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# PAVEMENT-VEHICLE INTERACTION (PVI): REVIEW AND TRENDS

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# PRESENTATION OUTLINE

- Background
- Pavement characteristics and vehicle fuel consumption
- Existing PVI models
- Implementation considerations
- Key takeaways

# BACKGROUND

# BACKGROUND

- FHWA established a Use Stage Technical Subgroup (USTS) in 2023
  - Provide technical input on critical issues related to the pavement use stage
  - Focus on pavement-vehicle interaction (PVI) effects related to roughness, structural response, and texture and how it affects vehicle fuel/energy consumption
- Goal: provide highway agencies with additional information and tools to help guide and inform pavement investment decision-making

# USTS MEMBERS

- Imad Al-Qadi (UIUC)
- Hessam AzariJafari (MIT)
- Jim Mack (WJE)
- Joseph Shacat (formerly NAPA) and Richard Willis (NAPA)
- Imad Basheer (Caltrans)
- Bernard Izevbekhai (MnDOT)
- Kiran Mohanraj (Transtec)
- Nadarajah Sivaneswaran (Siva) (FHWA)
- Robert Spragg (FHWA)
- Migdalia Carrion (FHWA)
- LaToya Johnson (FHWA)
- John Harvey (UC Davis)
- Tom Van Dam (WJE)
- Prashant Ram (APTech)
- Kurt Smith (APTech)

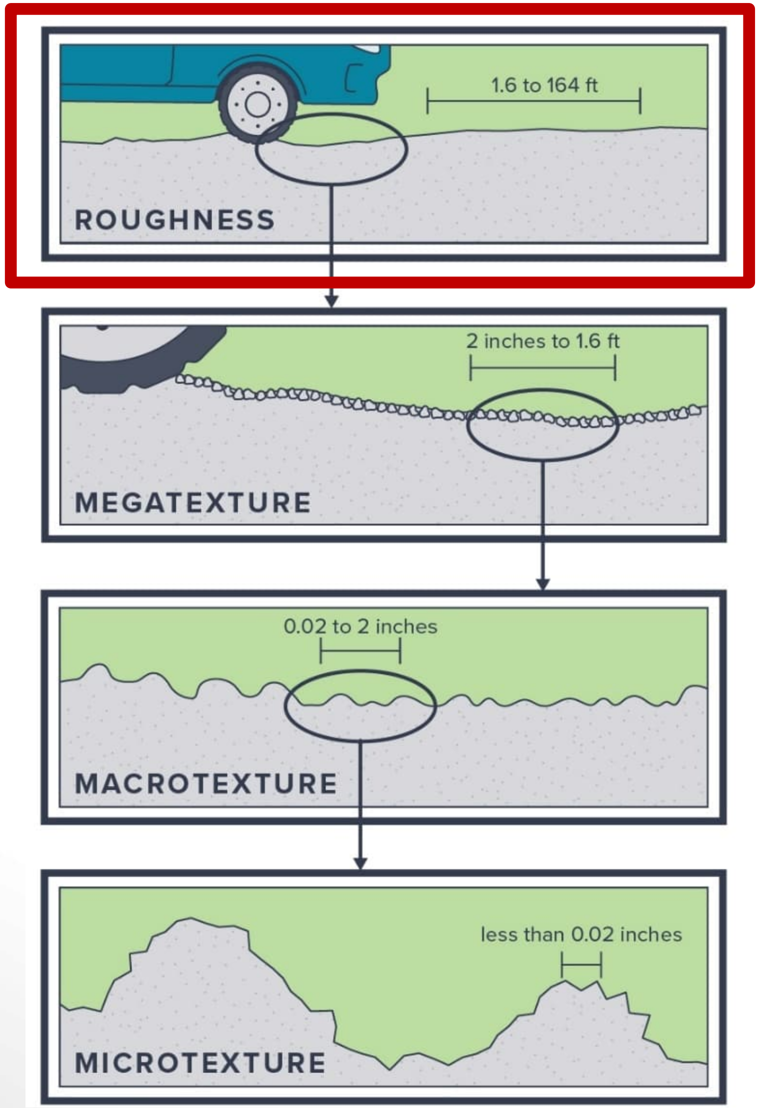
# PAVEMENT CHARACTERISTICS AND VEHICLE FUEL CONSUMPTION

