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OFFICE OF RESEARCH & DEVELOPMENT

2012 R&D REVIEW

Long Haul Whole-Body Vibration (WBV) Assessments of Locomotive Cabs

U.S. Department of Transportation

Federal Railroad Administration

Program Area & Risk Matrix

Long Haul Whole-Body Vibration (WBV) Assessments of Locomotive Cabs

Program Areas	Risk Factors	Trespass	Grade Crossing	Derailment	Train Collision	All Other Safety Hazards
Railroad Systems Issues						
Human Factors						
Track & Structures						
Track & Train Interaction						
Facilities & Equipment						
Rolling Stock & Components						
Hazardous Materials						**X**
Train Occupant Protection						
Train Control & Communications						
Grade Crossings & Trespass						

FRA WBV Program Goals & Objectives

- Federal Railroad Administration sponsoring unbiased, independent assessment

- Characterize representative sample of cab vibration and shock environment

- Collect the data in accordance with accepted international standards – ISO 2631

- Collect benchmark data for future locomotive cab ride-quality standards

Image reproduced from FRA report, *Gertler, J. & DiFiore, A. (2009). Work schedules and sleep patterns of railroad train and engine service workers. Report No. DOT/FRA/ORD-09/22. Federal Railroad Administration: Washington, DC.*

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ISO 2631 Standards for WBV

■ Standard for the health assessment of WBV

■ Standard is based on literature correlating discomfort and vibration
   – Assumption: discomfort associated with potential injury

■ Basis for health guidance
   – Studies show elevated risk of health impairment due to *long-term* exposure to *high-intensity* WBV
   – WBV likely effects: lumbar spine, nervous system and metabolic factors
   – Confounding variables include environmental factors, body posture and workspace ergonomics

■ Insufficient data to show an absolute quantitative relationship between WBV exposure and risk of adverse health effects
   – ISO standards provide general guidance regarding exposure limits

Key ISO 2631-1 and -5 Metrics

Weighted Acceleration - RMS (aw)

- A measure of the vibration to which the individual is exposed (2nd power)
- Not sensitive to shocks

Crest Factor

- Ratio of highest acceleration point to RMS – relative measure of the worst shock
- Use a_w when CF < 9
- Use VDV or MTVV when CF ≥ 9

Vibration Dose Value (VDV)

- A measure of the vibration which emphasizes shocks but also considers background vibration (4th power)

Maximum Transient Vibration Value (MTVV)

- The most severe 1-second, measured using a running RMS

ISO 2631-5

- Multiple Shock Health Assessment

Acceleration dose, Dk

- A measure designed to consider shocks alone (6th power)

Daily static dose, Sed

- Risk of adverse health effect over lifetime of exposure
- Values <0.5 MPa, low risk
- Values >0.8 Mpa, high risk

Apply frequency weightings

Calculate weighted RMS

Determine Crest Factor

Alternate evaluation method needed?

