Investigating the Impacts of Truck Platooning on Transportation Infrastructure in the South-Central Region

Tran-SET
Transportation Consortium of South-Central States

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Tran-SET webinar : Future Impacts of Connected and Automated Vehicles (CAV) Applications

Project Team

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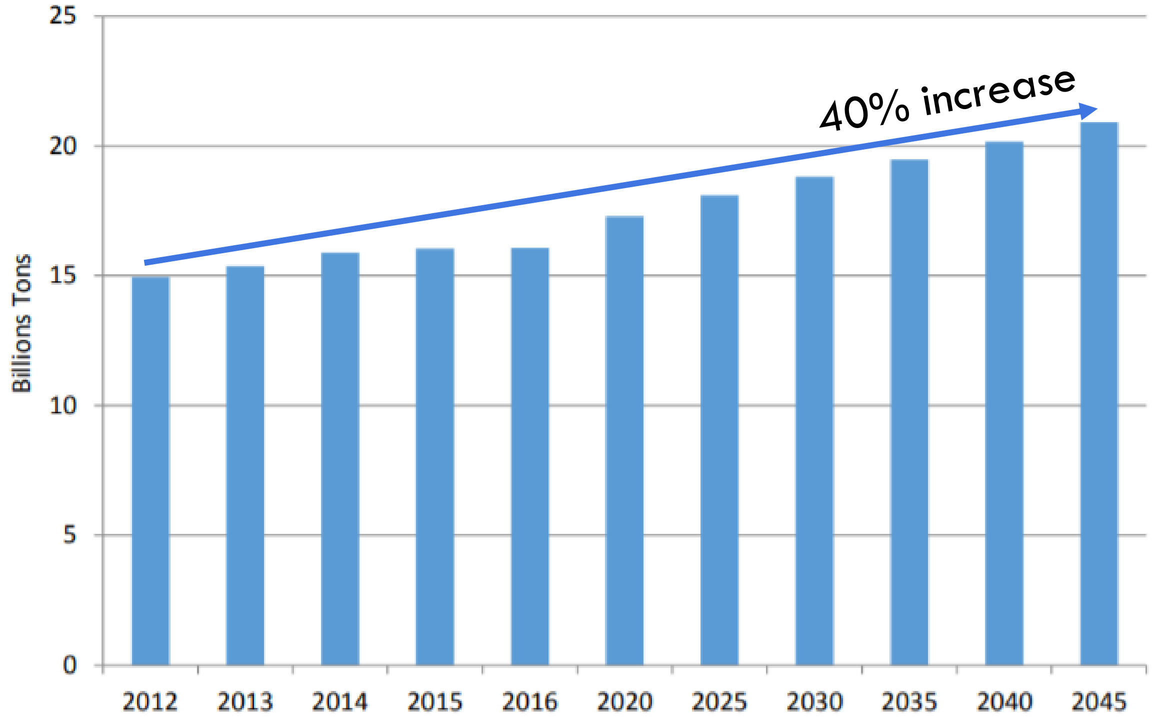
Outline

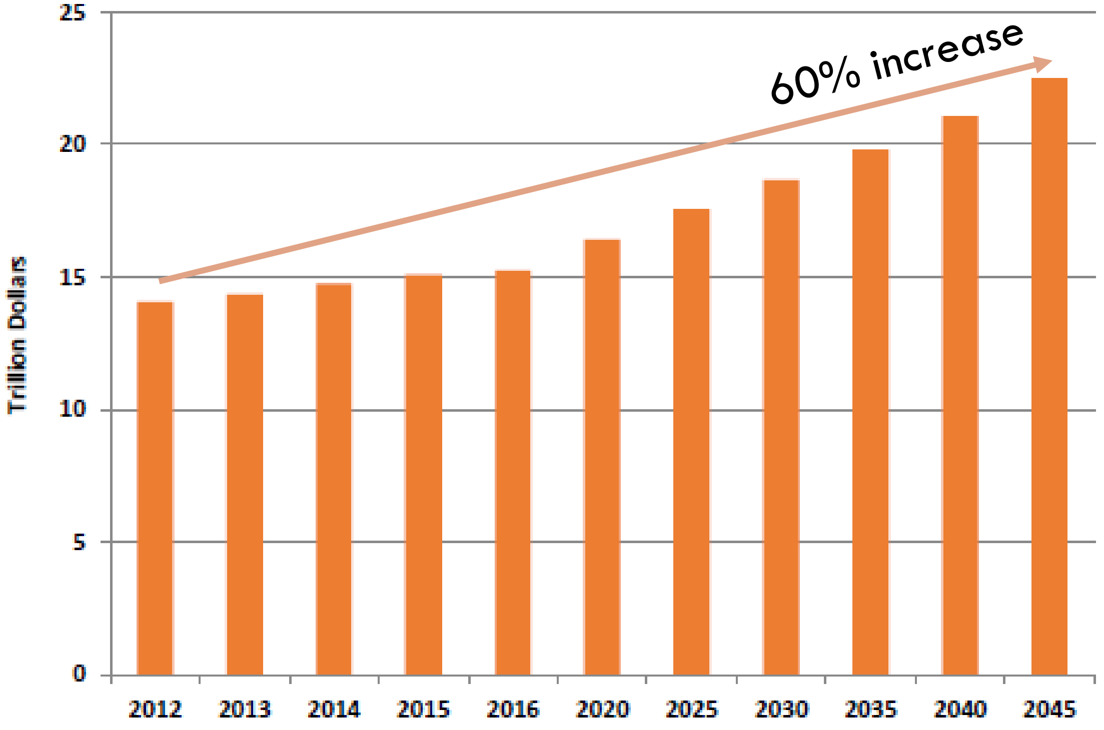
- Background
- Project objectives
- Methodology
- Corridor-Level Analysis
- Network-Level Analysis
- Next steps

Background

- Providing efficient and safe movement of freight is an essential component to the economy of the U.S. states and particularly to the states in Region 6.

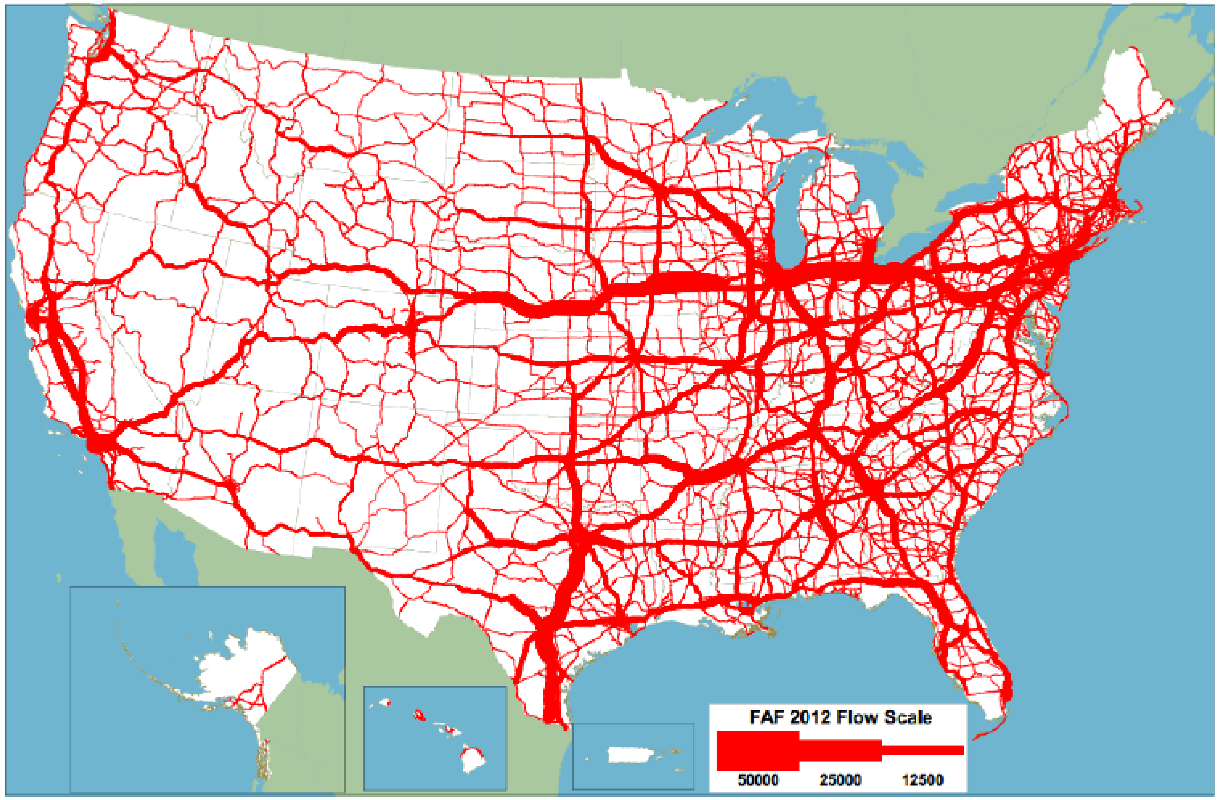


Total Domestic Freight Flows, 2012 – 2045
(Source: FHWA-HOP-16-043)



