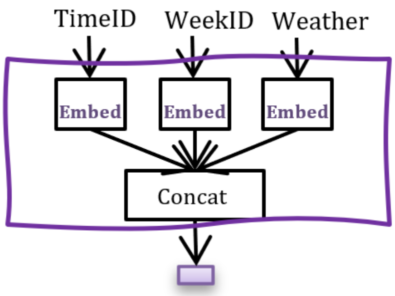


Detail structure of LSTM neuron

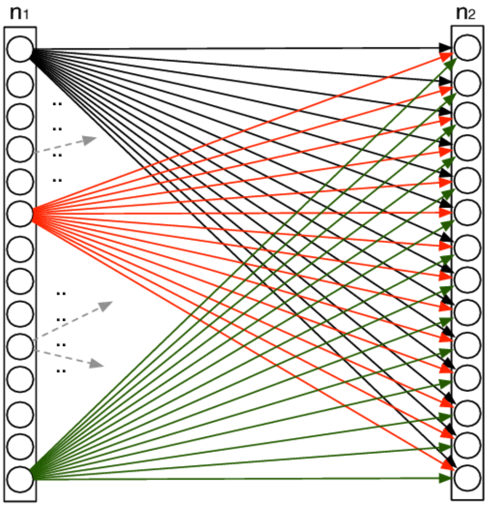
LONG SHORT-TERM MEMORY (LSTM)



ATTRIBUTES EMBEDDING



Attributes Representation Features (expandable)



Fully connected layers

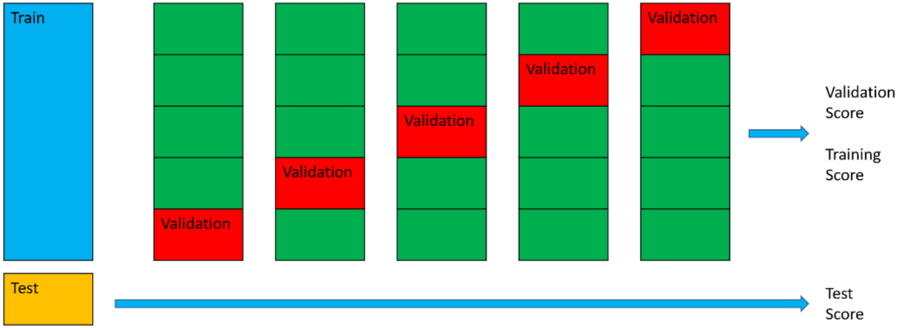
The size of the embedding vector for each attribute is settled as follows: weatherID mapping into $\mathbf{R}^3$, weekID mapping into $\mathbf{R}^3$ and time ID mapping into $\mathbf{R}^{10}$