Yes **No**

Calculate running RMS acceleration - MTVV

Calculate 4th power vibration dose value - VDV

Determine health effects from ISO 2631-1 Annex B
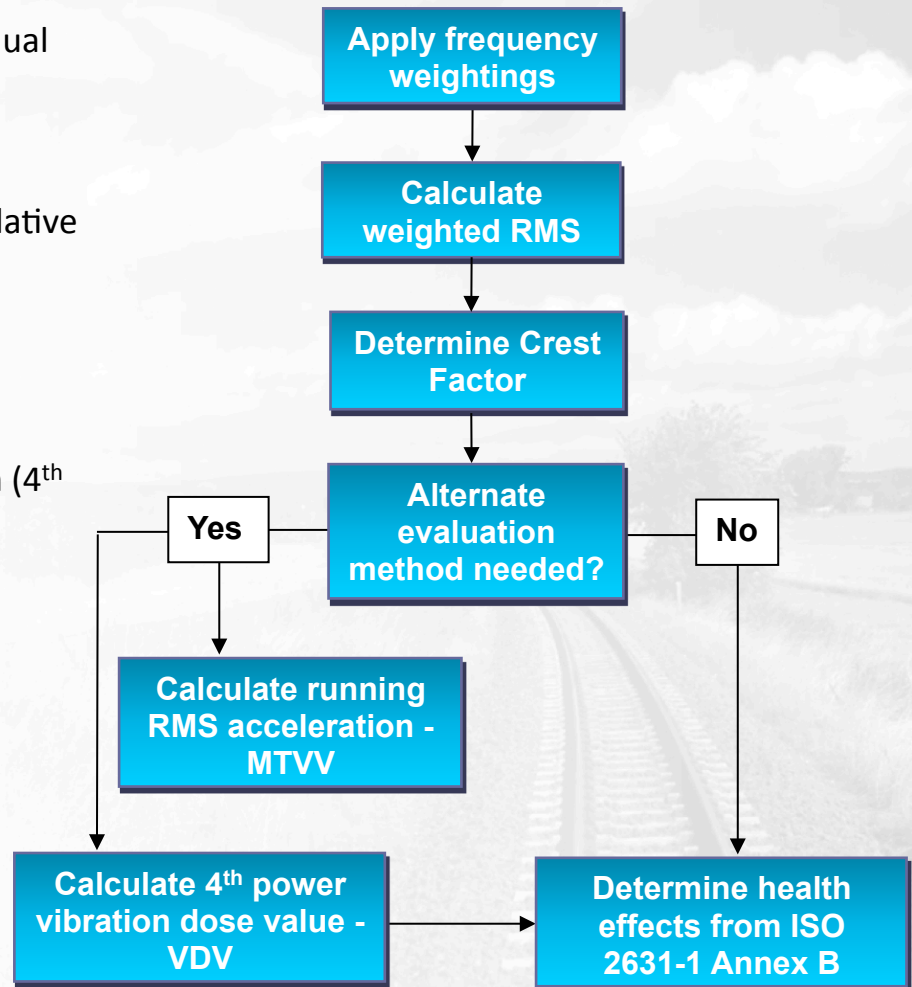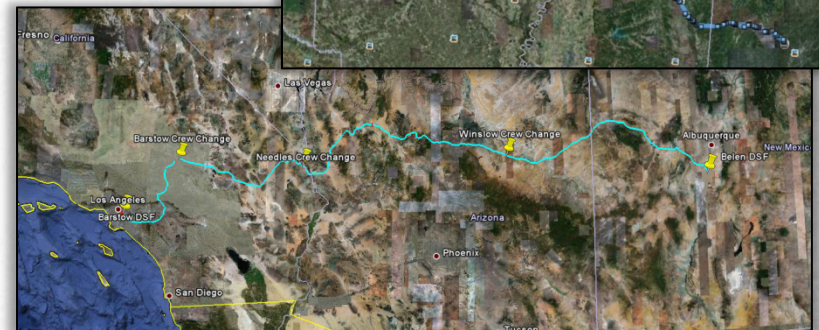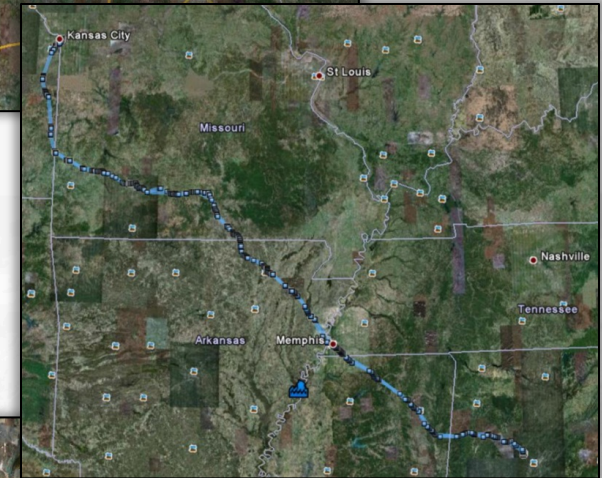
ISO 2631-1 Health Assessment