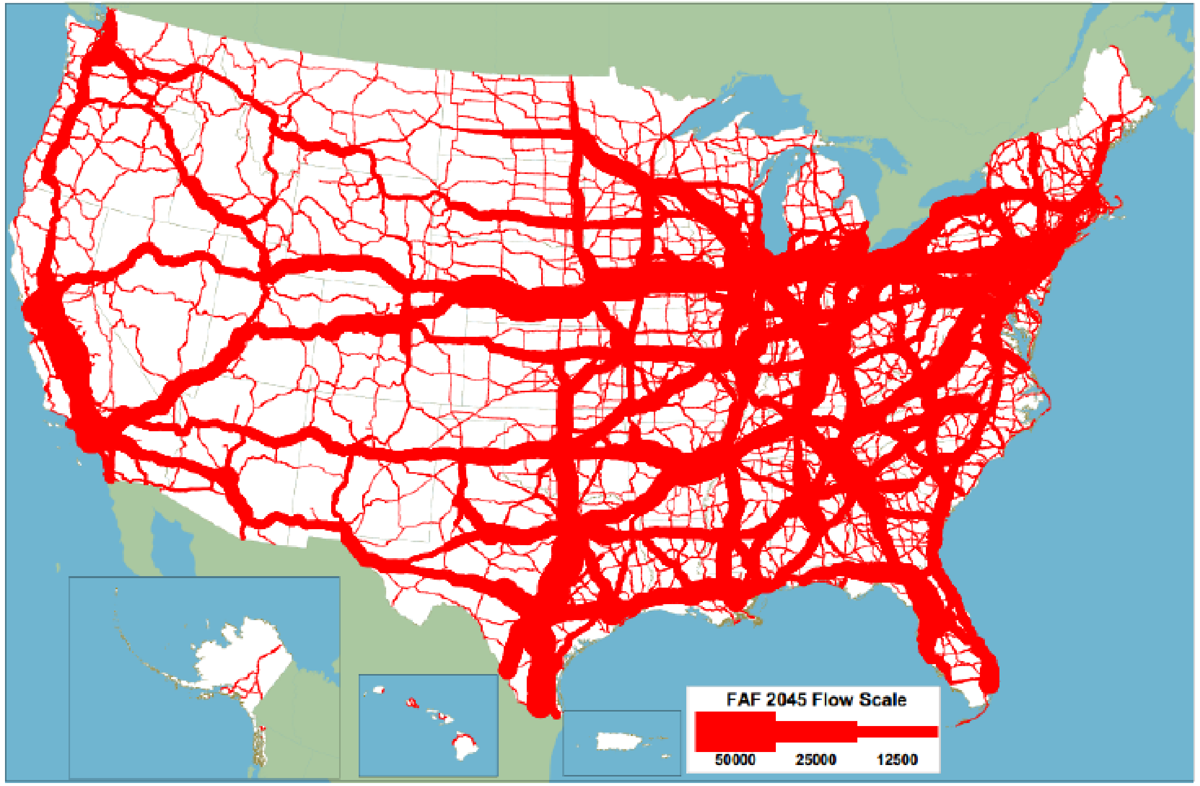
Total Real Values of Domestic Freight Flows, 2012 – 2045
(Source: FHWA-HOP-16-043)

Background



Freight OD Data Source: Office of Freight Management and Operation, US Department of Transportation, FHWA

2012 truck flows on the US National Highway System
(Source: FAF4 FREIGHT TRAFFIC ASSIGNMENT, 2016)



Freight OD Data Source: Office of Freight Management and Operation, US Department of Transportation, FHWA

2045 truck flows on the US National Highway System
(Source: FAF4 FREIGHT TRAFFIC ASSIGNMENT, 2016)

Background

- Several challenges affect the efficiency of freight movement including high fuel and labor costs, vehicular emissions, and traffic safety problems.

- Fortunately, emerging vehicle technology such as Connected and Autonomous Vehicle (CAVs) can help in minimizing these challenges.

- One CAV application of particularly interest to the freight industry is truck platooning.

Background (Cont.)

- The expected benefits of truck platooning include reduction of fuel consumption, reduction in emissions, lower labor costs, improving traffic safety and traffic flow improvements.

- However, truck platooning may accelerate the pavement damage due to its greater weight concentrations.

- Very little studies concentrated on the safety aspect of truck platooning as well as impacts on Pavements.

Project Objectives / Methodology

Louisiana State University

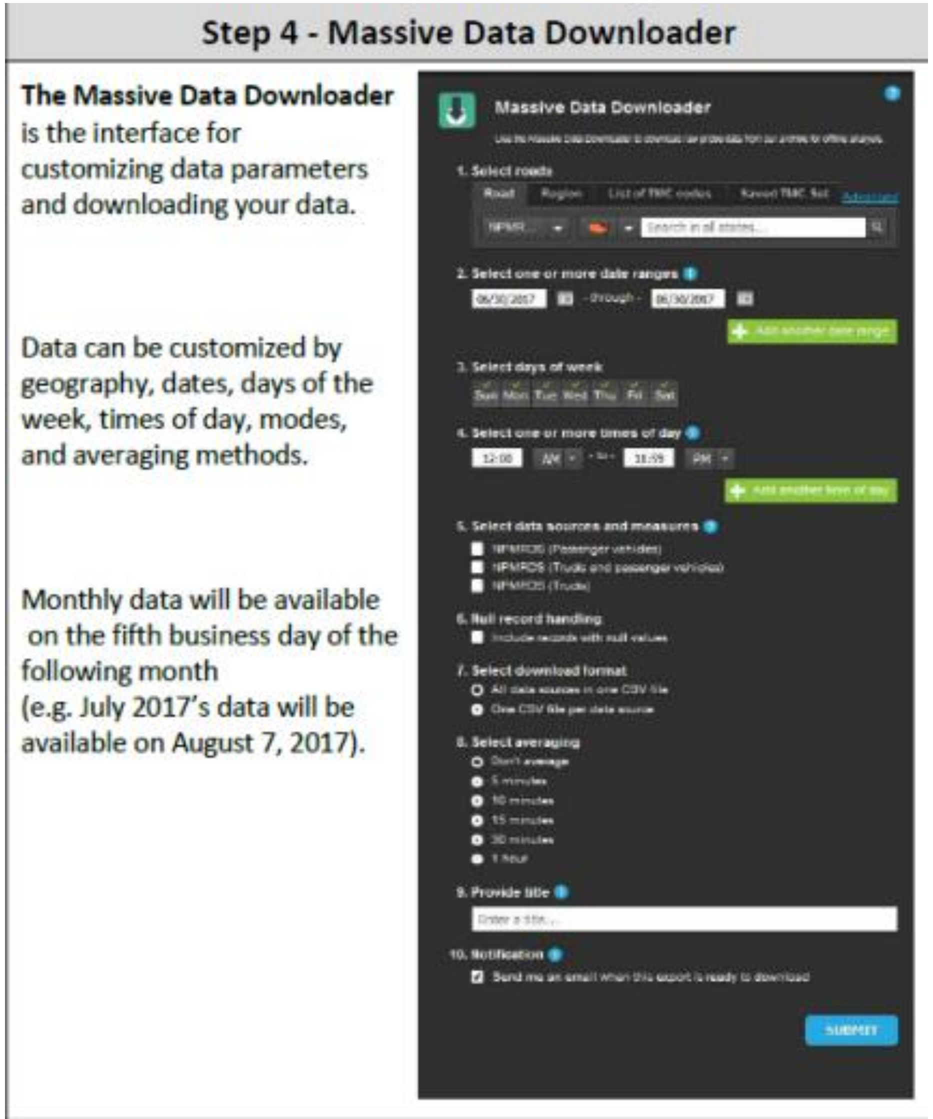
Objective	Methodology
1. Examine the operational and environmental impacts of truck platooning on US highways	A series of modeling case studies located in Region 6 will be developed using Vissim, at both the corridor- and network-level;
2. Explore the impact of truck platooning on pavement	finite element (FE) modeling will be used to quantify the impact on pavement
3. Conduct feasibility study and recommendations	An economic analysis will be conducted

Corridor Level Analysis

Data (NPMRDS)

- **Shapefiles** and **daily data** of TMC segments were collected from National Performance Management Research Data Set (NPMRDS).

- The NPMRDS provides a massive data downloader tool that includes daily data from 2011 to 2020 for 24-hr period with 10min, 15min, and 60min interval. The data can be filtered by TMC segments, dates, days of the week, time of days, modes and averaging methods.



Data (NPMRDS)

Louisiana State University

- The output provides two files, one containing Speed and travel time data and the other containing TMC segment data.

- **Speed/Travel time file** includes Speed, Historical Average Speed, Reference Speed, Travel Time, and Data Density Values for every time period.

tmc_code	measurement_tstamp	speed	Average_speed	Reference_speed	travel_time_minutes	data_density
113-04665	1/1/2020 6:00	55.32	65	68	5.06	A
113-04665	1/1/2020 7:00	67.02	64	68	4.17	C
113-04665	1/1/2020 8:00	65.55	65	68	4.27	C
113N04666	1/1/2020 6:00	56.2	62	68	0.58	A
113N04666	1/1/2020 7:00	62.25	62	68	0.53	B
113N04666	1/1/2020 8:00	63.8	62	68	0.51	B
113+04668	1/1/2020 6:00	72.65	62	68	0.59	A
113+04668	1/1/2020 7:00	68.16	62	68	0.63	B
113+04668	1/1/2020 8:00	71.05	62	68	0.6	B

Data (NPMRDS)

Louisiana State University

- **TMC segment data** includes useful information's like thrulanes (bidirectional lane numbers), aadt, aadt_singl, and aadt_combi.

❖ Thrulanes is the number of lanes designated for through-traffic in both travel directions.

❖ Aadt is annual average daily traffic. Aadt_singl is the annual average daily traffic for single-unit trucks and buses. Aadt_combi is the annual average daily traffic for Combination trucks.

