TRANSPORTATION RESEARCH BOARD
TRANSIT COOPERATIVE RESEARCH PROGRAM

D-12 PROJECT

GROUNDBORNE NOISE AND VIBRATION IN BUILDINGS CAUSED BY RAIL TRANSIT

APTA Track, Noise & Vibration Technical Forum
September 22, 2006
Toronto

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PRINCIPAL TEAM MEMBERS

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PROGRAM OBJECTIVES

Develop relationship between rail transit groundborne vibration exposure and human annoyance

- **Current Agency complaint experience**
- **Literature Review**
- **Develop dosage effect relationships that reflect community response to rail-generated ground vibration. Multiple curves?**

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PROGRAM OVERVIEW

PHASE 1

- Task 1 – Literature Review
- Task 2 – Survey North American Rail Transit Systems
- Task 3 – Identify Transit Systems for Field Studies
- Task 4 – Develop Field Survey and Measurement Program
- Task 5 – Interim Report #1
- Task 6 – Revised Interim Report #1

PHASE 2

- Task 7a – Field Tests: Pilot Study
- Task 7b – Field Tests
- Task 8 – Human Response Curve
- Task 9 – Interim Report #2
- Task 10 – Final Report

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TRANSIT AGENCY SURVEY

- Purpose - obtain impression of whether or not vibration is a significant problem
- Contacted APTA members at agencies by telephone, then e-mailed online survey to appropriate personnel

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TRANSIT AGENCYSURVEY RESULTS

- Overall response rate 57% (30 of 55)
- 53% reported no problems or complaints at all
- Only 1 system reported having major problems
- Most vibration problems tended to be focused, rather than system-wide

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TRANSIT AGENCY SURVEY RESULTS
Complaints

Complaints per year	No. Agencies
0	17
1 - 5	10
6 - 20	2
50+	1

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LITERATURE REVIEW
Objectives

- Examine International Standards
  - Evaluation Methods
  - Vibration Limits and Guidelines
- Review Published Literature
  - Laboratory Studies
  - Field Work/Social Surveys

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COMMON VIBRATION DESCRIPTORS

- Root-mean-square (rms) acceleration and velocity
- Weighting curves
- Root mean quad weighted vibration (rmq)
- Fourth power vibration dose ($m/s^{1.75}$)
- Imperial and metric units
- Decibels with different reference values

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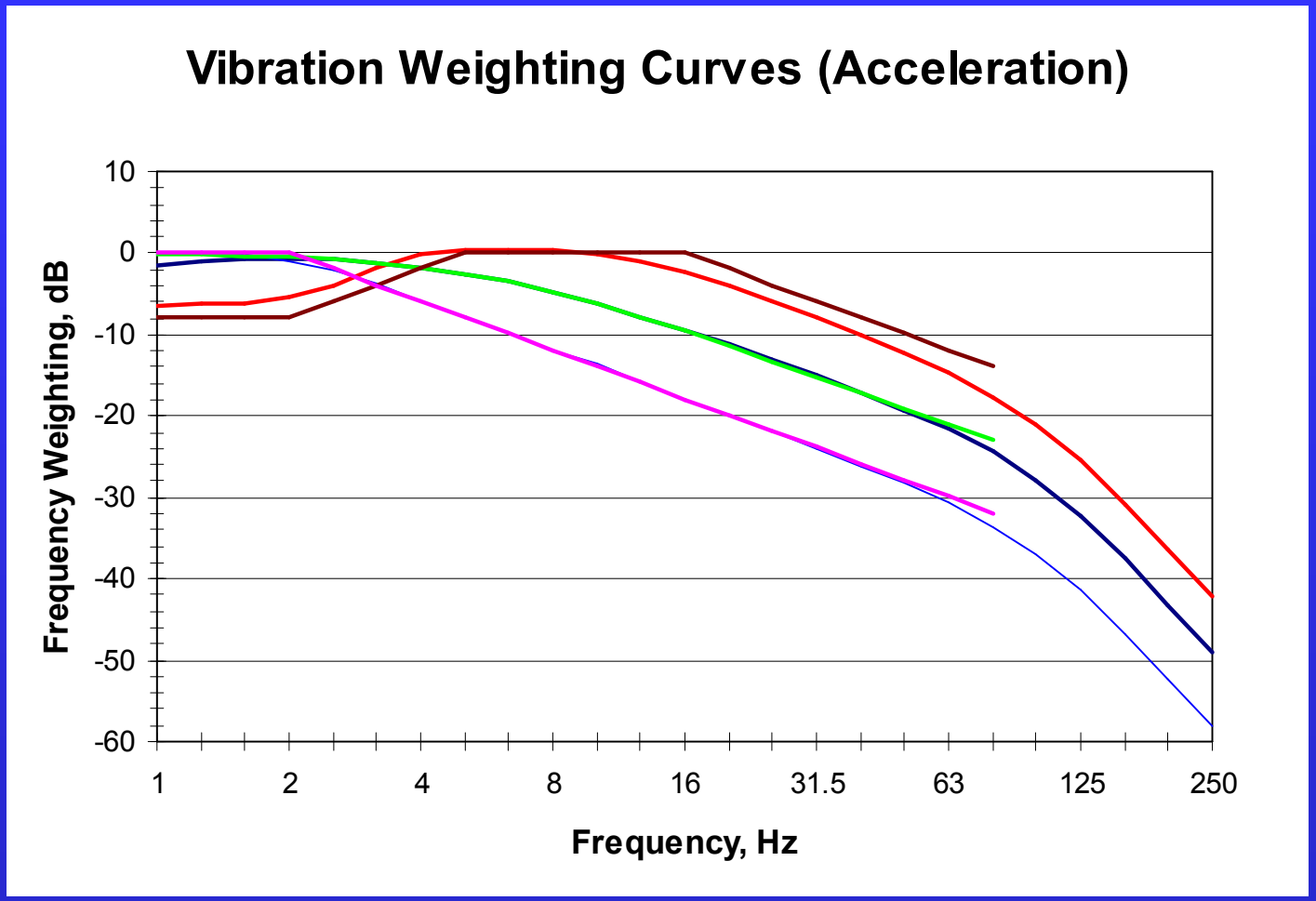
ACCELERATION WEIGHTING CURVES



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Wd (xy)