Result from previous procedure compared with health guidance cautions zones

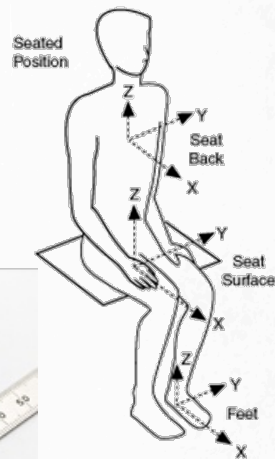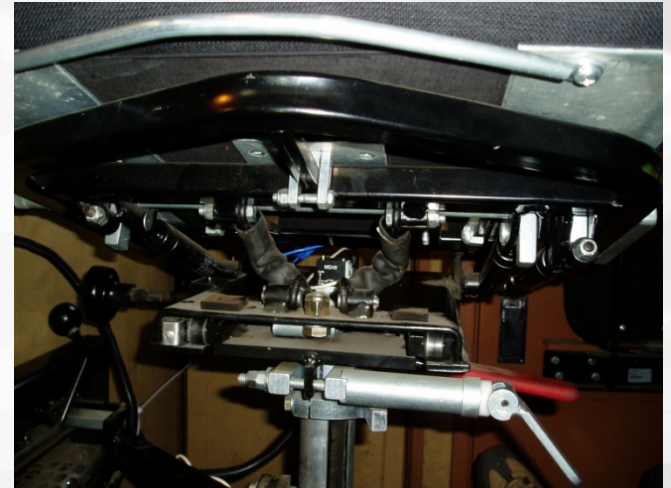Health Guidance Caution Zones
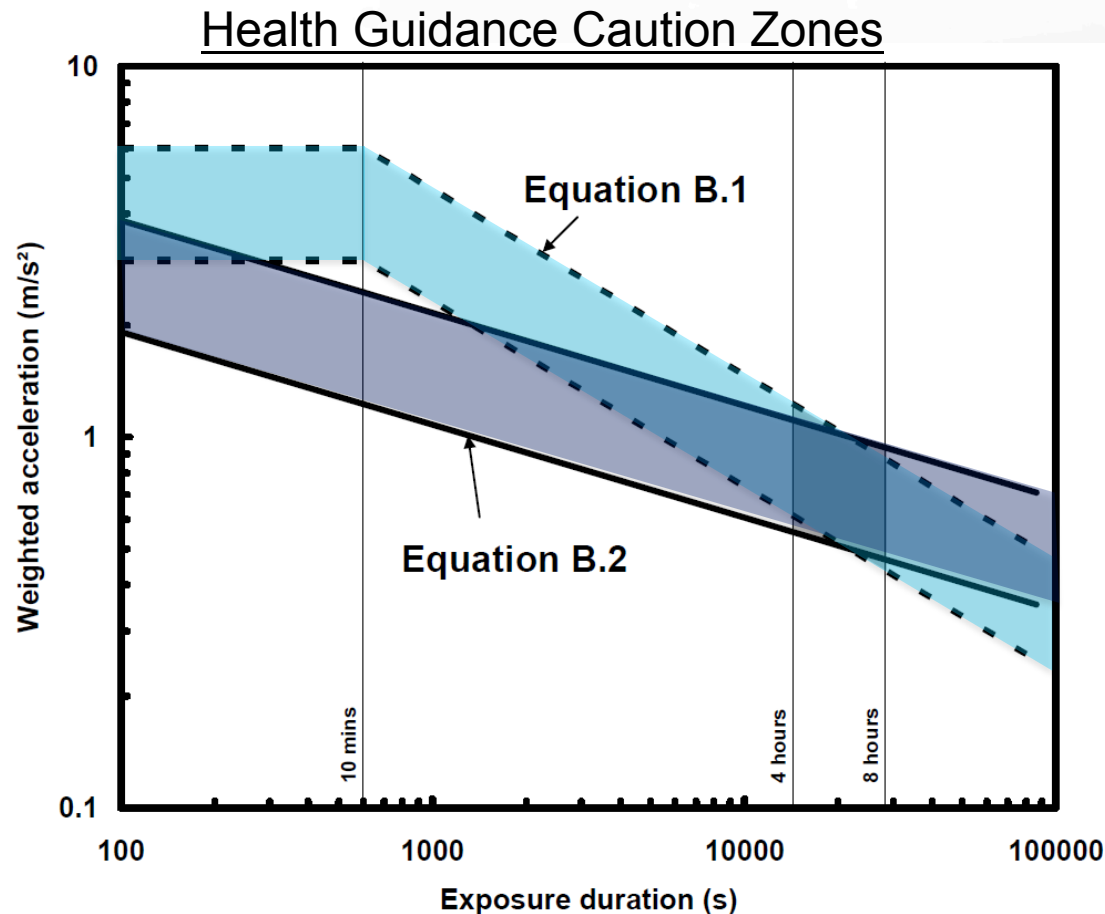
Data Collection - Routes Traveled

- Three data collection tests completed on BNSF Locomotives

- Total of 140 hours of data collected (2824 miles)
  - Ride I: Kansas City, MO → Amarillo, TX (550 miles / 17 hrs)
  - Ride II: Commerce, CA → Belen, NM (874 miles / 27 hrs)
  - Ride III: Kansas City, MO → Birmingham, AL (Round Trip 1400 mi / 96 hrs)