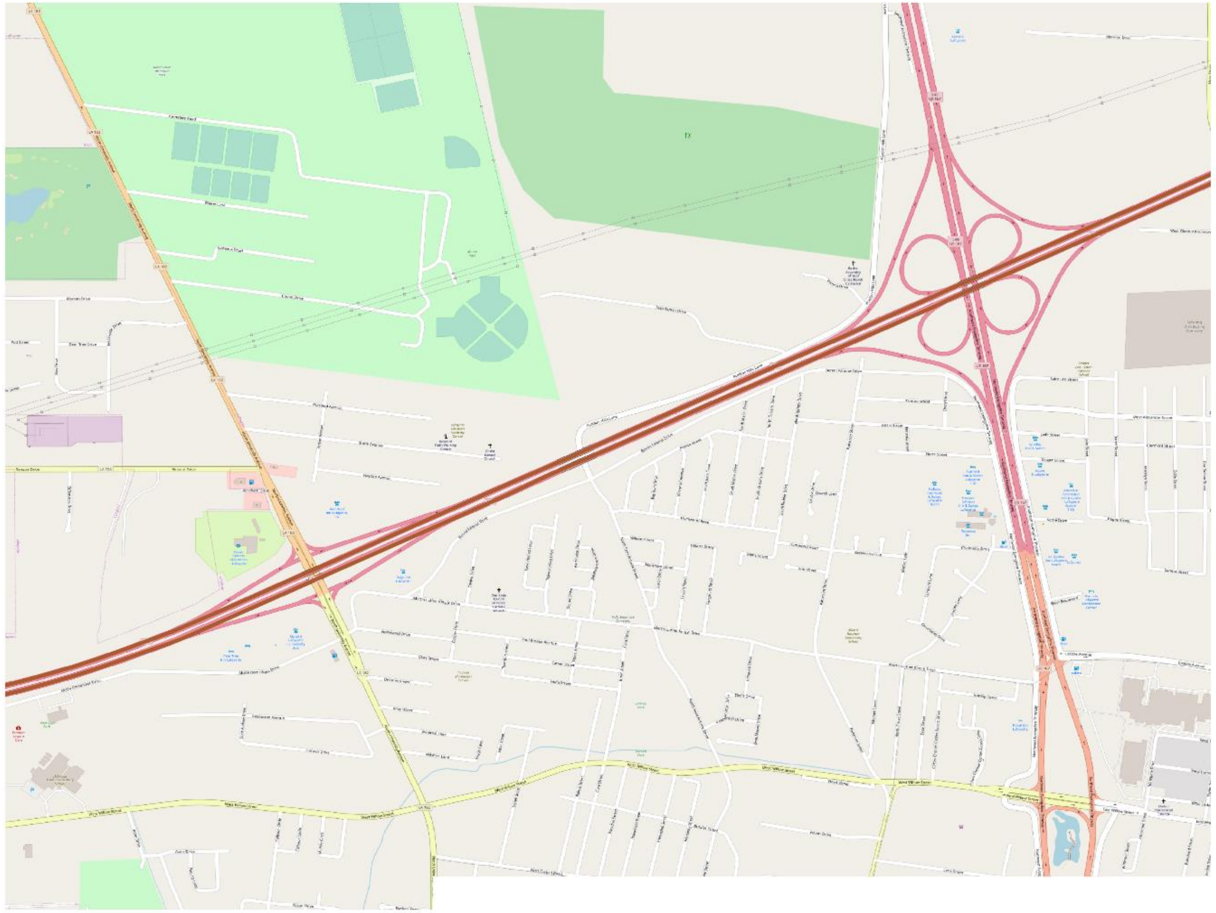
Data (CRPC)

- Traffic count data for 2017-2018 were collected for Baton Rouge area from Capital Region Planning Commission (CRPC).
- We will use these count data to estimate the vehicle input of our model and also validate the model

Study Area (corridor level analysis)

Louisiana State University

- A freeway segment was selected for micro-simulation study from the I-10 highway, which is a heavily utilized truck corridor.
- It is an approx. 6.95 km (4.3 miles) corridor with 8 merging and 8 diverging sections.



Study Area (corridor level analysis)

Louisiana State University

Vissim Network

Study Area (corridor level analysis)

Vissim Network

Scenarios (corridor level analysis)

Louisiana State University

The effects of truck platooning will be investigated using the following variables in the scenario:

1. Platoon size (2,3,4,5)

2. Inter-platoon distance (50m, 100m)

3. Intra-platoon distance (0.3s, 0.5s, 0.7s)

4. Market Penetration rate (25%, 50%, 100%)

5. Time period (Peak and Off-peak hour)

Performance indicators (PI)

- To align the microscopic analysis with the project objective, following surrogate measures were considered:
  1. Operational: Total Network delay, Time to merge and diverge
  2. Environmental: Total emission of CO2, NOx and PM10
  3. Safety: Time Integrated Time to Collision (TIT)

Expected Results

- Truck platooning will show reduced emission of CO_2, NOx and PM10

- Due to Truck platooning, traffic flow on merging and diverging sections will be affected. The effects will be significant with higher penetration rate of truck platoons.

- Truck platooning may have a negative impact on traffic safety

- Optimal truck platooning size and strategy that will have a positive impact on operational, environmental, and safety aspects of highways and reduce stress on pavement.

Network Level Analysis

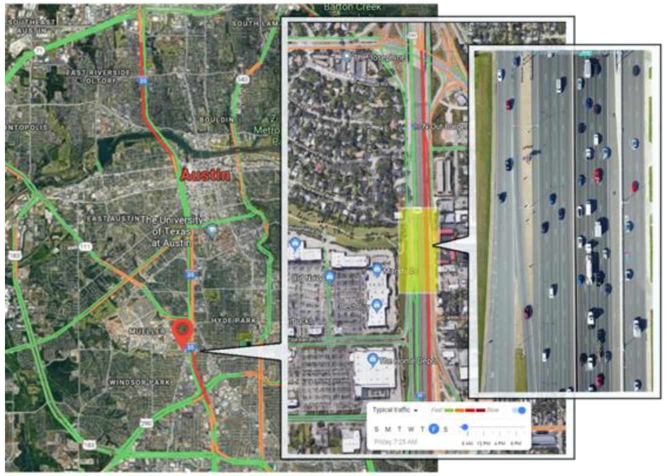
Mesoscopic Simulation: Methodology

ILLINOIS

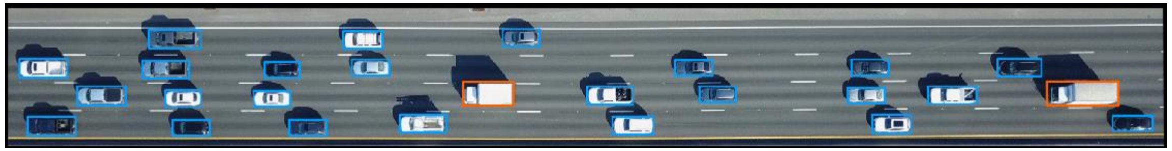
- Accurate modeling of the impacts of truck platooning at the mesoscopic level requires accurate speed-density diagrams.
- Speed-density diagrams can be developed utilizing either
  - Microscopic simulation (inaccurate without proper calibration)
  - Real-world data (mostly unavailable)
- We utilized aerial videography using Unmanned Aerial Vehicle (UAVs) to collect data from I-35 in Austin, TX.
  - The collected data was then utilized to calibrate our microscopic simulation models.
  - The calibrated microscopic simulation model was then utilized to develop speed-density and flow-density diagrams for various platooning strategies.

Mesoscopic Simulation: Data Collection

- Location:
  - I-35 Austin (Exit 237B - 238A)
  - Friday 7:30-9:30 am



- Vehicle Detection: location, size, type



- Trajectory Extraction: coordinate conversion, Kalman Filter, location, speed, acceleration

Mesoscopic Simulation: Model Calibration

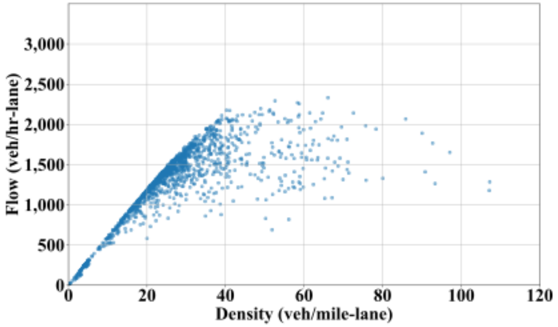
- The genetic algorithm is based on the calibration approach introduced by Hamdar and Mahmassani.

- Kim and Mahmassani's methodology to capture the correlation between model parameters will be utilized here.
  - Each vehicle trajectory in the dataset will be divided into calibration and validation sets.
  - The model will be first calibrated using the data in the calibration set.
  - The calibrated model parameters will be used to simulate the data in the validation set.

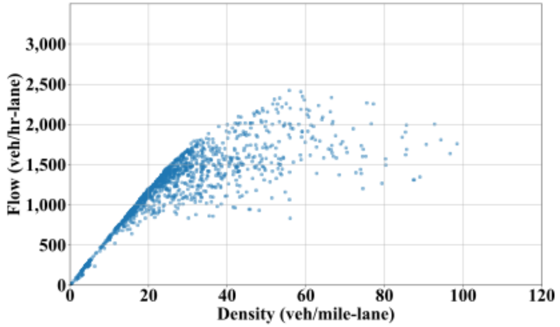
Mesoscopic Simulation: Calibration Outcome

- Our focus is on the interaction between human drivers and automated vehicles.
  - A human driver following an automated vehicle
  - A human driver changing lane into the gap between vehicles in a platoon
  - An automated vehicle or a platoon of automated vehicles changing lane in front of a human driven vehicle

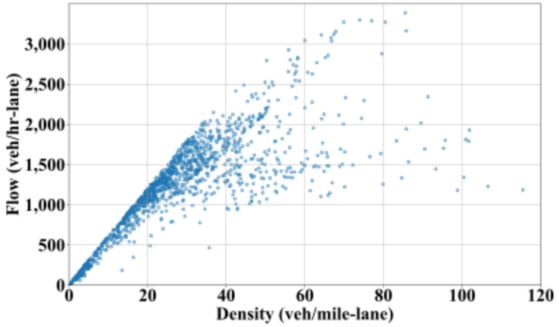
Mesoscopic Simulation: Flow-Density



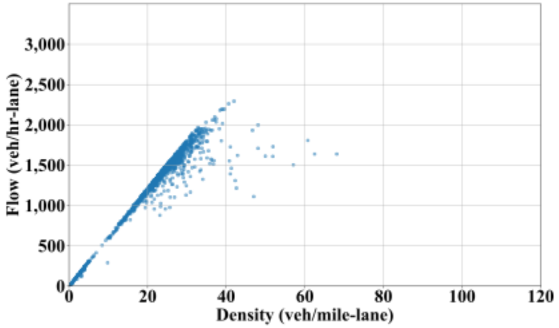
10% Automated Vehicles
10% Trucks
No Platooning



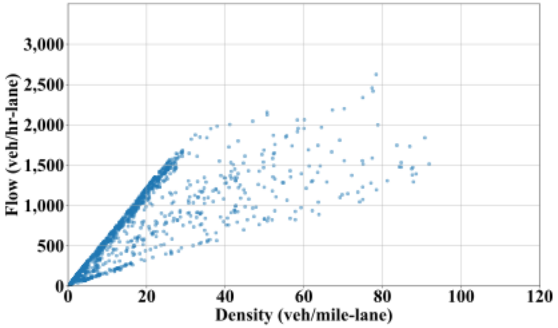
10% Automated Vehicles
10% Trucks
2 Vehicles/Platoon



10% Automated Vehicles
10% Trucks
10 Vehicles/Platoon



60% Automated Vehicles
10% Trucks
No Platooning



60% Automated Vehicles
10% Trucks
10 Vehicles/Platoon

Next Steps

- Complete:
    - ❖ Corridor level Analysis.
    - ❖ Network level Analysis
    - ❖ Impacts of truck platooning on Pavement

- Conduct An economic analysis

Thank You

Questions !