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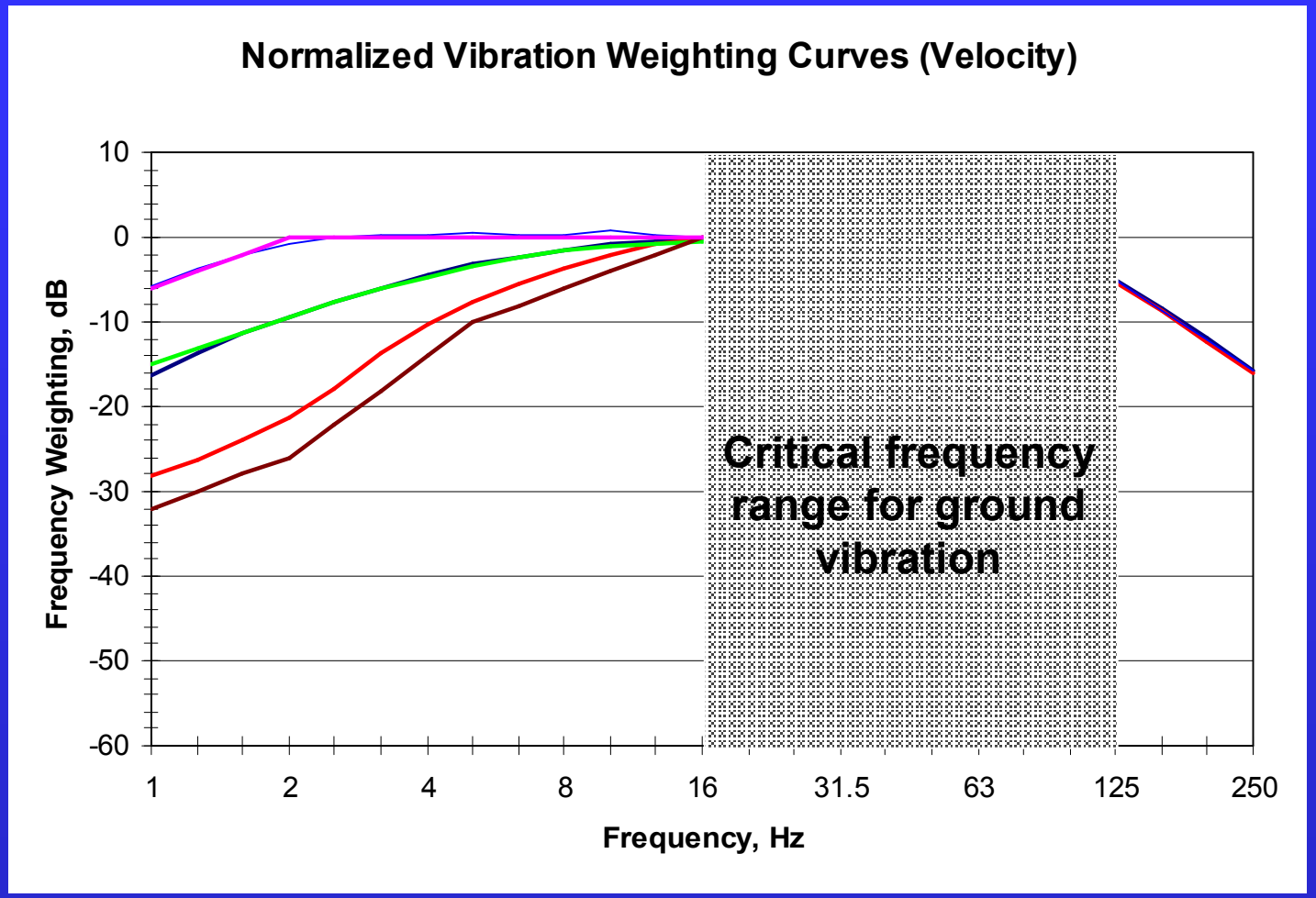
NORMALIZED VELOCITY WEIGHTING CURVES



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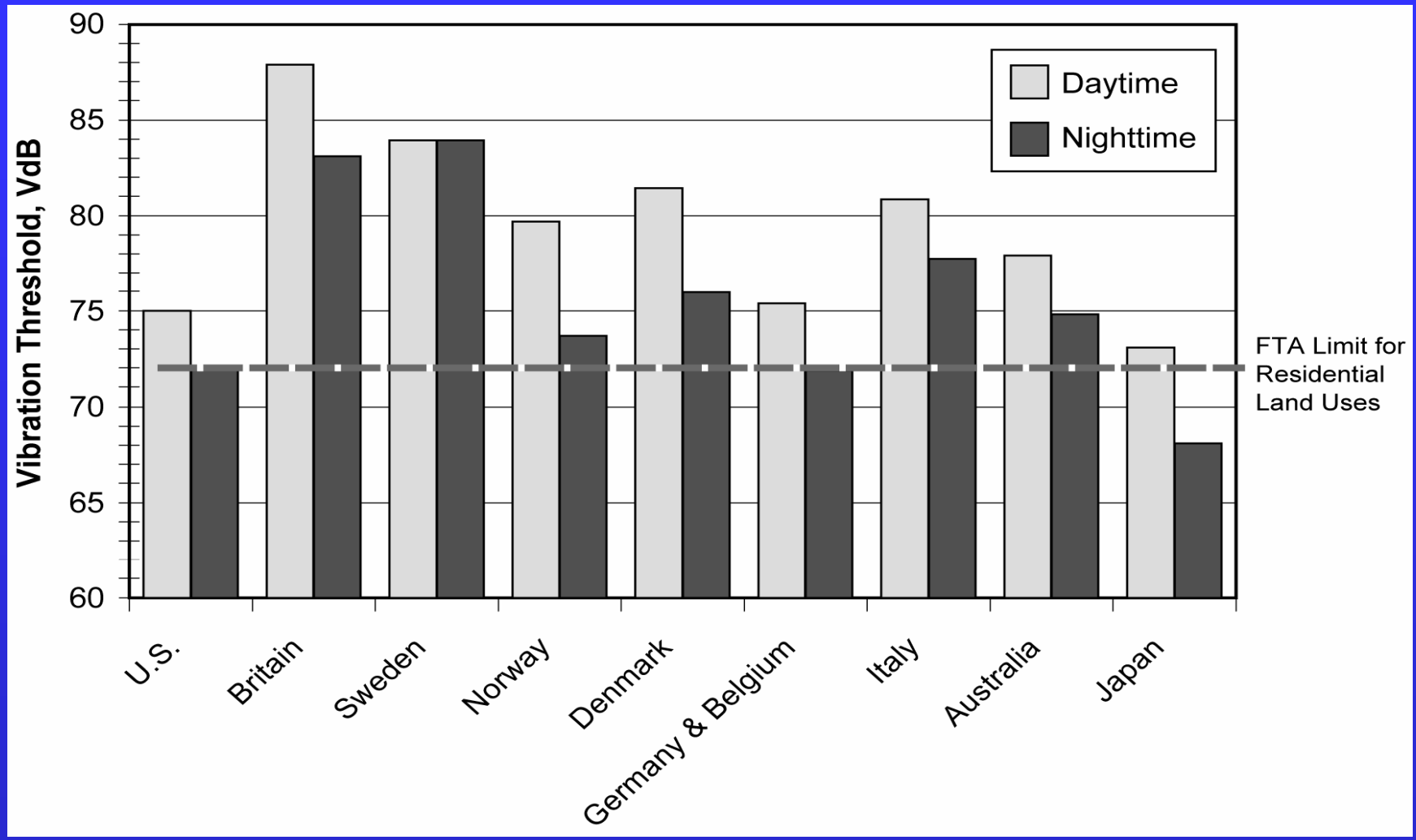
COMPARISON OF VIBRATION STANDARDS



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LITERATURE REVIEW
Related Research

- **Laboratory Studies**
  - Thresholds of Perception and Equal Annoyance Contours
  - Annoyance vs. Vibration Levels
  - Combined Effects of Noise and Vibration