The total dimension size of attributes is $\mathbf{R}^{16}$

$$h^{in} = I * W + B$$
$$h^{out} = \mathrm{ReLU}(h_{in})$$

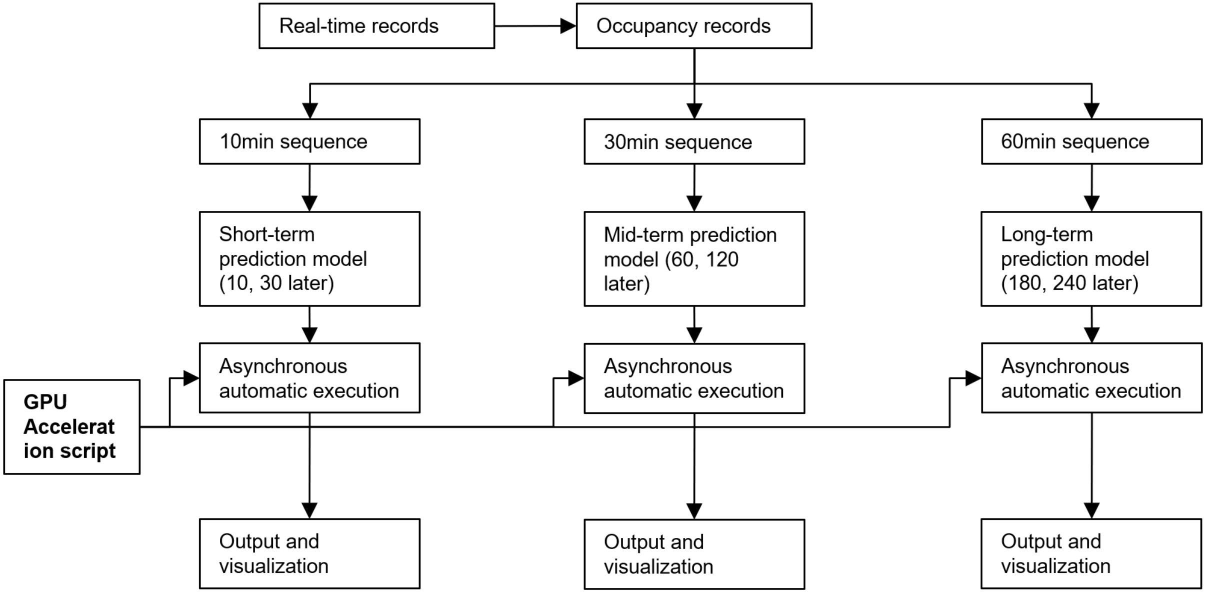
EXPERIMENT

- During the training phase, we use 65% of data for training and 15% for validation and 20% for testing
    - **Training Dataset:** The sample of data used to fit the model
    - **Validation Dataset:** The sample of data used to provide an unbiased evaluation of a model fit on the training dataset while tuning model hyperparameters
        - The evaluation becomes more biased as skill on the validation dataset is incorporated into the model configuration
    - **Test Dataset:** The sample of data used to provide an unbiased evaluation of a final model fit on the training dataset



5-fold cross-validation

OVERALL REAL-TIME PREDICTION FRAMEWORK



RESULT SUMMARIZATION

- The input sequence data records are from t to t-15 (16 data records) with three-time gaps: 10min, 30min and 60min
- Three models will be parallelly operated to predict 10 minutes later and 30 minutes later for model one, 1h later and 2h later for model two and 3h later and 4h later for model three
- Mean Absolute Percentage Error (MAPE) and Mean Absolute Error (MAE) measures were used for model validation
- Empowered by the customized deep learning neural network, **the prediction system achieve less than 12% error availability prediction from 10 minutes to 4 hours later**

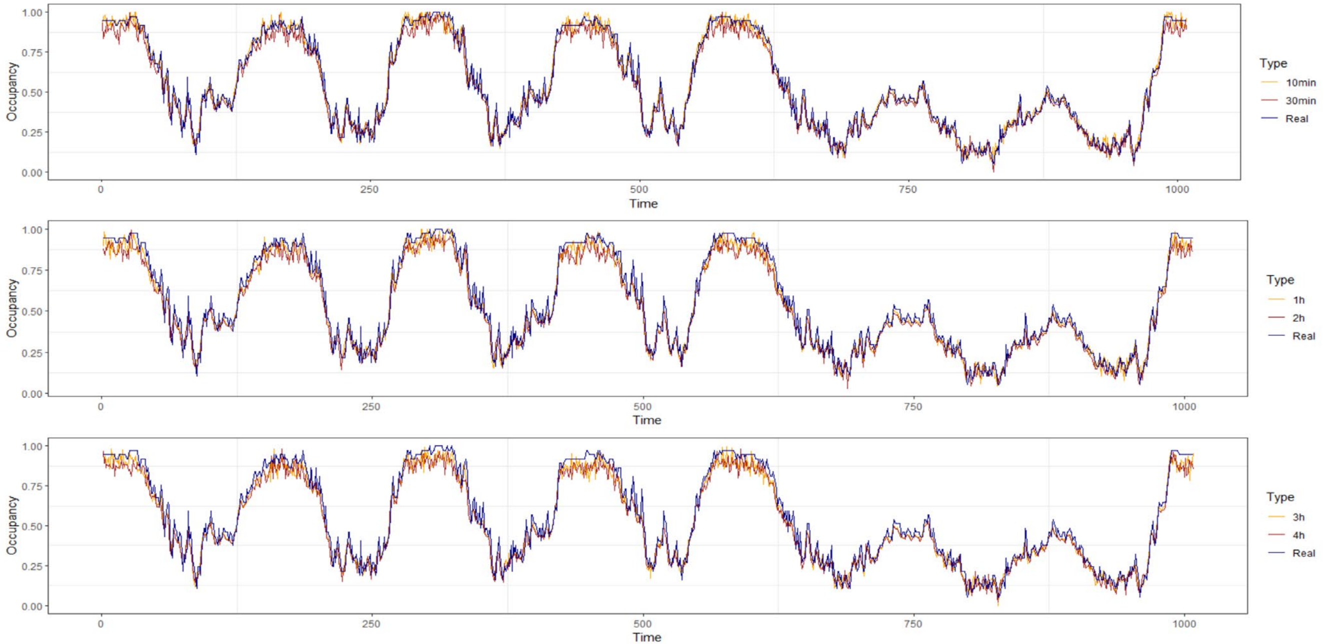
$$\mathcal{M}_{P_j} = |\frac{P_j - \hat{P}_j}{\hat{P}_j - \varepsilon}| * 100\%$$