# PAVEMENT CHARACTERISTICS AND VEHICLE FUEL CONSUMPTION

- PVI: Relationship between vehicle system (tires, suspension, mass) and following pavement characteristics:
  - Roughness
  - Surface Texture
  - Structural Response
- Contributes to rolling resistance but also affects vehicle maintenance, freight damage, human comfort, driver safety, and tire-pavement noise
- PVI also directly impacts pavement performance and longevity

# ROUGHNESS

- Consumption of vehicle energy through viscoelastic working of shock absorbers and drive train components, and deformation of tire side walls
- Wavelengths: 1.6 ft. to 164 ft.
- Originates from initial construction and pavement degradation over time
- Affected by timing and type of maintenance and rehabilitation treatments
- Measurement metric: IRI (most common)

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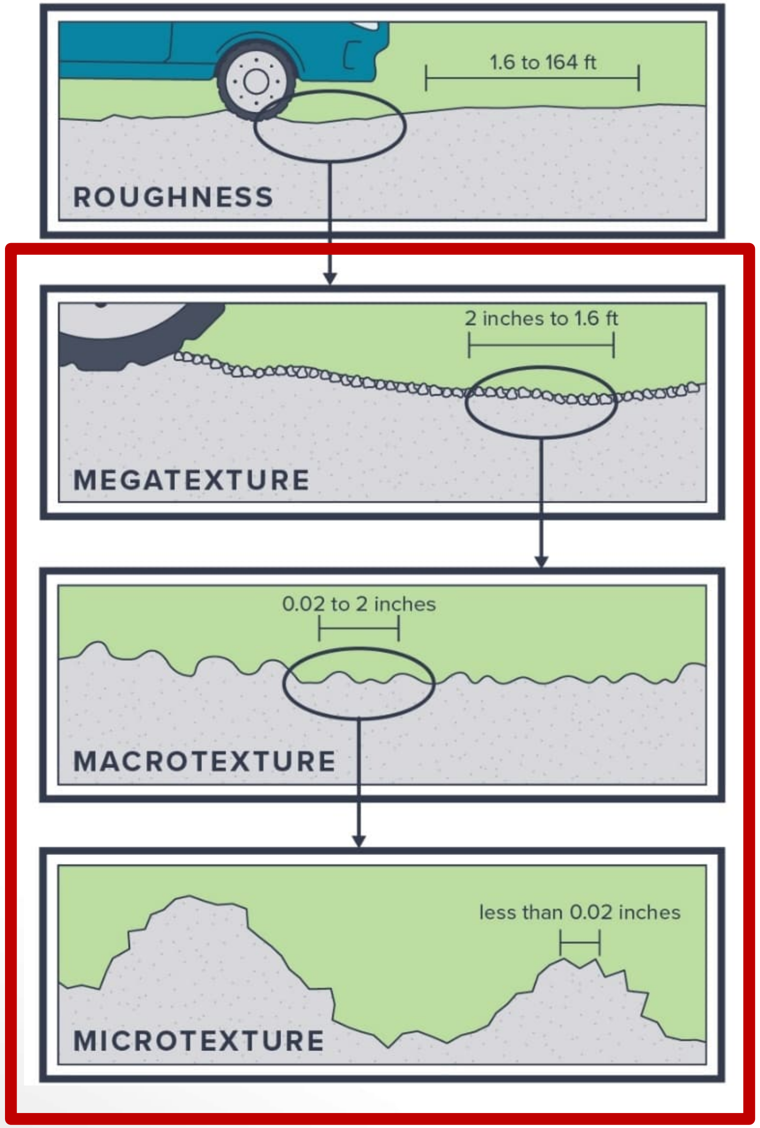
# PAVEMENT TEXTURE

- Consumption of vehicle energy through the viscoelastic working of the deformable tire tread rubber in the tire-pavement contact area as it passes over positive surface macrotexture
- Microtexture: slow speed skid resistance; little effect on excess fuel consumption (EFC)
- Macrotexture: friction at high speeds on wet surfaces; impacts EFC and rolling resistance
- Megatexture: contribution to EFC remains unclear
- Macrotexture metrics: mean texture depth (MTD); mean profile depth (MPD)