- **Social Surveys**

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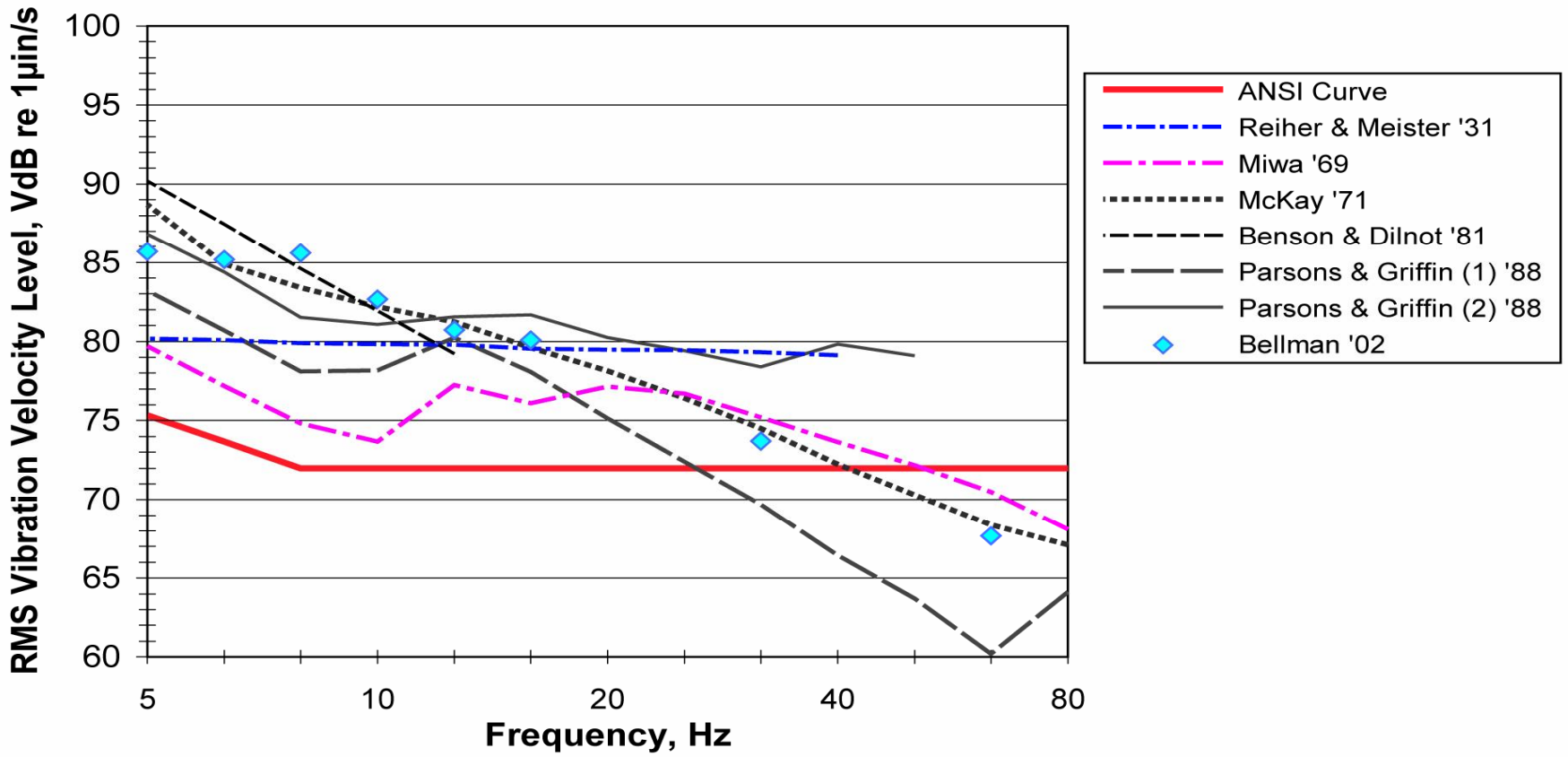
PERCEPTION THRESHOLD



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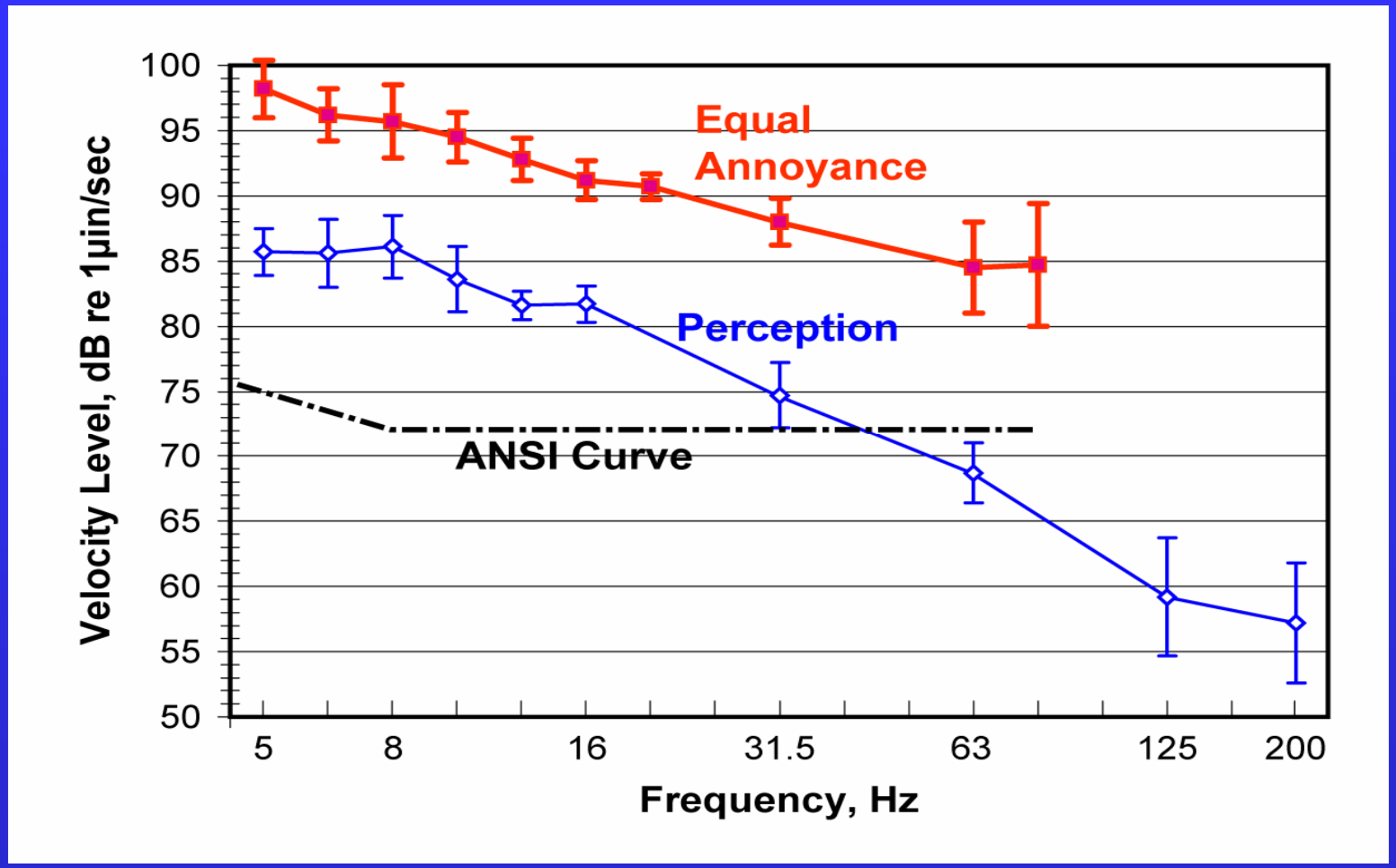
ANNOYANCE vs. FREQUENCY