- Two GE Evolution Series locomotives
  - ES44DC (4400 HP, DC traction, 6 traction motors)
  - ES44C4 (4400 HP, AC traction, 4 traction motors, A1A-A1A wheel arrangement)

- One SD70-ACe Locomotive
  - 4300 HP, AC traction, 6 traction motors

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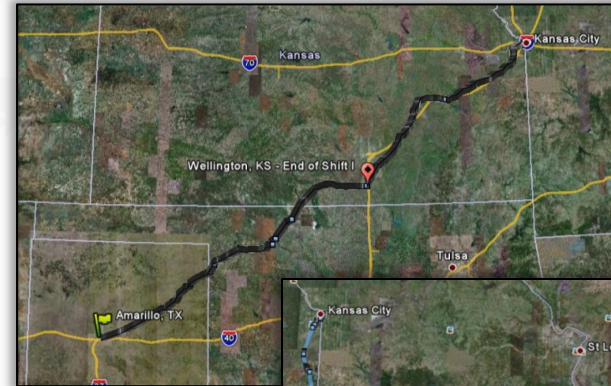
Data Acquisition

Video Data

On-board cameras for SMA Removal

- On-board DVR
- 2 camera views
- GPS time stamp (synchronize to DAQ)
- 5+ days of continuous recording with 2 cameras

Rear Camera View

Front Camera View

Data Analysis Steps

- Download vibration data from the DTS Bridge Slice to hard drive for data processing.
- Apply ISO 2631-1 and -5 filters using MATLAB.
  - Data processed in 1-hr increments to view metric changes over length of ride.
- Each hour examined for SMAs in three axes of movement.
- SMAs removed using MATLAB
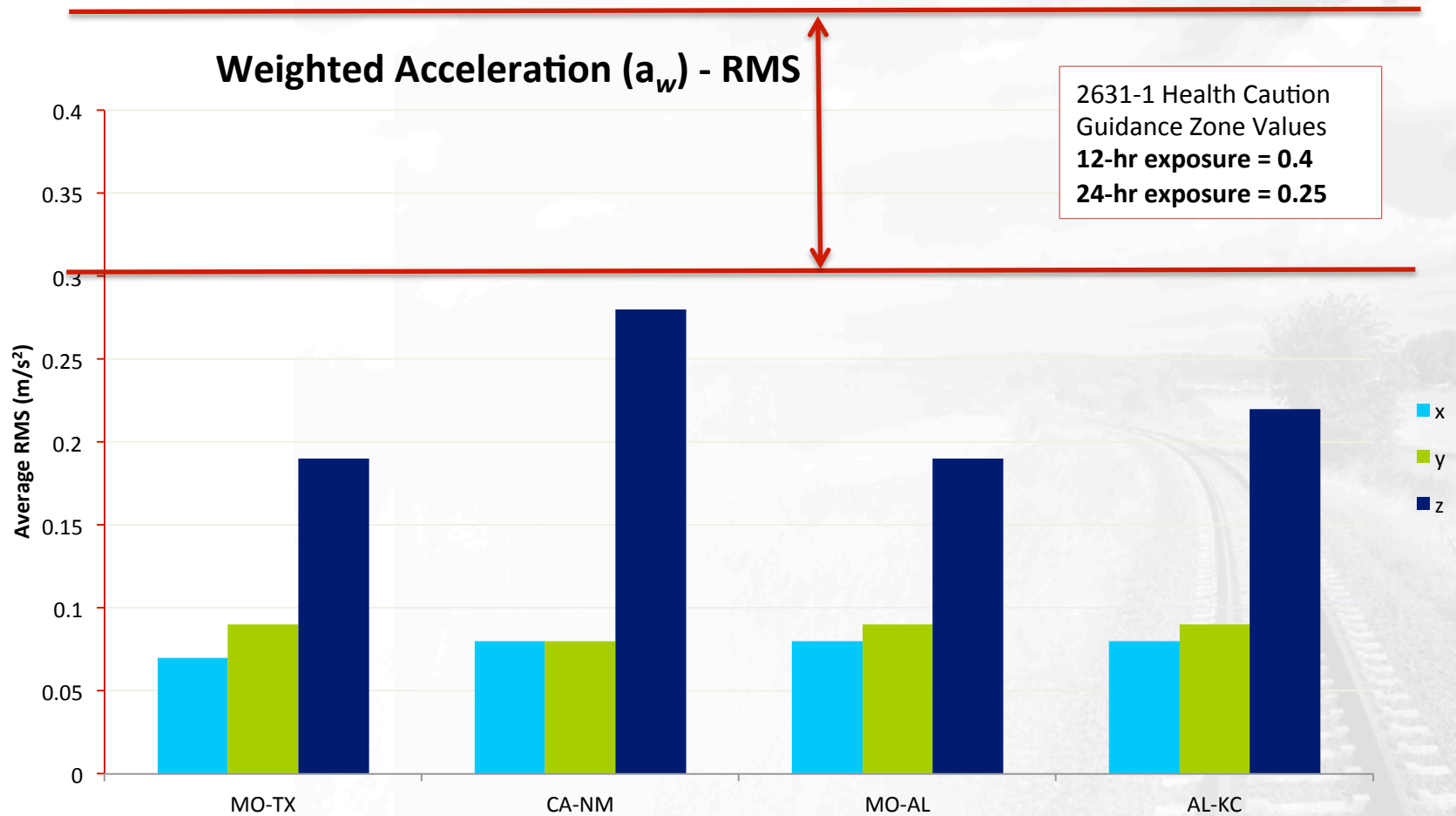- "Clean" data is submitted to MATLAB for ISO calculations