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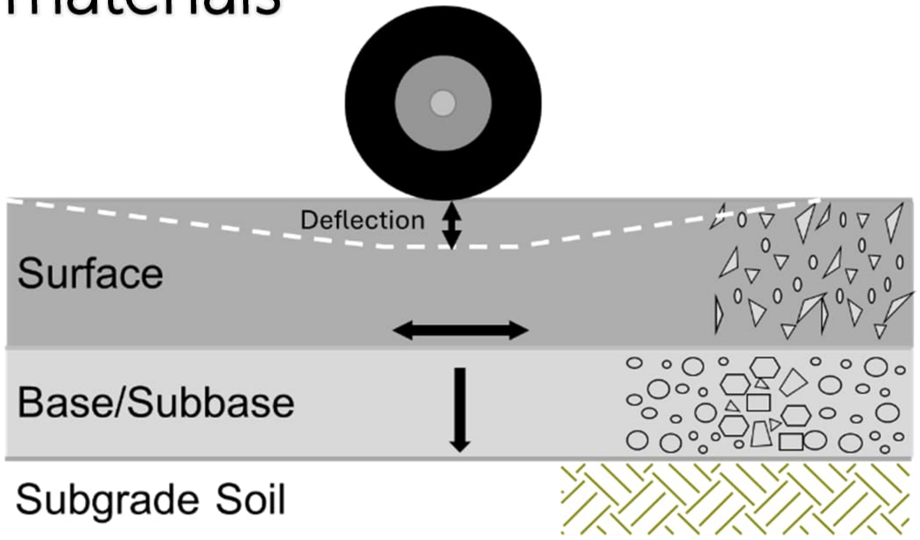
# STRUCTURAL RESPONSE

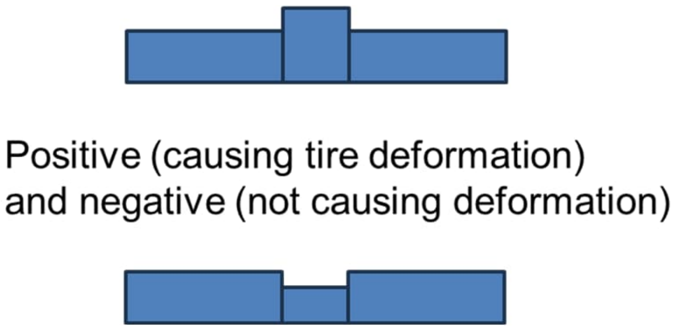
- Consumption of vehicle energy in the pavement through viscoelastic deformation of pavement materials
- For viscoelastic materials, structural response is sensitive to daily and seasonal temperature changes
- Influenced by layer thickness, stiffness, and material properties that affect pavement response




- For elastic systems, no energy dissipation regardless of amount of deflection
- Modeled as: viscoelastic energy dissipation; delayed pavement deformation

# RATIONALE FOR INCLUDING PVI IN LCA

- PVI parameters contribute to rolling resistance and EFC
  - Additional greenhouse gas (GHG) emissions from fossil-fuel propelled vehicles
- Roughness can have largest impact:
  - IRI > 170 inches/mile: EFC between 1.5 and 5%
  - IRI around 250 inches mile: EFC between 2 to 8%
- Macrotexture:
  - MPD b/w 0.5 and 2 mm: EFC between 0  to 3%
  - Positive macrotexture produces greater impact
- Structural response:
  - EFC between 0 to 5% for typical ranges of viscoelastic behavior



# EXISTING PVI MODELS

# EXISTING PVI MODELS

- Pavement surface characteristics models (PSC models)
  - Estimate rolling resistance caused by surface properties like roughness and texture
  - Use data from field measurements to assess vehicle fuel consumption
  - Considers: roughness (IRI), macrotexture (MPD)
  - Calculates: Rolling resistance, instantaneous/excess fuel consumption
- Pavement structural response models (PSR models)
  - Determine energy dissipation during vehicle movement by analyzing pavement deflection, stiffness, and layer properties
  - Considers: layer moduli, thickness, other material properties
  - Calculates: dissipated energy, excess fuel consumption

## PSC MODELS

- NCHRP 1-45 (Chatti and Zaabar 2012)
- MIRIAM Model (Carlson, Hammarström, and Eriksson 2013)
- NRC Phase III Model (Taylor and Patten 2006)
- UIUC Roughness Speed Impact Model (Ziyadi et al. 2018)
- FHWA Updated HERS Model (Hajj et al. 2017; Hajj et al. 2018)
- MIT Roughness Induced Model (Loughalam et al. 2018)