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COMMUNITY RESPONSE SURVEY
Scotland

- **Woodroof & Griffin (1986)**
  - 459 interviews (160 noticed vibration)
  - 3 axis vibration measured in 52 residences (24-hour)
  - Conclusion: "…vibration is among the least annoying aspects of a railway's presence in a neighborhood."
  - vertical vibration most important (greatest axis, greatest sensitivity)
  - best correlated metric

    number of trains/day that can be perceived

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COMMUNITY RESPONSE SURVEY
Sweden

- **Öhrström (1997)**
  - Buildings where inhabitants had complained about vibrations
  - Much higher vibration levels than in Scotland
  - Wide variation in exposure-effect relationships

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COMMUNITY RESPONSE SURVEY
Norway

- Klæboe, Turunen-Rise, Hårvik and Madshus (2003)
  - 1503 telephone interviews
  - Vibration exposure estimated using semi-empirical model
  - Exposure ranged from below perception to 100 VdB
  - Statistically valid dose-response curves developed using V_{95}

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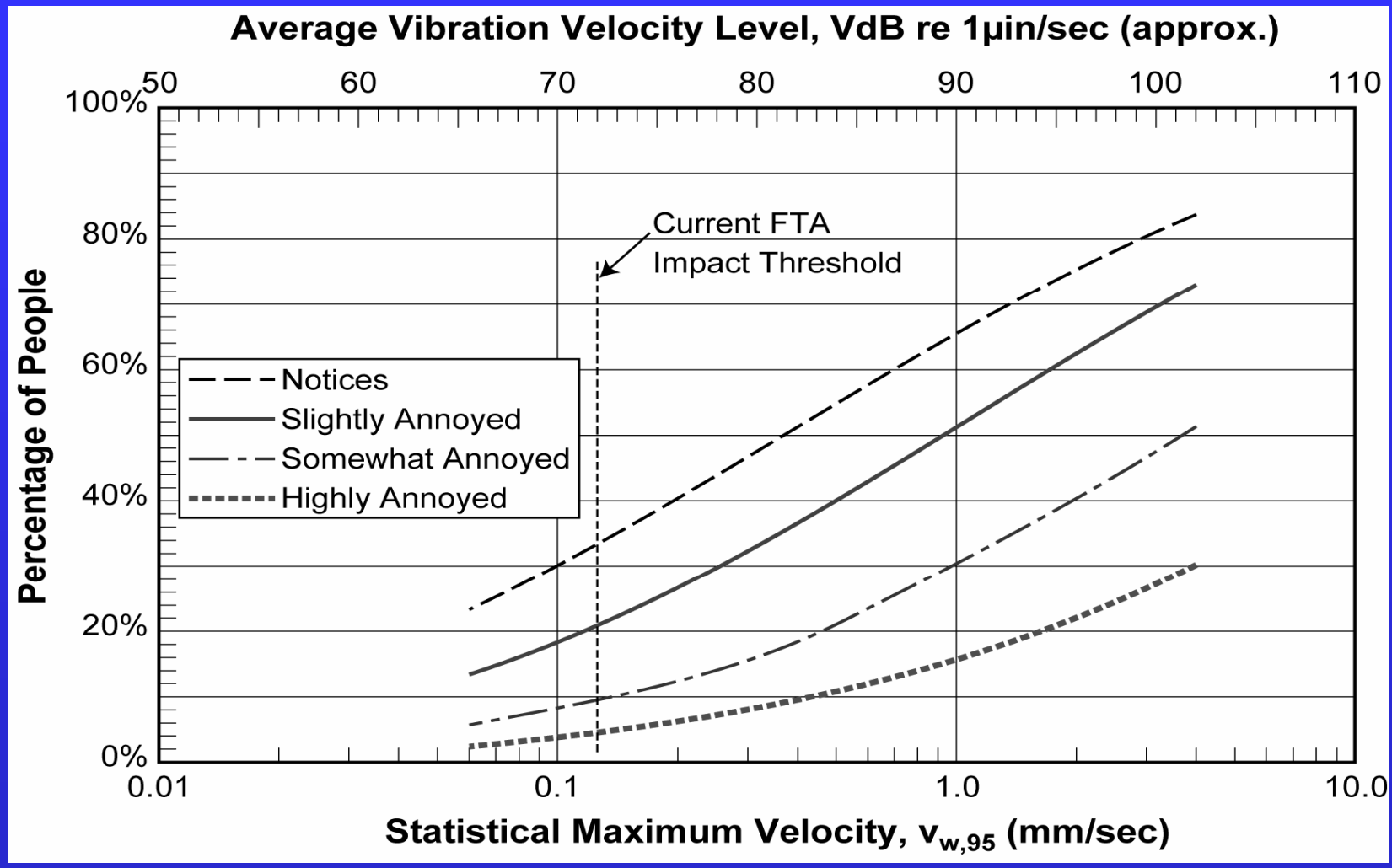
NORWEGIAN STUDY (Klaeboe et al, 2003)
Annoyance vs. Vibration Level



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LITERATURE REVIEW
Summary

- Vertical vibration sufficient measure
- Not necessary to test inside every home
- Many (1000's) interviews needed