ISO2631 Filtered Z-Accelerations [g]
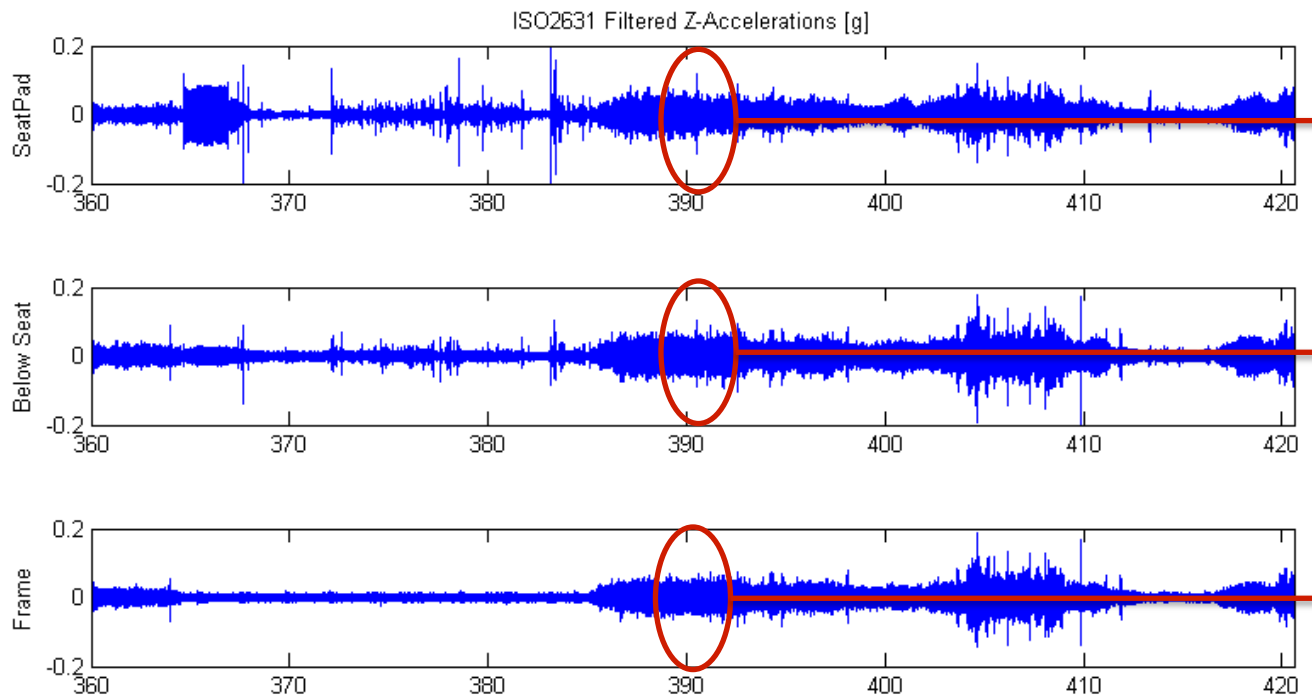
Potential seat motion artifact