## PSR MODELS

- MIT Deflection-Induced Model (Louhghalam, Akbarian, and Ulm 2014)
- OSU Excess Vehicle Fuel Model (Estaji et al. 2019)
- MSU Structural Rolling Resistance Model (Balzarini, Zaabar, and Chatti 2017)

# IMPLEMENTATION CONSIDERATIONS

# ASSESSMENT OF PAVEMENT CHARACTERISTICS FOR PVI IMPLEMENTATION: ROUGHNESS

- Can be considered in project-level design
- Sensitivity analyses considering variability of models is recommended
- Pavement ME model should be checked against PMS data
- Need to consider life-cycle of M&R treatments for comparison of alternative designs
- Can be used in network-level analysis if lane-based IRI data is available
- Gaps and Needs:
  - Robust IRI models for implementation
  - IRI data by lane
  - Inclusion of future M&R lookahead
  - Adequate vehicle characterization information

# ASSESSMENT OF PAVEMENT CHARACTERISTICS FOR PVI IMPLEMENTATION: TEXTURE

- Can be considered in project-level design but texture is related to surface management not structural design
- Gaps and Needs
  - Limited models for negative textures and concrete pavements
  - Database of different MPD values for different DOT surface materials
  - Limited MPD performance models

# ASSESSMENT OF PAVEMENT CHARACTERISTICS FOR PVI IMPLEMENTATION: STRUCTURAL RESPONSE

- Can be implemented in design and has been demonstrated
- Simplified models are available for energy dissipation
- Gaps and Needs
  - Time-series dynamic deflection data needed for viscoelastic characterization
  - Deflection due to a moving wheel needs to be determined
  - Aging and other models considering depth, climate, and material that influence viscoelastic properties for prediction over life-cycle

# IMPLEMENTATION READINESS

| Move Forward to Implementation | Begin Moving Forward to Implementation |
|---|---|
| • Data and models available at agency level<br>• Implementation guidance is published<br>• Training and incorporating into standard practice are needed for each agency | • Data and models are known and published with some external review<br>• Data collection methods are known but data not yet being collected<br>• Implementation guidance needs to be development<br>• Knowledge sharing is needed<br>• Training and incorporation into standard practice is needed |
| Roughness | Texture and Structural Response |

# KEY TAKEAWAYS

# KEY TAKEAWAYS FROM USTS: ROUGHNESS

- IRI is widely used; incorporated into most models
- Current roughness models estimate EFC within similar orders of magnitude (Mohanraj et al. 2022)
- Some DOTs looking to maintain adequate levels of pavement smoothness as one strategy to reduce EFC
- Further exploration needed to understand how different pavement profile parameters influence EFC across vehicle types
- Research at UIUC demonstrated effects of suspension systems, tire characteristics, roughness, and dynamic loading on EFC

# KEY TAKEAWAYS FROM USTS: TEXTURE

- Negative textures may result in lower EFC compared to positive textures
- Contribution of megatexture to EFC remains unclear since it is not typically measured
- Impact of pavement surface temperature on tire inflation and EFC has not been documented
- When IRI falls within range of 60 to 110 inches per mile, texture and structural response are likely the primary factors influencing EFC
- A minimum level of macrotexture is required for safety, with considerations depending on rainfall, traffic speeds, and road slopes

# KEY TAKEAWAYS FROM USTS: STRUCTURAL RESPONSE

- Uncertainty regarding whether a perfectly elastic system, regardless of geometry combined with rigid tire (pushed wheel) contributes to EFC
  - Later discussions with structural modeling experts indicated that elastic systems have no structural response energy consumption (Weissman, Harvey, and Smith 2025)
- Most studies have modeled roughness, texture, and structural response independently (interactions still not clearly understood)
- At high roughness levels, roughness and structural response may be interrelated (dynamic loading)
- Conducing a controlled full-scale field study is challenging

# KEY TAKEAWAYS FROM USTS:
# STRUCTURAL RESPONSE (CONT'D)

- Traffic Speed Deflection Devices (TSDDs) could be useful to simultaneously characterize mechanical response and EFC
    - ➢ Concerns: analytical models that assume elastic pavement behavior
- Tire is not a rigid body; tire deflections must also be considered to assess influence on EFC

# THANK YOU!

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