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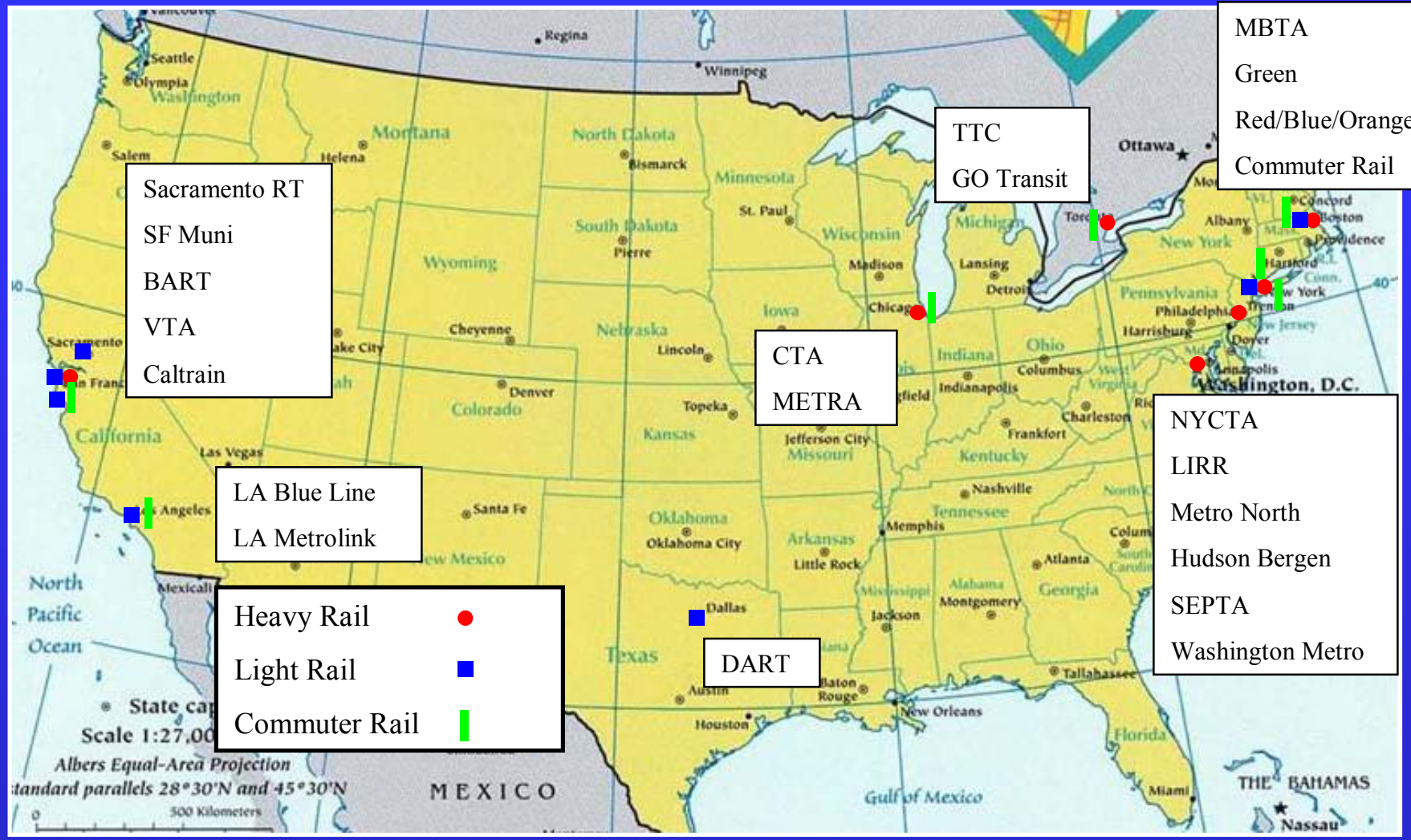
CANDIDATE SYSTEMS FOR FIELD STUDY



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PARTICIPATION STATUS

Washington Metro	
MBTA Commuter Rail	
MBTA Green Line	Mr. Joe Oriolo
MBTA Red/Orange/Blue	Mr. Joe Oriolo
Hudson Bergen (NJ)	Mr. D.C. Agrawal
Long Island Railroad	
Metro North Railroad	
NYCTA (New York City)	Mr. Tony Cabrera
GO Transit (metro Toronto)	Mr. Greg Ashbee
TTC - Rapid Transit	Mr. Brian Longson
SEPTA	
Chicago METRA	
CTA (Chicago)	

DART (Dallas)	
~~Los Angeles Metrolink~~	
Caltrain (SF to San Jose)	Mr. Ian McAvoy
Sacramento	
Los Angeles Blue Line	Mr. Gerald Francis
~~San Francisco MUNI~~	
VTA San Jose	Mr. Mark Robinson
BART (SF/Oakland)	

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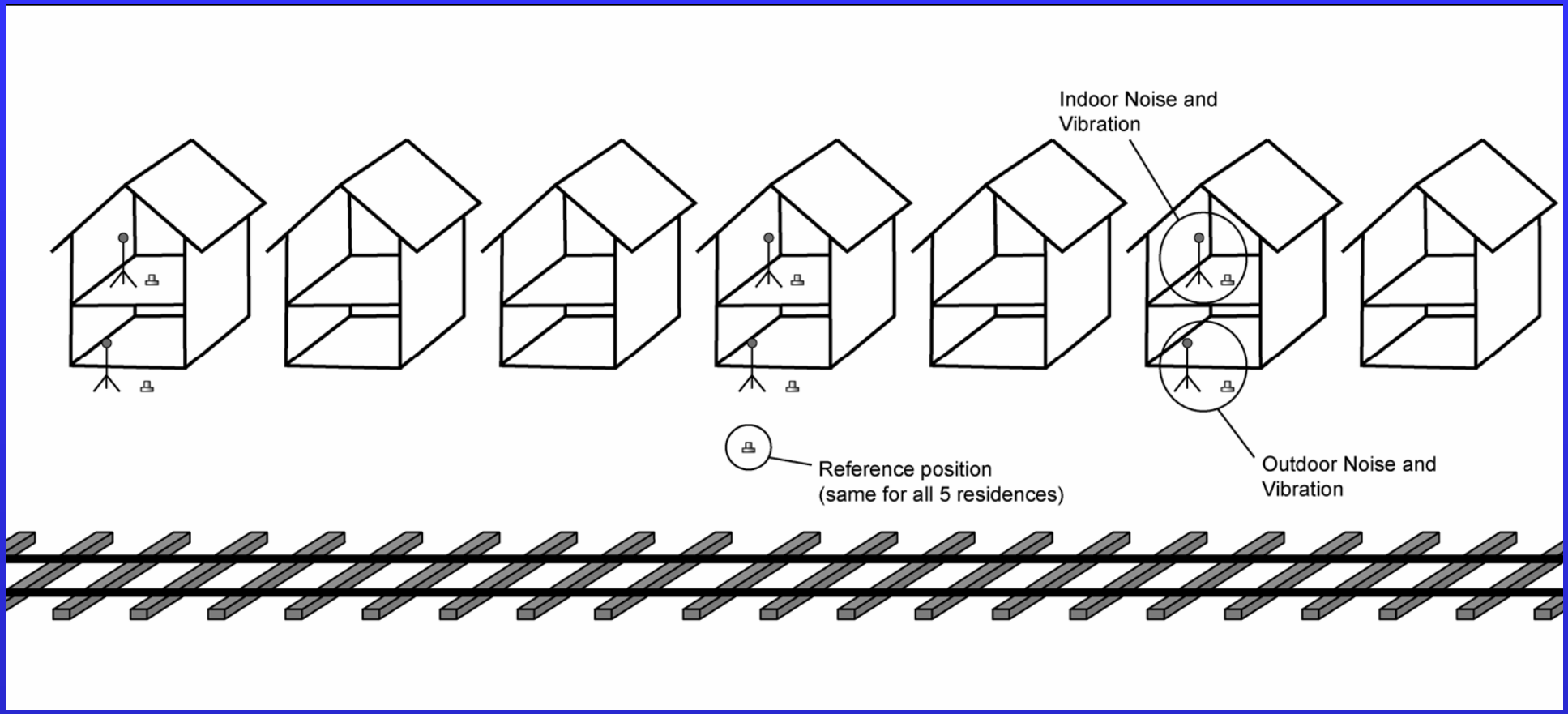
FIELD MEASUREMENTS
Measurement Locations