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June 10, 2020

Tran-SET
Transportation Consortium of South-Central States

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The University of Texas at San Antonio™

Experimental and numerical assessment of CAV impact on Flexible Pavement

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Background

- Heavy Vehicles Platooning (HVP) offers (potential) mobility, safety and environmental benefits
- Self-driving technology continually being developed and deployed
- Unclear impacts to infrastructure (pavements)

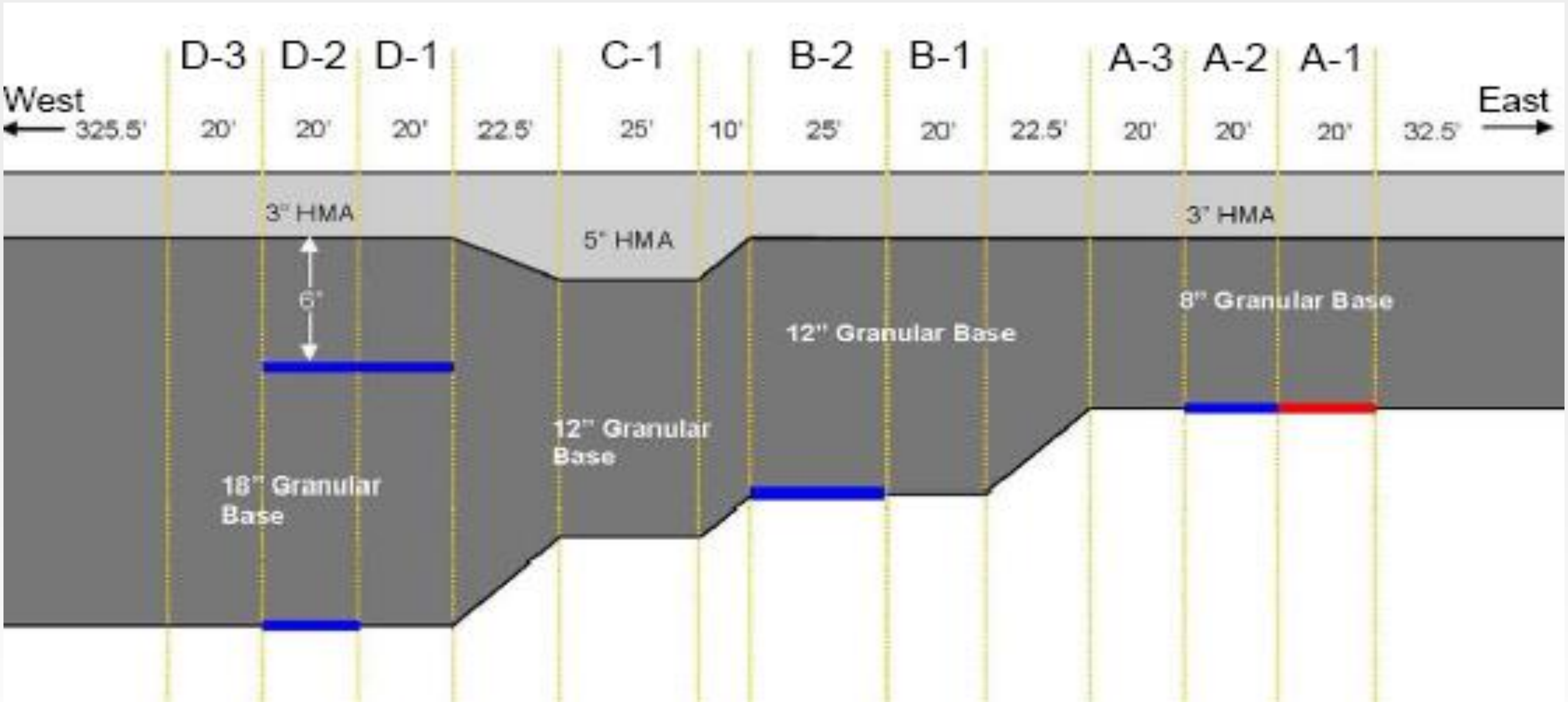
Project Objectives

3

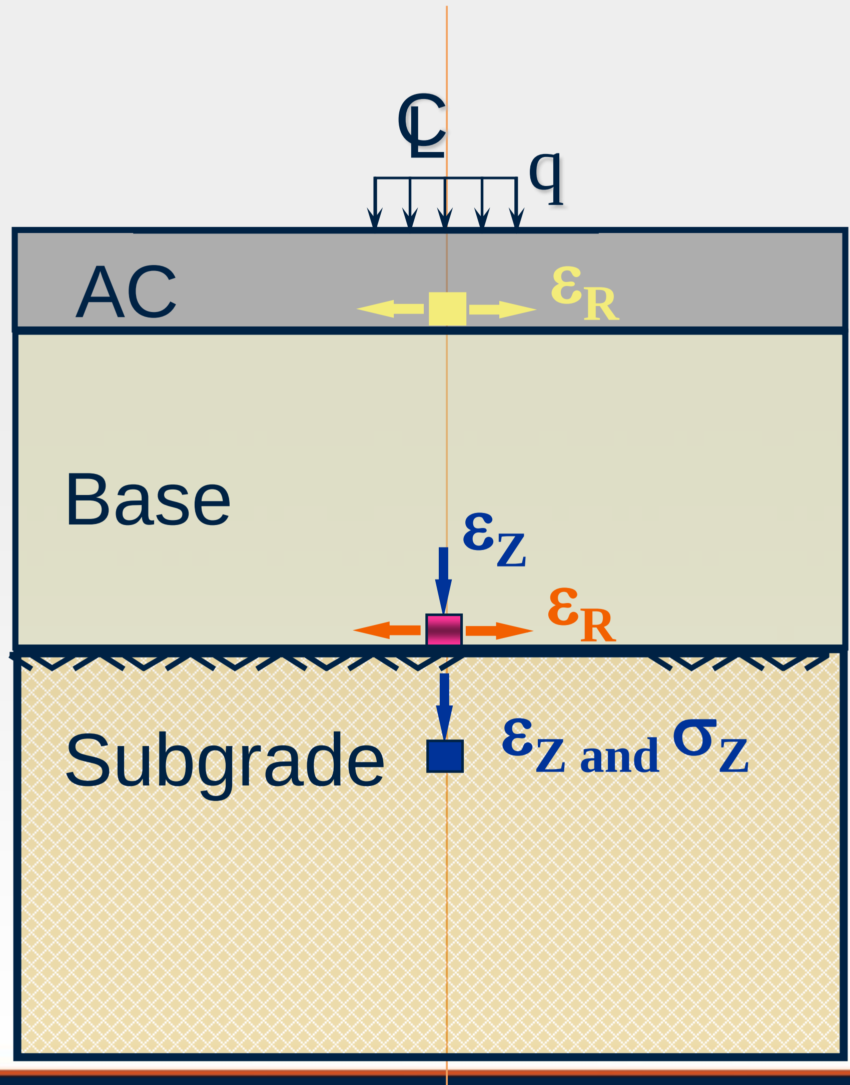
1. Learn from controlled accelerated testing studies the impact of truck loading on flexible pavement

2. Conduct finite element modeling (FEM) to estimate structural and performance impact of HVP on highway pavement structures

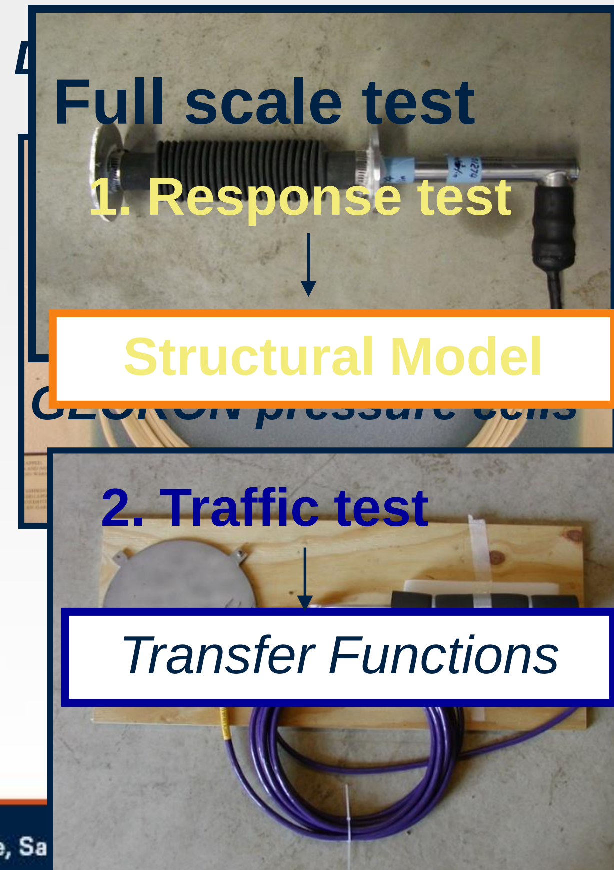
Pavement Section Layout



Measured Pavement Responses



Linear Variable Displacement Transducers (LVDT)