Slight attenuation in below seat response

Note lack of frame input

Weighted Acceleration by Axis and Trip

Weighted Acceleration (a_w) - RMS

2631-1 Health Caution Guidance Zone Values
12-hr exposure = 0.4
24-hr exposure = 0.25

Vibration Dose Value Evaluation
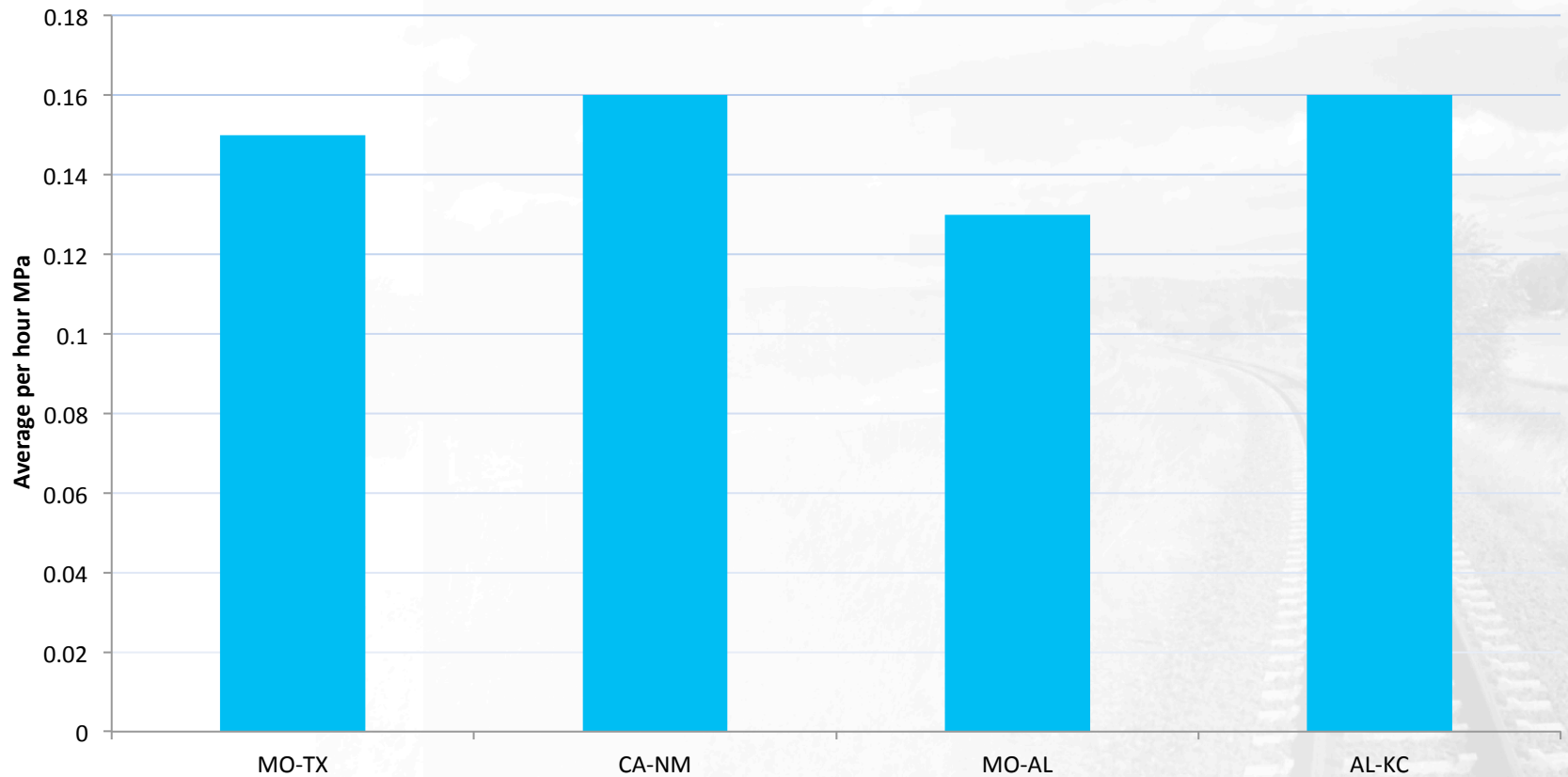

VDV for Crest Factor > 9
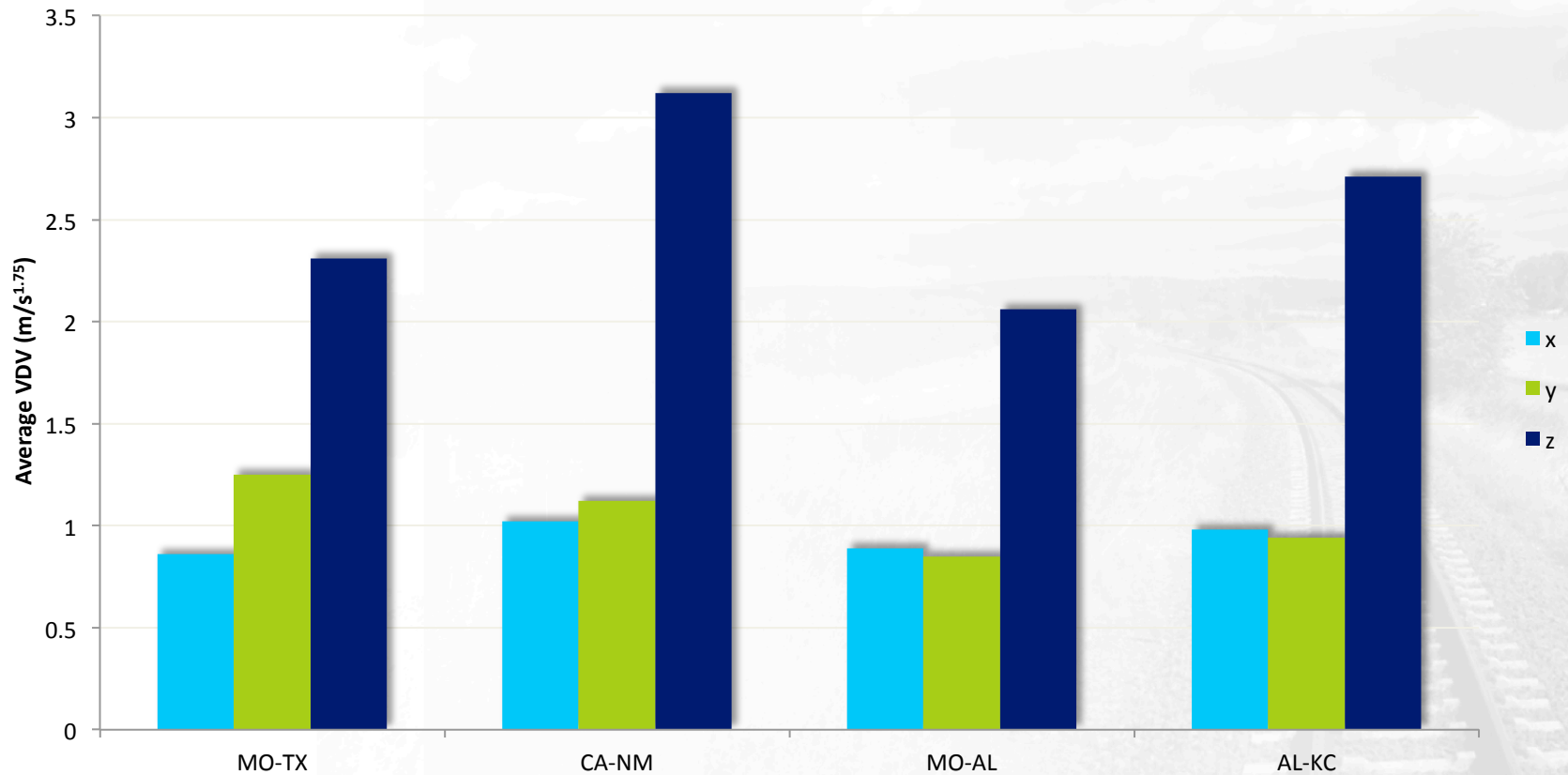
British Standards limit VDV to 15

Multiple Shock Assessment

ISO 2631-5 S_{ed}

$S_{ed} < 0.5$ low risk of adverse health effect

Summary

- **Weighted acceleration values (a_w)**
  - Within the limits of ISO 2631-1 Health Guidance Caution Zones for Crest Factor values less than 9

- **When CF > 9 (approximately 50% of data)**
  - VDV is within limits of accepted standards

- **Equivalent spinal compression dose (S_{ed} ISO 2631-5)**
  - All values less than 0.5 indicating low risk of adverse health effect over lifetime of exposure