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FIELD MEASUREMENTS
Data Collection

- All data to be recorded
  (flash card recorder)
- Vibration – measure acceleration in field
  (seismic accelerometers)
- Sound – unweighted sound pressure
  (1/2” microphones)

- Raw waveforms to be recorded
- All recorders time synchronized
- Personnel to monitor and record event times in field

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FIELD MEASUREMENTS
Data Processing

- Use MATLAB to
  - scale data
  - 1/3 octave band filters
  - create vibration/sound time histories
  - calculate event metrics

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SOCIAL SURVEY
Design Considerations

- Overall goal of survey is to collect sufficient information about prevalence of adverse effects to support useful dosage-effect analyses
- Observations needed under a reasonable range (at least 20 dB) of exposure conditions
- Sufficient data required to yield 90% confidence intervals for sample proportions on the order of ± 5% or smaller

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SOCIAL SURVEY
Design Considerations (cont'd)

- Sample size requirements imply need for ~ 200 completed interviews per site - with diverse exposure
- Sampling frame of ~1000+ households eligible for interview required at each site (assuming 70% completion rate)
- Sites with straight track alignments and reasonably homogeneous exposure/housing construction preferred

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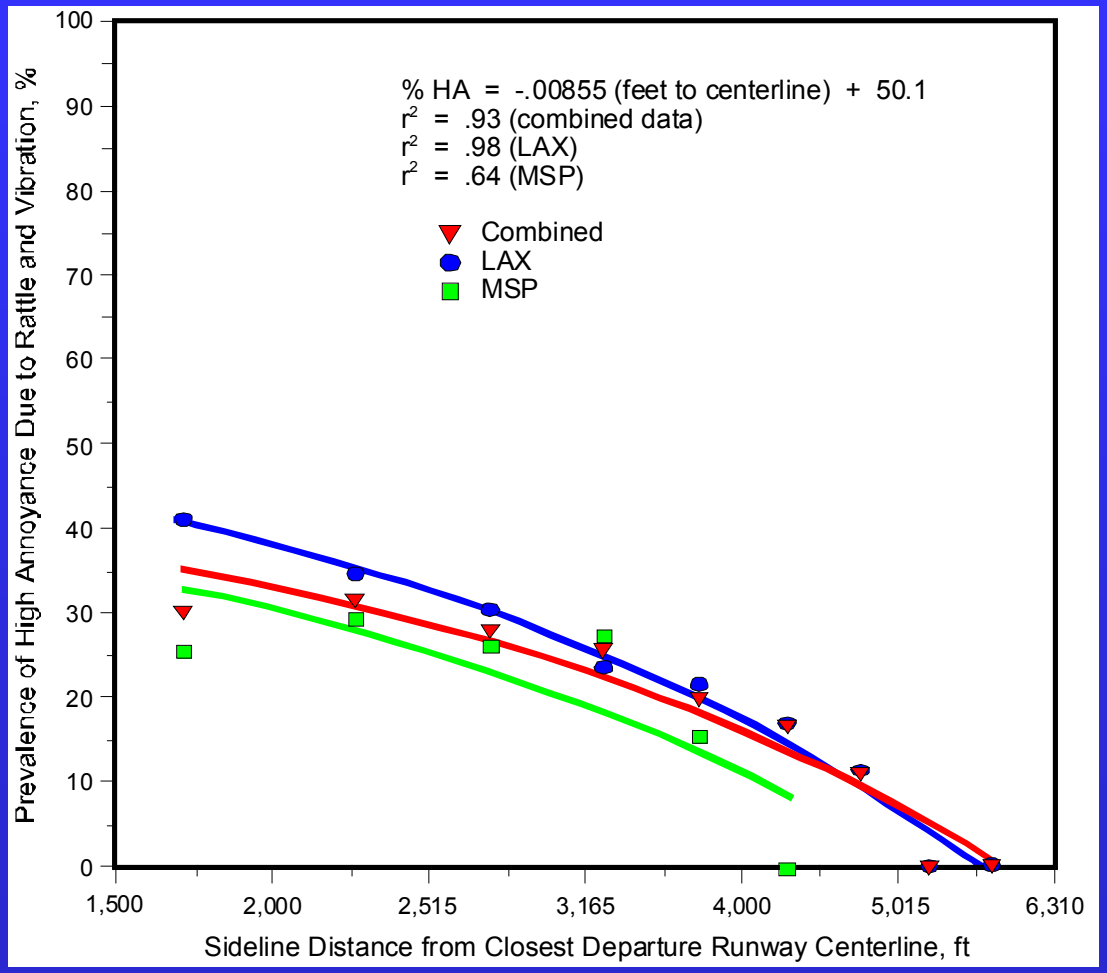
EXAMPLE: ANNOYANCE DUE TO RATTLE VS. DISTANCE FROM SOURCE



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SOCIAL SURVEY
Key Questionnaire Items

- ITEM 1: Can you please tell me how long you have lived at (street address)?
- ITEM 2: What do you like most about living conditions in your neighborhood?
- ITEM 3: What do you like least about living conditions in your neighborhood?

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SOCIAL SURVEY
Key Questionnaire Items (cont'd)

- ITEM 5: While you've been at home over the past year, have you been bothered or annoyed by the sounds that San Francisco Muni trains make as they pass by outside your home?

- ITEM 6: Do you notice low rumbling sounds inside your home as San Francisco Muni trains pass by outside?

- ITEM 7: While you've been at home over the past year, have you ever been awakened by low rumbling sounds, rattling, shaking, or vibration inside your home when San Francisco Muni trains pass by?

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SOCIAL SURVEY
Key Questionnaire Items (cont'd)

- ITEM 8: Do you ever hear rattling sounds from windows, doors, wall hangings, or other items in your home when San Francisco Muni trains pass by?

- ITEM 9: Do you ever feel your home shake or the floors, walls, counters, or furniture vibrate when San Francisco Muni trains pass by?