Full scale test

1. Response test

Structural Model

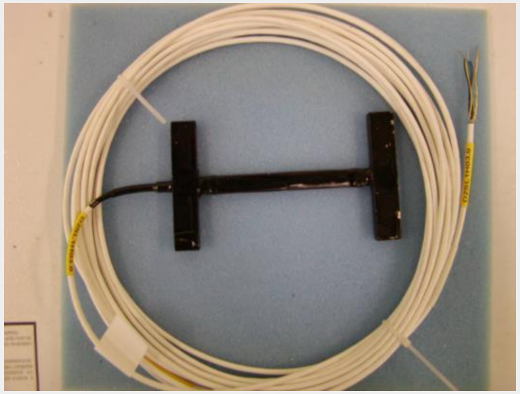
2. Traffic test

Transfer Functions

Load Associated Instruments

Pressure cell

HMA strain gauge

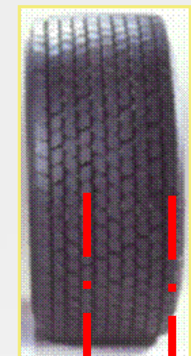


LVDT

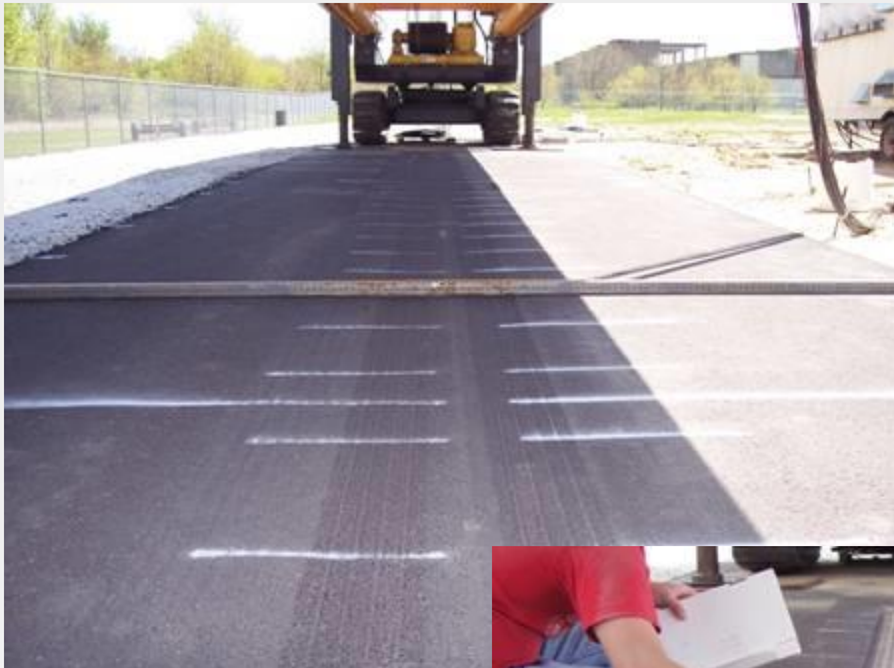
Location: centerline at wheel loading path

Advanced Testing and Loading Assembly (ATLAS)

- Tire configuration: Dual-tire assembly, and Wide-base (455)
- Tire load: 26, 35, 44, 53 and 62 kN
- Tire inflation pressure: 550, 690 and 760 kPa
- Tire speed: 8 and 16 km/h
- Offset: @ tire center and edge
- No. of passes: 5-10 for each condition



Rutting on Reinforced Section: B2

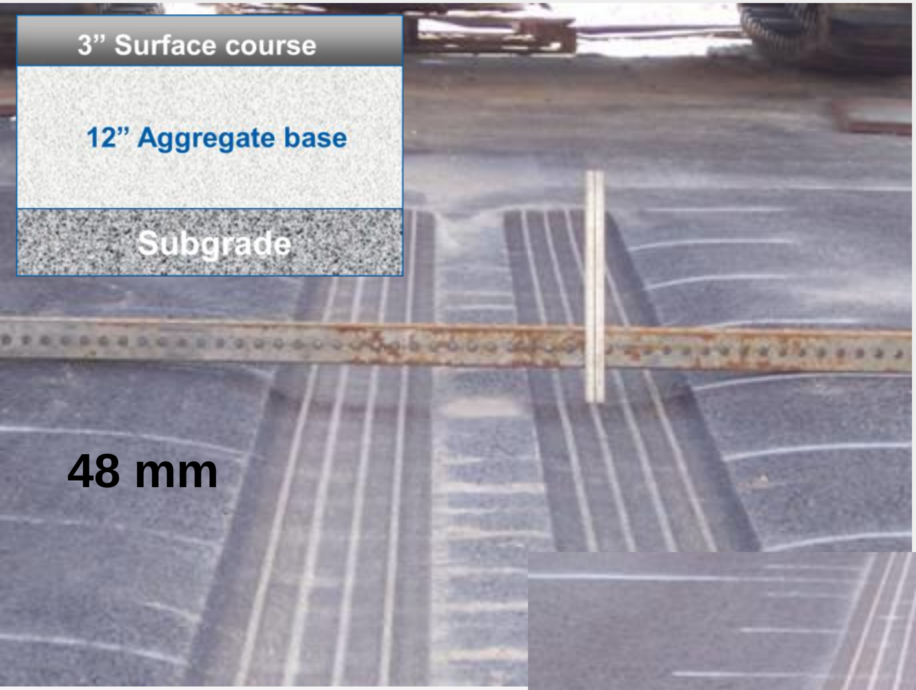


Rutting before testing

Rutting after 10000 passes

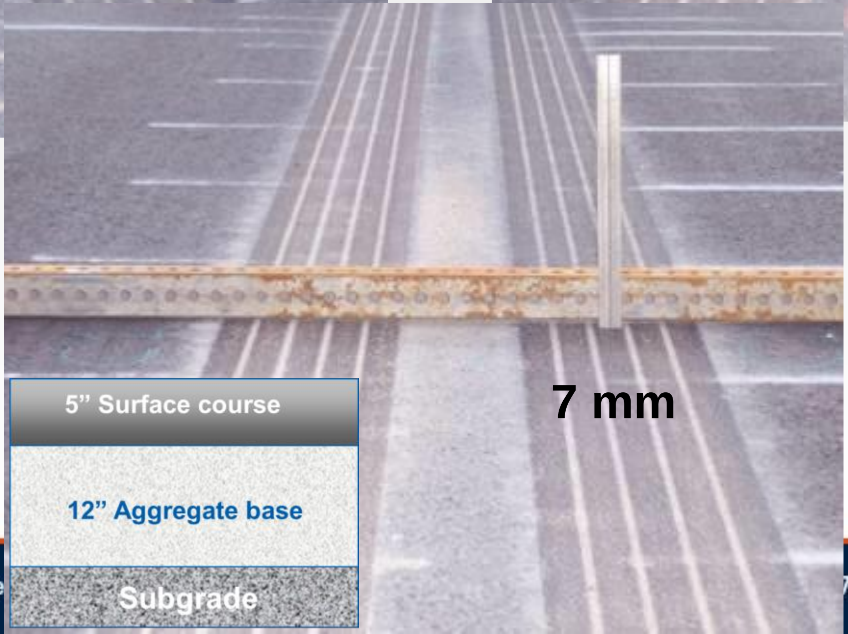
Rutting after 30000 passes

Rutting after 50,000 Passes



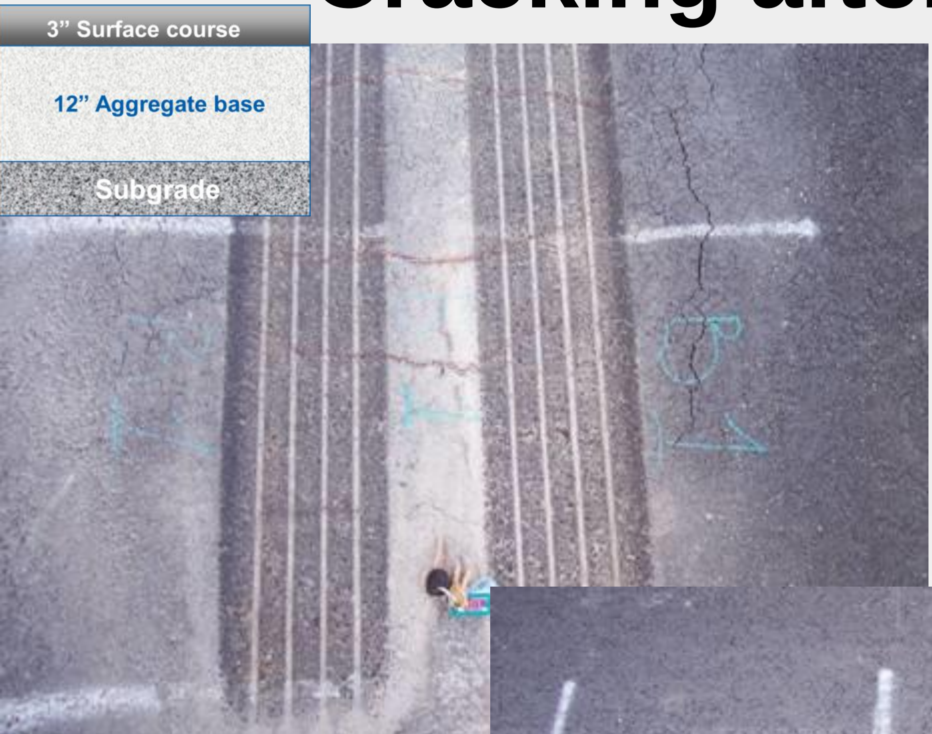
B1 (Control)

B2 (Reinforced)

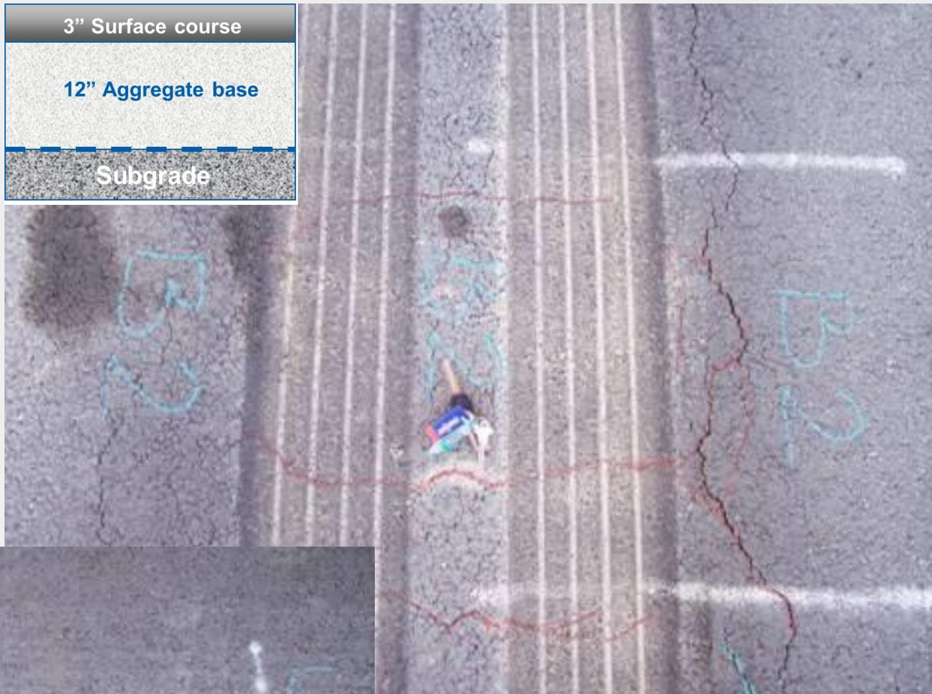


C1 (Thick HMA)

