NCHRP Project 25-34 / Report 791 Supplemental Guidance on the Application of FHWA's TNM Chapter 13 "Tunnel Openings"

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Transportation-related Noise and Vibration
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Tunnel Openings
Overview of the Process

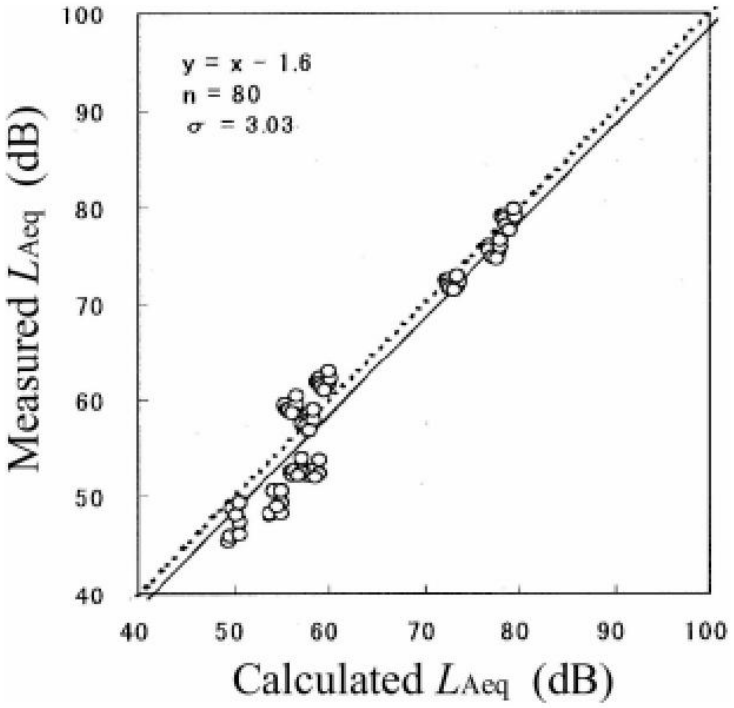
- Survey Project Team and TRB ADC40
- Conduct Review of the Scientific Literature
- Compile Modeling Techniques and Existing Validation Data
- Identify Candidate Modeling Techniques within TNM
- Prepare Interim Report
- Process Existing Validation Data and/or Collect Additional Data
- Test and Evaluate Modeling Techniques within TNM
- Best Practices for Modeling the “Tunnel Effect” in TNM

Tunnel Openings
Survey, Data Collection, and Literature Review

- **Survey of TRB ADC40 and Project Team**
  - Survey produced no usable information
  - Past modeling approach: place source at tunnel mouth with sound power equal to what would radiate from tunnel
- **Review of the Scientific Literature: 7 Works Cited**
  - Limited measurement data cited in the literature
  - Takagi, K., T. Miyake, K. Yamamoto, H. Tachibana, “Prediction of road traffic noise around tunnel mouth,” proceedings of Inter-noise 2000, paper no. 566
  - Probst, Wolfgang, “Prediction of sound radiated from tunnel openings,” Noise Control Engineering Journal, Vol. 58(2), pp. 201-211, 2010

Tunnel Openings
Compile Modeling Techniques: Takagi, et al

- **Tunnel-Radiated Sound Power**
  - Direct & reflected
  - Sound power within tunnel integrated over its length /w absorption
  - Semi-circular & rectangular sections
- **ASJ Model 1998**
- **Within 1.6 dB of Measured Data**



Source: Takagi, et al, 2000

Tunnel Openings
Compile Modeling Techniques: Probst

- Based on Room Acoustics for a Diffuse Sound Field
- Directivity of Tunnel Opening
- Increase in Levels at a Tunnel Opening (no absorption)