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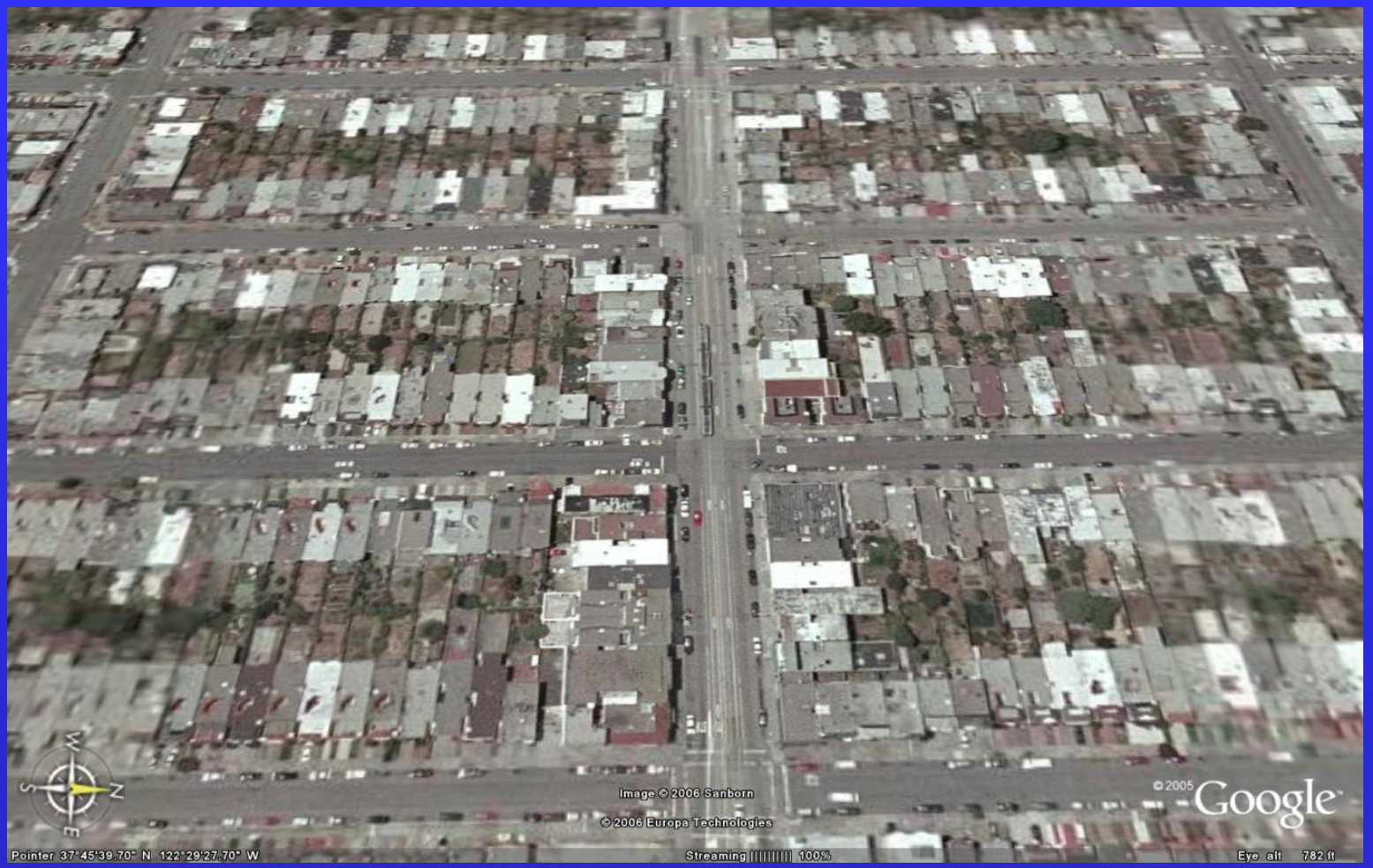
PILOT STUDY
San Francisco Muni Judah St. Line



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PILOT STUDY
Ground View of Judah Street Line

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PILOT STUDY UPDATE
San Francisco Muni

- June 16, Contact letters from APTA were sent out to 21 systems identified as candidates for field test
- Survey dates set for July 20-23
- July 20, Muni contacted Martin asking that the work be halted because of recent legal issues in the test area
- Data collection halted on 21 July (after 6 hours or interviewing)
- At present, no plans to pursue Muni further

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PILOT STUDY – WHAT WE LEARNED

- Sampling frame of ~1100 residential households with listed telephone numbers prepared along 80 block faces of apartment buildings within 300 ft of Judah street frontage
- Computer-assisted telephone interviewing by experienced, trained, and centrally supervised personnel
- 94 interviews completed in approximately 6 hours
- Mean duration of interview slightly greater than 5 minutes

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PILOT STUDY
Preliminary Findings

- Responses to questions about notice of adverse effects (airborne noise, rumble, rattle, and shaking) are orderly and interpretable
- 72% of all respondents noticed low rumbling sounds inside their homes as San Francisco Muni trains pass by outside
- About 37% of the respondents noticed rattling sounds in their homes as Muni trains passed by

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PILOT STUDY
Preliminary Findings (cont'd)

- About 11% of all respondents considered rattling noises to be highly annoying
- About the same number of respondents who noticed rattle also reported feeling shaking or vibration in their homes as Muni trains pass by
- The frequency of notice and degree of annoyance due to shaking are similar to those of rattle

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PILOT STUDY
Preliminary Findings (cont'd)

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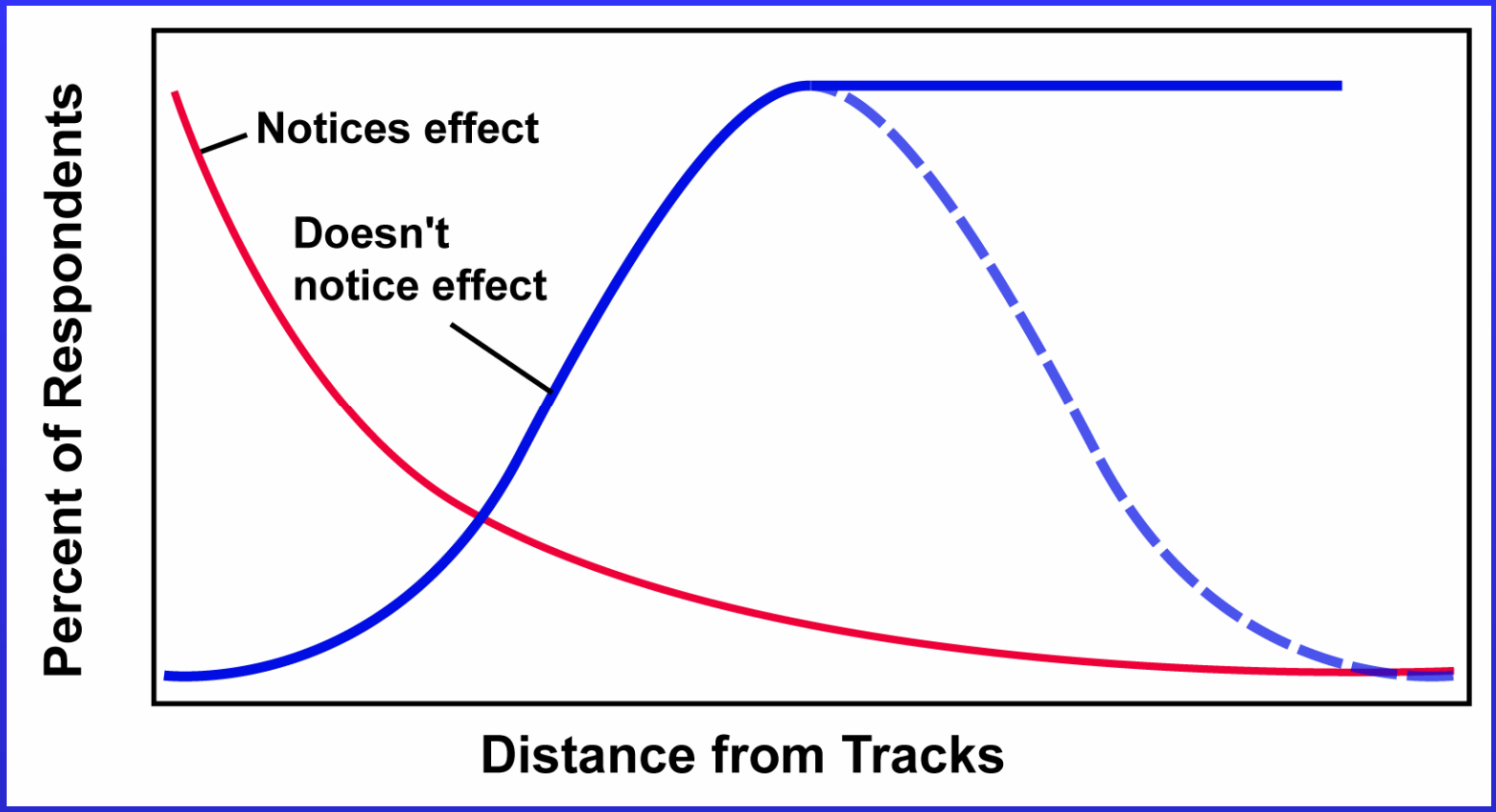
IDEALIZED PERCENTAGES OF RESPONDENTS HEARING/NOT HEARING RATTLE vs. DISTANCE FROM TRACK