Cracking after 50000 Passes



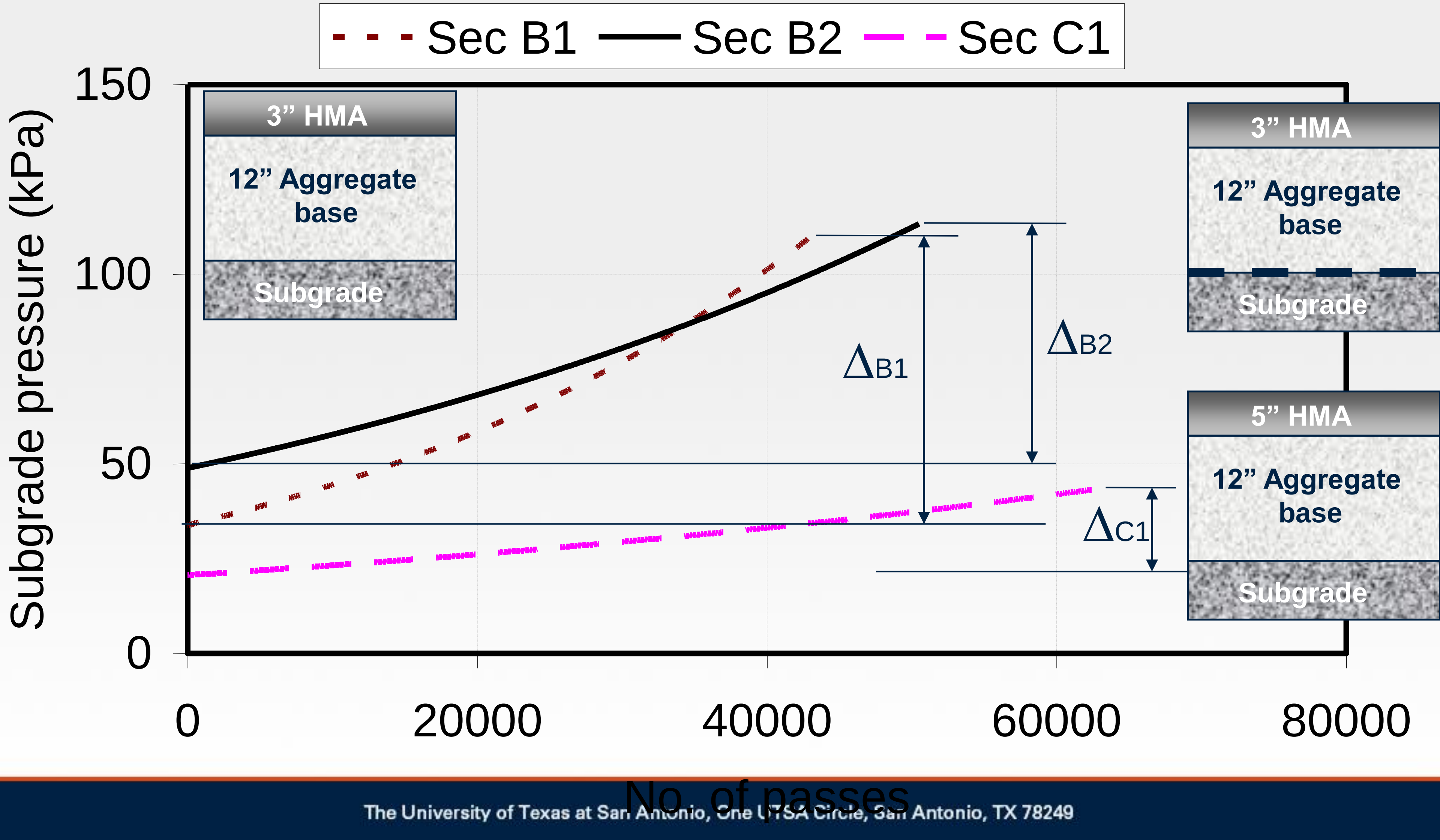
B1 (Control)



B2 (Reinforced)

C1 (Thick HMA)

Pavement Response Evaluation

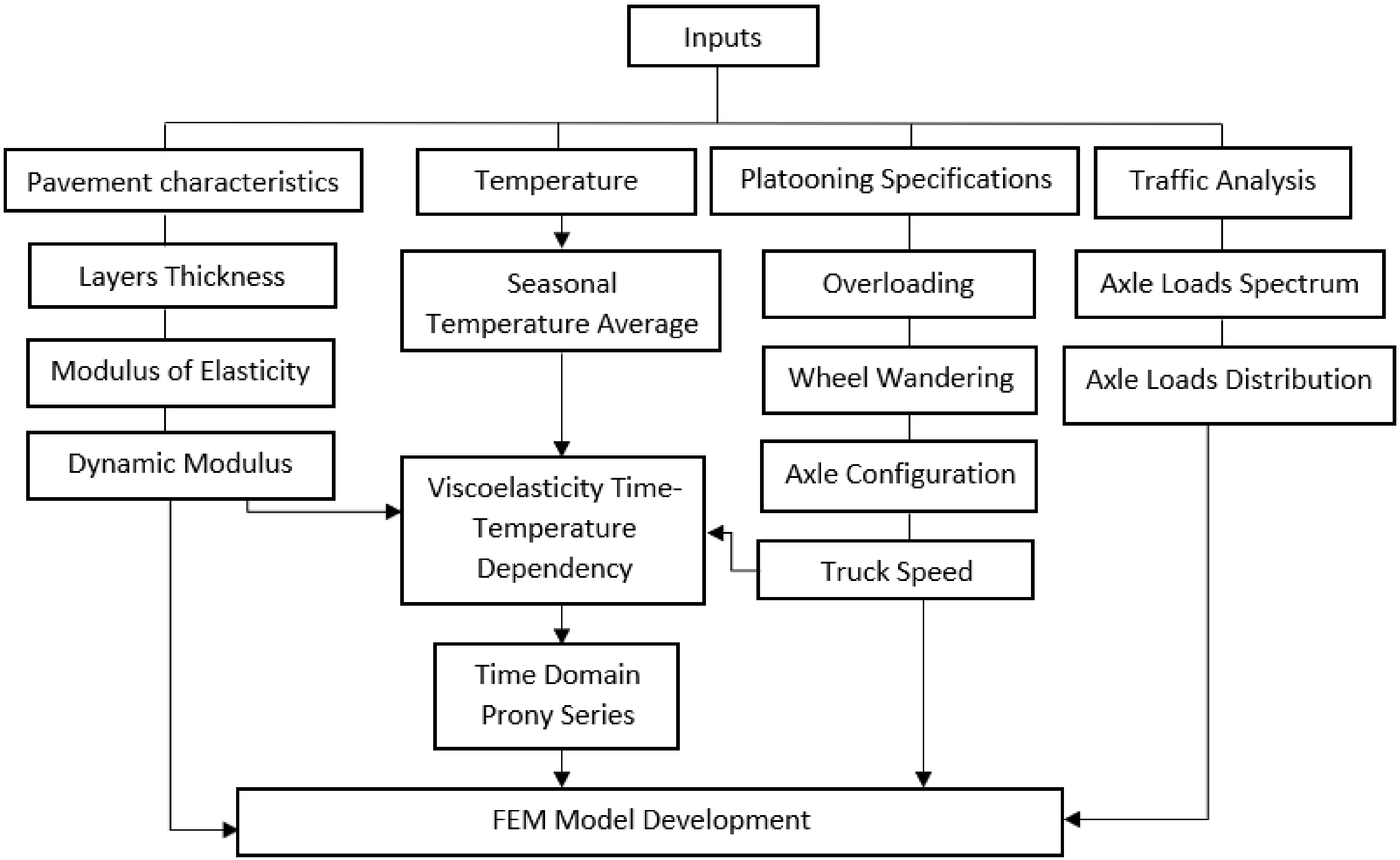


Platooning Effect on Pavement-Literature

- ✓ Platooning can affect the pavement service life in terms of "limited wandering" or "less headway distance".
- ✓ Overloading also may have an intensified effect while trucks drive on a fixed wheel path. Overloading can cause a 20-50% reduction in pavement's fatigue life.
- ✓ Although numerous studies are conducted to evaluated various aspects of HVP, the effects on pavement condition have not been studied thoroughly.

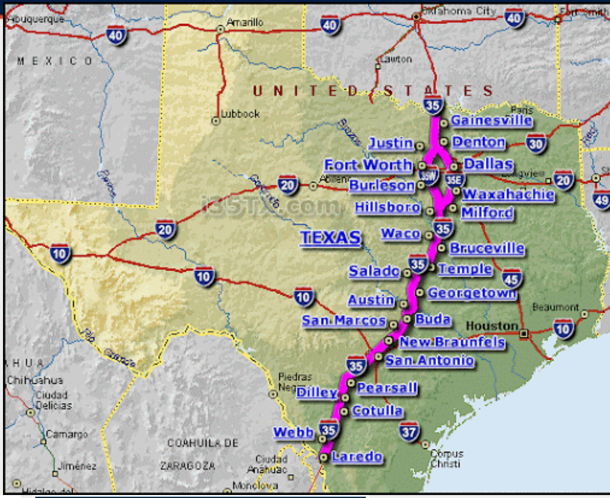
S. Erlingsson, S. Said, and T. McGarvey, "Influence of Heavy Traffic Lateral Wander on Pavement Distribution," EPAM-4th Eur. Pavement Asset Manag. Conf. Statens väg-och Transp., 2012.
S. M. Zaghloul and T. D. White, "Guidelines for Permitting Overloads; Part 1: Effect of Overloaded Vehicles on the Indiana Highway Network," no. FHWA/IN/JHRP-93/05, Jun. 1994.