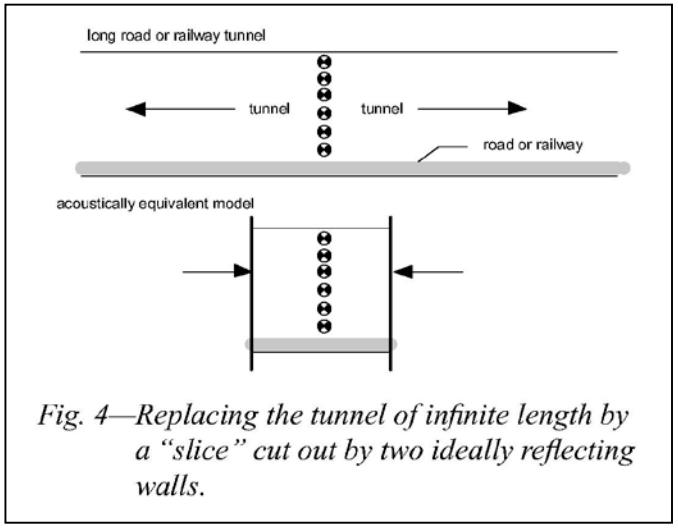


Fig. 4—Replacing the tunnel of infinite length by a "slice" cut out by two ideally reflecting walls.

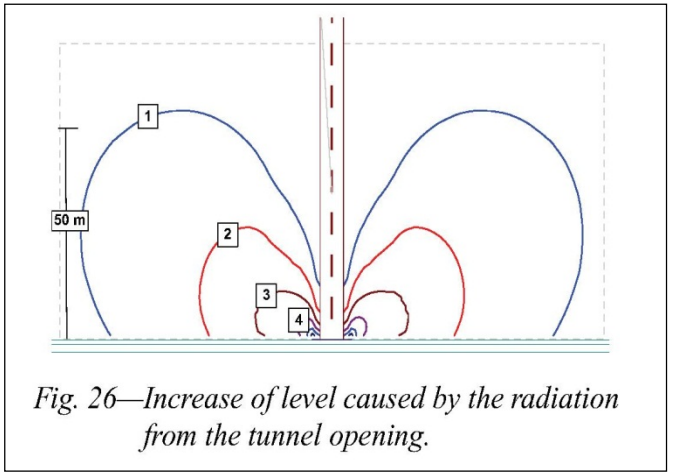


Fig. 26—Increase of level caused by the radiation from the tunnel opening.

Source: Probst, 2010

Tunnel Openings
Modeling in SoundPLAN and TNM

- **Probst Method Complex with Many Variables**
  - Not likely practical to implement on typical highway project
  - Can be modeled using Cadna/A and a room acoustics model
  - Not directly validated with measurement data
- **Takagi Method Implemented in SoundPLAN**
  - Validated with measurements
  - Relatively straightforward
  - Available to SoundPLAN users
  - Strong basis for comparison with TNM and development of TNM techniques to match results
  - So, SoundPLAN was used as the benchmark