MAPE Mathematical function

	10min	30min	1h	2h	3h	4h
MAPE	8.79%	9.01%	9.16%	9.47%	10.27%	11.34%
MAE	4.31	4.41	4.49	4.64	5.03	5.56

Prediction result summary for different time scale

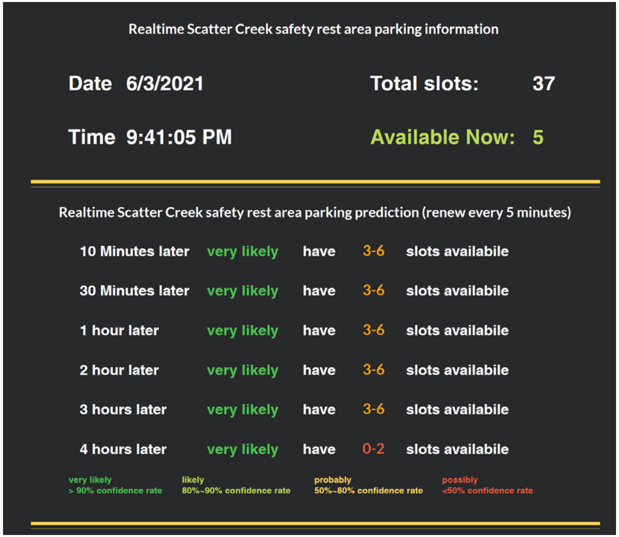
PERFORMANCE VISUALIZATION



Truck parking dataset prediction and metadata comparison, parking lot ID 1, Mar 2nd - 9th 2020