Analysis Flowchart



IH-35 structural layers

✓ The pavement section is comprised of five asphalt layers. The dynamic modulus data for all layers were obtained, analyzed, and used to develop the master curves and Prony series parameters.

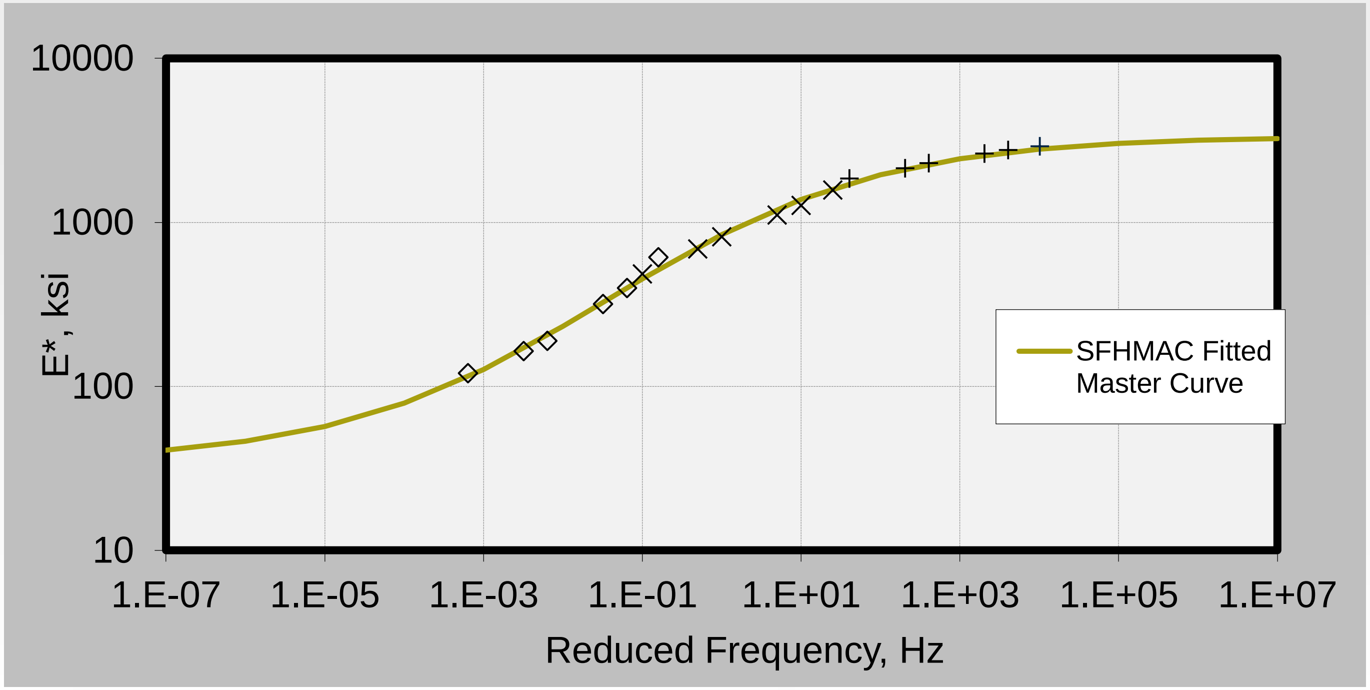


	Layer Designation, Materials, and Functions				Thickness (inches)
Layer 1	PFC (SS3231)	Porous Friction Course		Sacrificial layer	1.0 – 1.5
Layer 2	HDSMA (SS3248)	Heavy-Duty SMA	1/2″ Aggregate + PG 76-XX	Impermeable load carrying layer	2.0 – 3.0
Layer 3	SFHMAC (SS3249)	Stone-Filled HMAC	3/4″ Aggregate + PG 76-XX	Transitional layer	2.0 – 3.0
Layer 4	SFHMAC (SS3248)	Stone-Filled HMAC	1.0-1.5″ Aggregate + PG 76-XX	Stiff load carrying layer	8.0 - Variable
Layer 5	Superpave (SS3248)	Superpave (RBL)	1/2″ Aggregate + PG 64-XX (Target lab density=98%)	Stress relieving impermeable layer	2.0 – 4.0
Layer 6	Stiff base or stabilized subgrade		Construction working table or compaction platform for succeeding layers		6.0-8.0
Subgrade					∞

IH-35 SA Thickness (in.)
1.5
2
2
12
4
6

- ✓ Master-curves were developed to predict the pavement modulus of elasticity or E^* at the required temperatures (seasonal averages) using Arrhenius shift-factor equation

$$\log(E^*) = \delta + \frac{Max - \delta}{1 + e^{\beta + \gamma\{\log(t) - log a_T\}}}$$

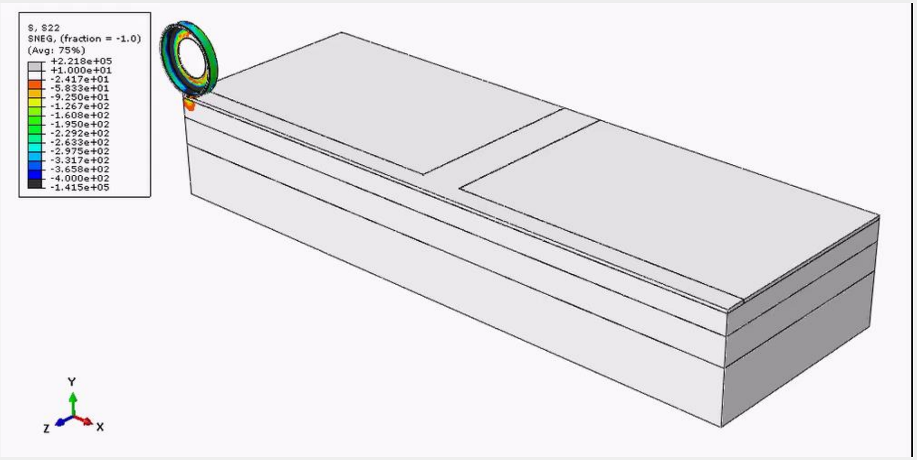


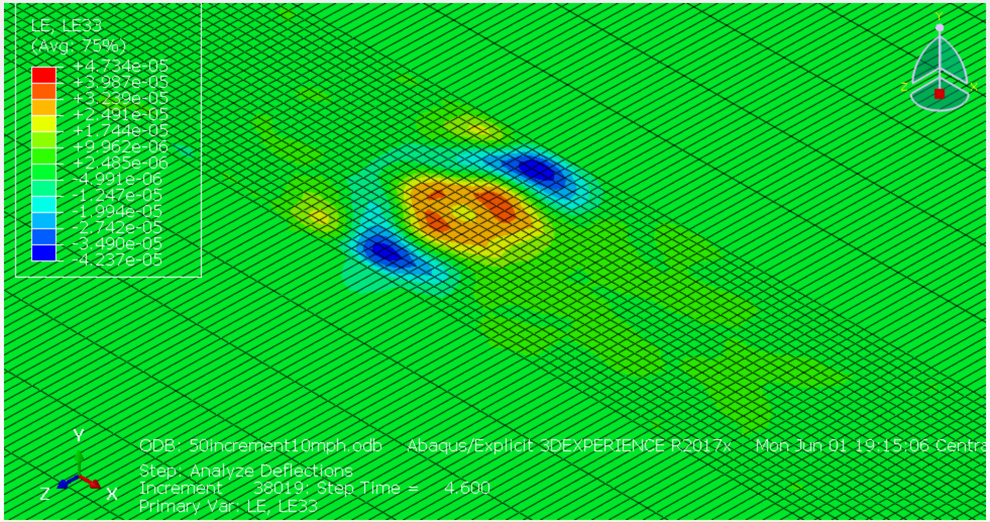
Traffic distribution of IH-35 (from TAMU [Dr. Walubita]).

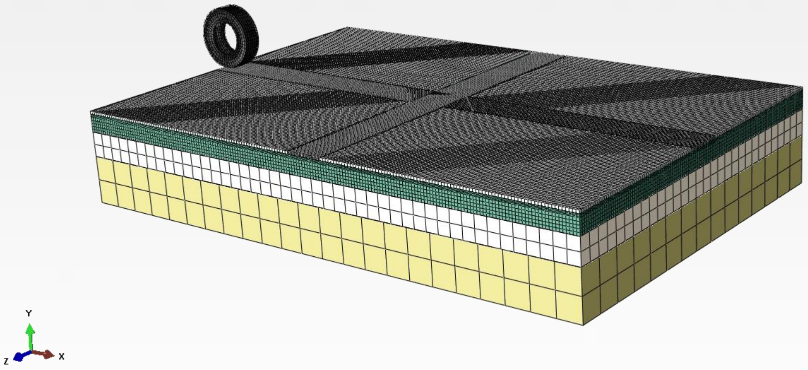
Steering		Non-Steering Single Axle		Tandem		Tridem		Quad	
Axle Load (kips)	Percent	Axle Load (kips)	Percent	Axle Load (kips)	Percent	Axle Load (kips)	Percent	Axle Load (kips)	Percent
3	0.7	3	6.4	6	0.0	12	15.4	12	0.0
4	0.4	4	5.6	8	0.0	15	8.4	15	0.0
5	0.6	5	6.7	10	4.9	18	10.0	18	0.0
6	0.9	6	5.2	12	6.7	21	7.1	21	0.0
7	2.4	7	6.0	14	7.7	24	5.2	24	0.0
8	3.5	8	6.5	16	8.6	27	3.4	27	0.0
9	7.9	9	6.5	18	9.1	30	6.4	30	0.0
10	12.5	10	5.5	20	8.8	33	6.5	33	0.0
11	22.3	11	6.3	22	8.2	36	5.0	36	0.0
12	19.6	12	4.9	24	7.6	39	4.7	39	0.0
13	21.6	13	6.8	26	8.4	42	7.8	42	0.0
14	6.2	14	6.6	28	7.7	45	8.5	45	0.0
15	0.7	15	5.9	30	7.6	48	3.1	48	0.0
16	0.4	16	4.8	32	7.1	51	1.8	51	0.0
17	0.2	17	5.4	34	4.7	54	2.8	54	0.0
18	0.1	18	5.4	36	1.9	57	1.8	57	31.8
19	0.0	19	2.6	38	0.7	60	0.6	60	31.8
20	0.0	20	1.7	40	0.2	63	0.6	63	0.0
21	0.0	21	0.6	42	0.1	66	0.0	66	0.0
22	0.0	22	0.3	44	0.0	69	0.3	69	0.0
23	0.0	23	0.1	46	0.0	72	0.3	72	0.0
24	0.0	24	0.1	48	0.0	75	0.0	75	0.0
25	0.0	25	0.0	50	0.0	78	0.0	78	0.0
26	0.0	26	0.0	52	0.0	81	0.0	81	0.0
27	0.0	27	0.0	54	0.0	84	0.0	84	0.0
28	0.0	28	0.0	56	0.0	87	0.0	87	31.8
29	0.0	29	0.0	58	0.0	90	0.0	90	0.0
30	0.0	30	0.0	60	0.0	93	0.0	93	0.0
31	0.0	31	0.0	62	0.0	96	0.0	96	1.6
32	0.0	32	0.0	64	0.0	99	0.0	99	0.0
33	0.0	33	0.0	66	0.0	102	0.0	102	3.1