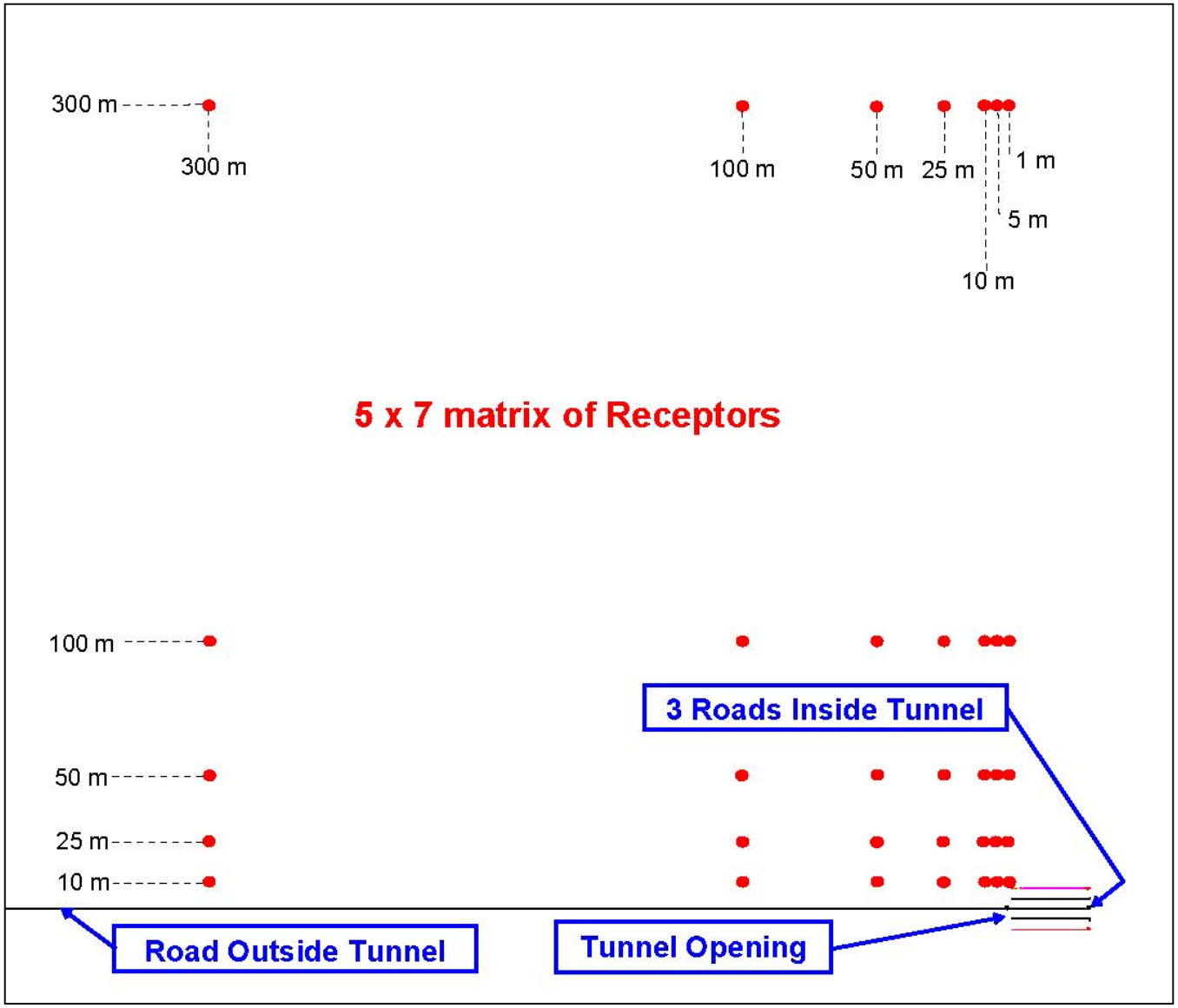
Tunnel Openings
Test Case Used in TNM

- **Single TNM Roadway (1,500 meters long 0.0% grade) Located Outside the Tunnel**
- **3,600 autos, 150 MT, and 120 HT per hour at 55 kph**
- **Pavement as Default Ground Type**
- **A 5 x 7 Matrix of Receptors**
  - At 10, 25, 50, 100, and 300 meters from roadway centerline
  - At 1, 5, 10, 25, 50, 100, and 300 meters from the tunnel
  - Receptor heights of 1.5 & 4.5 meters AGL
- **Noise Barriers at a Height of 30 meters to Represent the Side Walls of the Tunnel**