PREDICTION VISUALIZATION ON WEB AND APP

https://uwstarlab.wixsite.com/wsdotparking



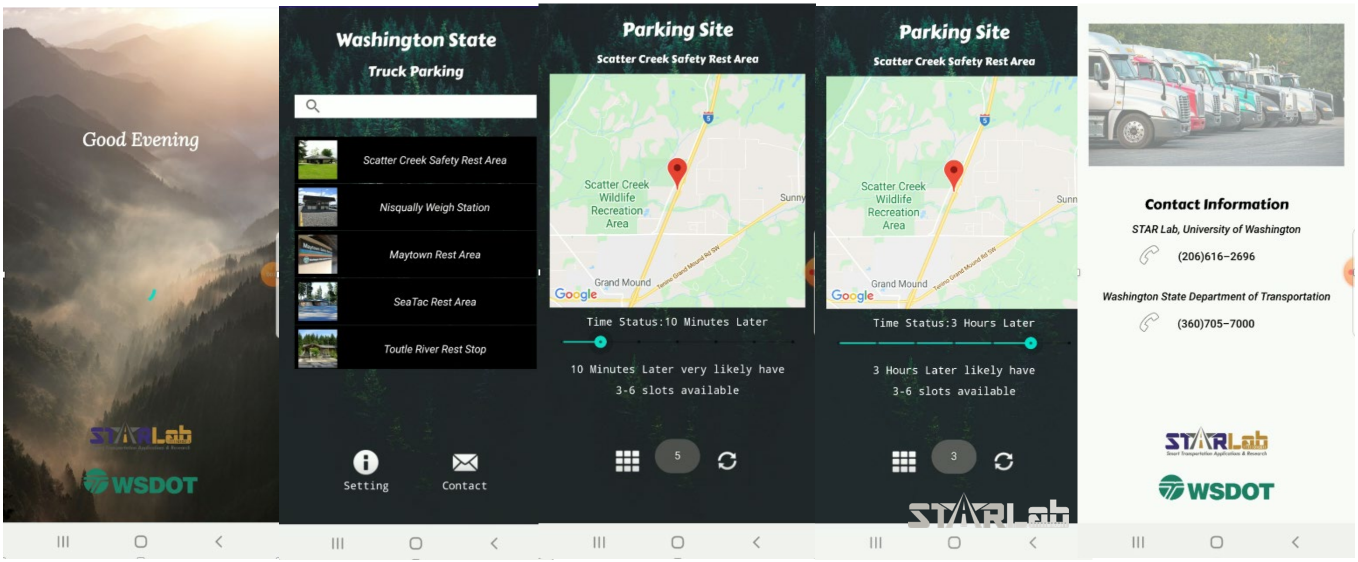
Prediction visualization on web and app

PREDICTION ALGORITHMS FINDINGS

- **The TPOP can provide useful information to researchers, drivers and operators:**
  - Truck parking pattern is impacted mainly by historical records (habits) as well as attributes impacts (time of day, day of week)
  - Eliminating the weather information causes an error increment of 0.165% for parking behavior in WA state
    - For other areas, the weather information might be more useful
  - For some extreme high-occupancy situation(>95%), the prediction methods need to be further investigated to capture the fine changes in time
  - During the off-work mode, the predictably of parking behavior is much lower due to:
    - 1) the average parking period is short (<10 minutes)
    - 2) illegal parking (small vehicles, parking in multiple parking spaces), convoy parking and other external factors

DEMO TIME

- Website demo
  - https://uwstarlab.wixsite.com/wsdotparking
- App demo video



FUTURE WORK

Algorithm Prediction Time and Accuracy

Parking Space Reservation System

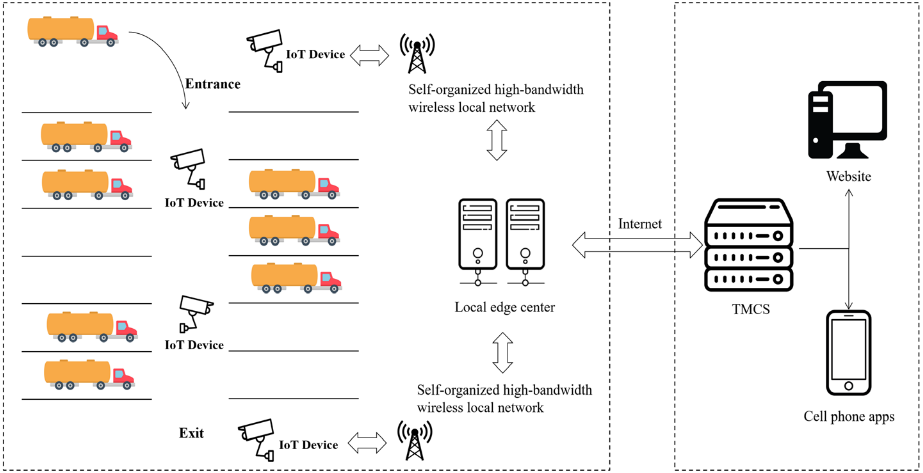
Route Planning

FUTURE OF TRUCK PARKING MANAGEMENT IN WASHINGTON STATE

- WSDOT is working on additional opportunities to expand the TPIMS:
  - Truck Parking Workshop outcomes (completed June 2021)
    - Included State, Local, Federal, Private stakeholders in truck parking in Washington State
    - Developed strategies with respect to land use, policy, and technology to support improving the State's truck parking strategies
    - Summary of conclusions in development will be available at https://wsdot.wa.gov/freight/trucking

FUTURE OF TRUCK PARKING MANAGEMENT IN WASHINGTON STATE

- WSDOT is working on additional opportunities to expand the TPIMS:
  - Evaluation of other detection methodologies to optimize cost and accuracy
    - Spot-based detection algorithm used in this pilot
    - Video Detection or Loops at facility entrance/exit are other methods for consideration



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FUTURE OF TRUCK PARKING MANAGEMENT IN WASHINGTON STATE

- WSDOT is working on additional opportunities to expand the TPIMS:
  - Expansion to other State-owned facilities
    - Awarded FMCSA grant application to expand detection to 400 parking stalls in 28 facilities. Will include:
      - User testing
      - Detection methodology evaluation
      - Algorithm updates
      - Application updates - Expansion to iOS

Questions?

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Oct. 2021

Thanks a lot!