3D Finite Element Simulation of IH-35

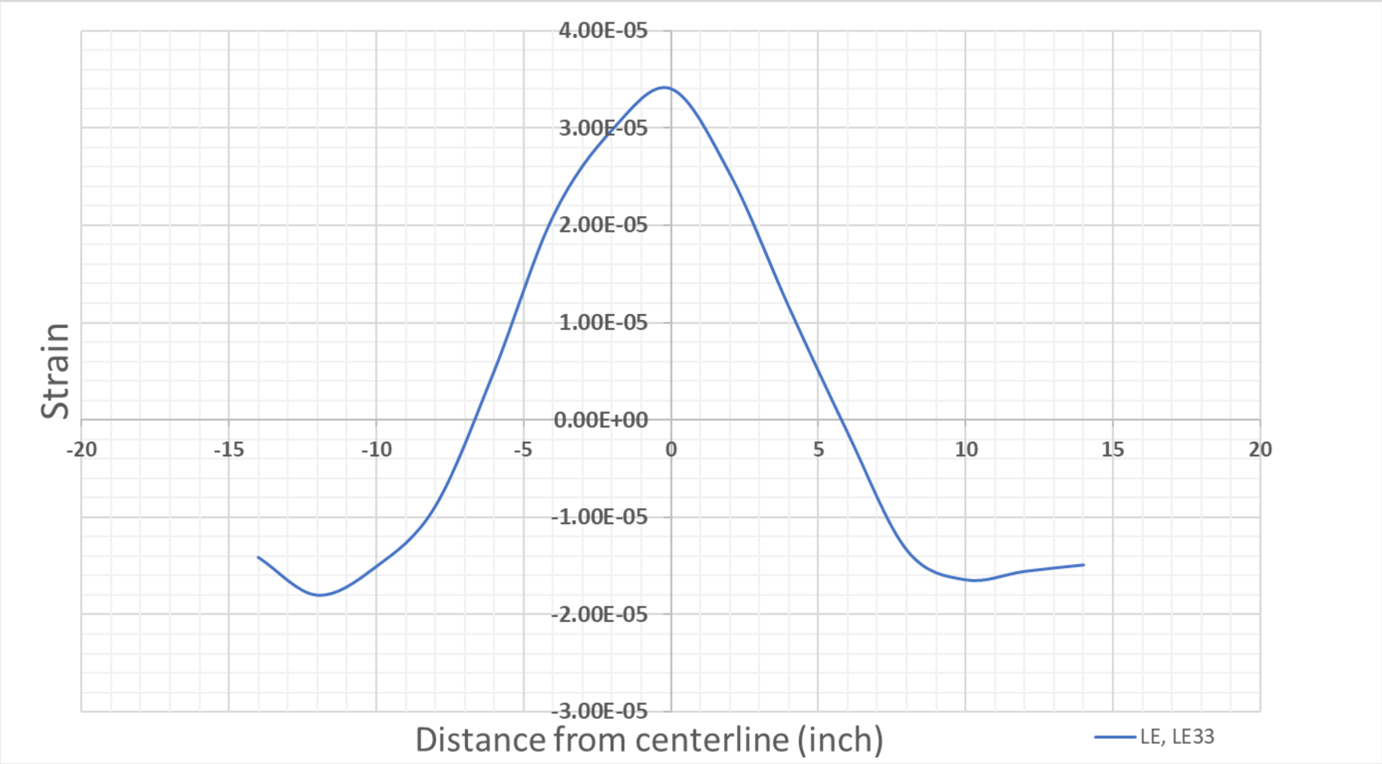
- ✓ A 100-meter length model is developed in ABAQUS.
- ✓ The mesh in the loading area is finer to obtain higher accuracy
- ✓ A moving wheel is rolling at center of model to simulate HVP.





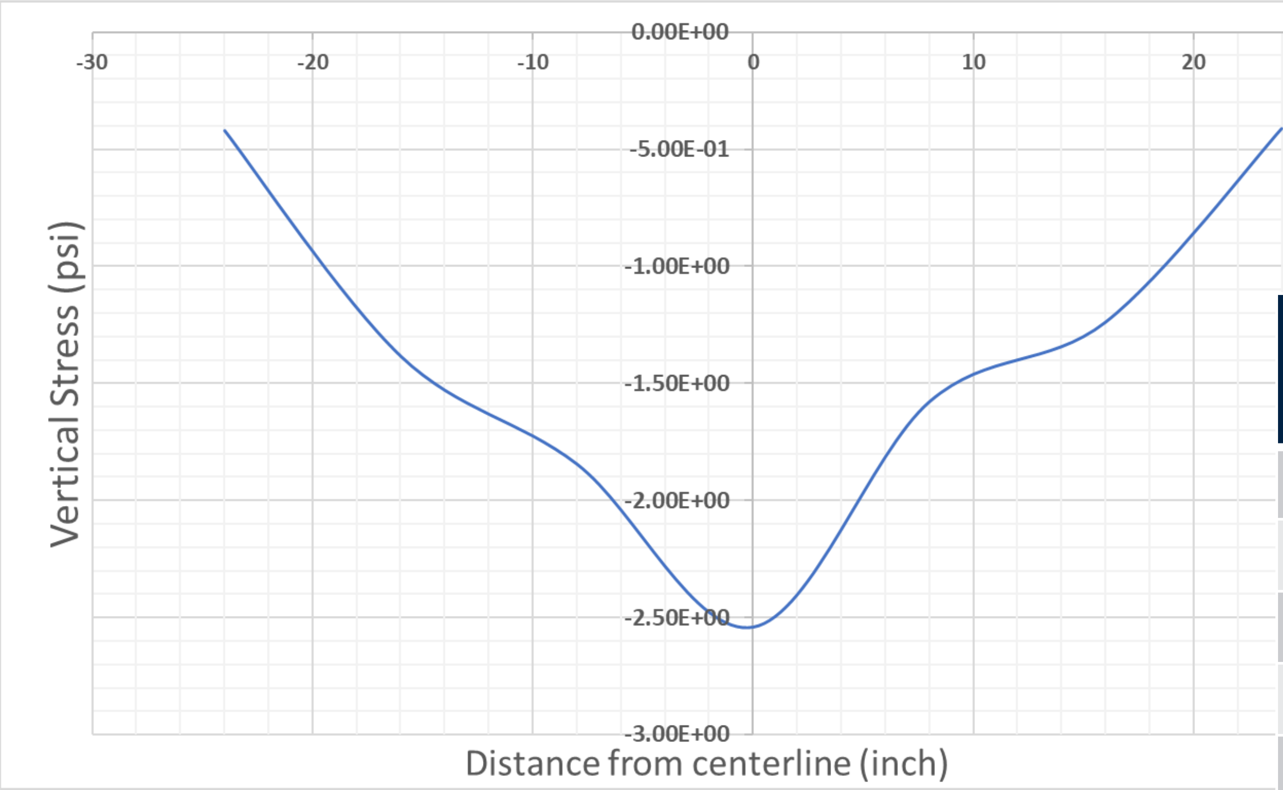


Horizontal Strain at Bottom of Asphalt Concrete Layer



Distance from center	Tangential Strain
14	-1.49E-05
12	-1.56E-05
10	-1.65E-05
8	-1.34E-05
6	-1.35E-06
4	1.16E-05
2	2.53E-05
0	3.41E-05
-2	2.98E-05
-4	2.09E-05
-6	5.00E-06
-8	-8.93E-06
-10	-1.51E-05
-12	-1.80E-05
-14	-1.41E-05

Vertical Stress at the Top of the Subgrade



Distance from center (in.)	Vertical Stress (psi)
24	-0.411065
16	-1.2384
8	-1.57841
0	-2.54142
-8	-1.84523
-16	-1.38449
-24	-0.419702

Conclusion

- ✓ Based on the tangential strain values at the bottom of the AC layer, it can be concluded that wandering can have influential effect on the tensile strains.
- ✓ Only a 5 inch offset (from the center of the tire) would decrease the strain magnitude to 25% of values at the center.
- ✓ Compared to a fixed path platooning, a normal 5-inch distribution of wandering can have a 3.5 times higher fatigue life.

- ✓ Comparison between the vertical stress values on the subgrade at different wandering offsets implies the significant Impact of wandering on the vertical stress.

- ✓ An 8 and 16 inch offset (from the center of the tire) would roughly decrease the vertical stress magnitudes to 62 and 48% of values at the center, respectively.

- ✓ Compared to a fixed path platooning, a normal 8-inch distribution of wandering can induce a 1.6 times less rutting depth (for the same temperature and number of loading cycles).

Future Work-Expectations and Suggestions

- Further field measurement of the mechanical properties (strain, stress, or deflection) can be used to optimize the model and give a more realistic view of the platooning effect on substructures.
- Suggest policies and regulation needed for overloading situations and trucks' weight limits.
- Examine using alternative mix design or PCC exclusively for the platooning lane.