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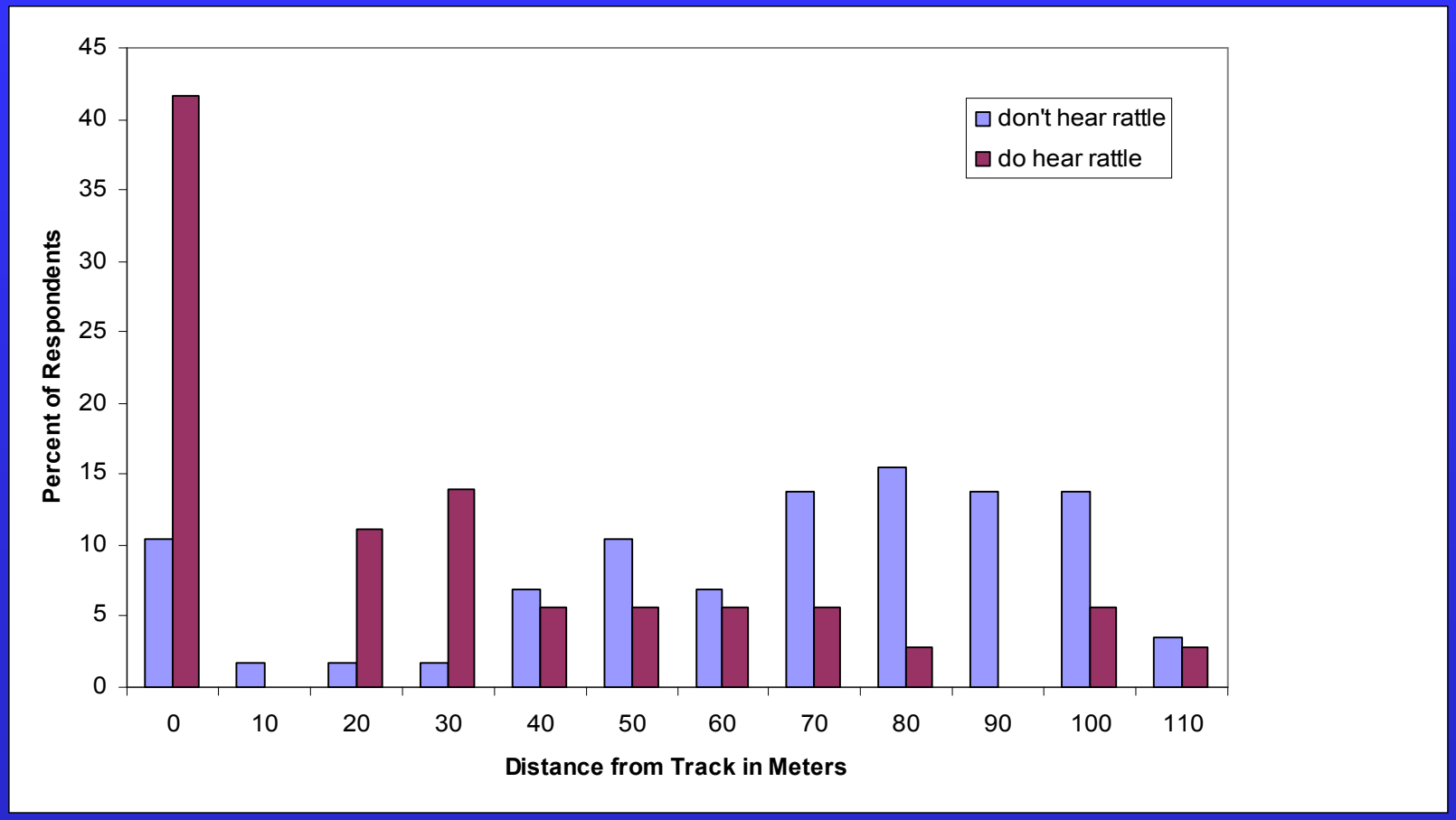
ACTUAL PERCENTAGES OF RESPONDENTS HEARING/NOT HEARING RATTLE vs. DISTANCE FROM TRACK



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MEAN DISTANCES FROM RIGHT OF WAY AT WHICH EFFECTS WERE NOTICED

EFFECT	MEAN DISTANCE AT WHICH NOTICED (meters)	MEAN DISTANCE AT WHICH **NOT** NOTICED (meters)	t_{df}	P
RUMBLE	42	58	2.21_{90}	.01
RATTLE	27	62	5.42_{92}	<.001
SHAKE	32	59	3.84_{88}	<.001
AWAKENING	40	43	0.38_{51}	ns

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ROUGH ESTIMATES OF WIDTHS OF DOSAGE-EFFECT RELATIONSHIPS

EFFECT	RATIO OF MEAN DISTANCES	20 LOG RATIO OF DISTANCES
RUMBLE	1.4	2.8 dB
RATTLE	2.3	9.8 dB
SHAKE	1.8	5.3 dB

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PLANNED WAY AHEAD
Field Testing

- Proceed immediately with VTA (San Jose) as pilot test site #2
- Rank order remaining 19 agencies for testing.
- Proceed down list and test as many as possible within budgetary limits.
- Goals
  - 2000 completed interviews (10,000 contacts)
  - 120 in-residence measurements

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PROPOSED TEST ORDER

LR	VTA San Jose	contact: Mark Robinson
RT	TTC (Toronto) - Rapid Transit	contact: Brian Longson
RT	NYCTA (New York)	contact: Tony Cabrera
RT	BART (SF/Oakland)	
CR	Caltrain (SF to San Jose)	contact: Ian McAvoy
RT	MBTA Red/Orange/Blue	contact: Joe Oriolo
LR	Hudson Bergen (NJ)	contact: Mr. D.C. Agrawal
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CR	GO Transit (metro Toronto)	contact: Greg Ashbee
CR	Metro North Railroad	
RT	SEPTA	
CR	Chicago METRA	
LR	Sacramento	

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