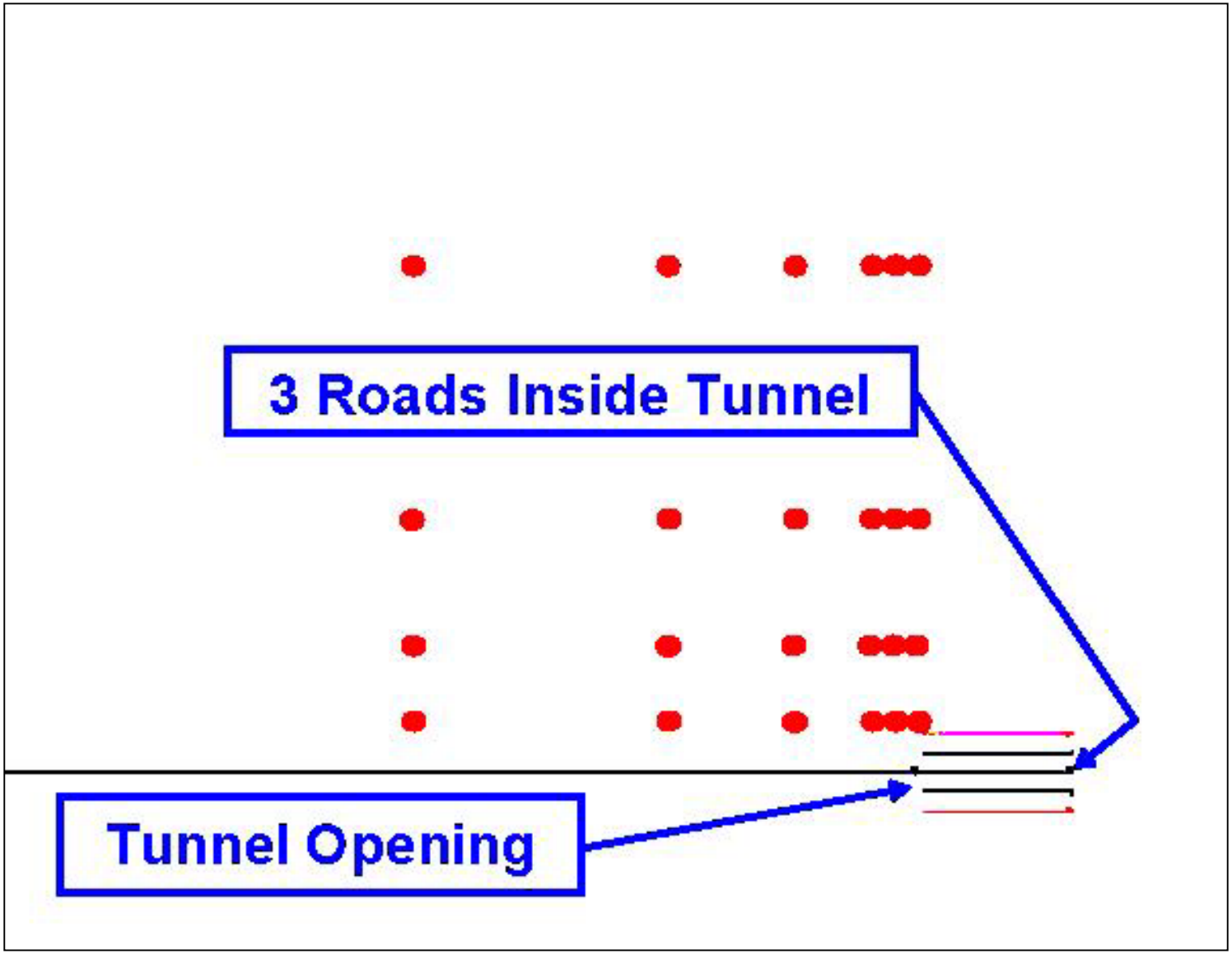
Tunnel Openings
Test Case Used in TNM (continued)

- **Various Numbers of Roads inside the Tunnel**
  - Direct sound field
  - Reflected sound field
- **Two Tunnel Opening Sizes**
  - 5 meters wide by 6 meters high
  - 15 meters wide by 6 meters high
- **Tunnel Lengths of 1, 30, 150 and 1,000 meters**

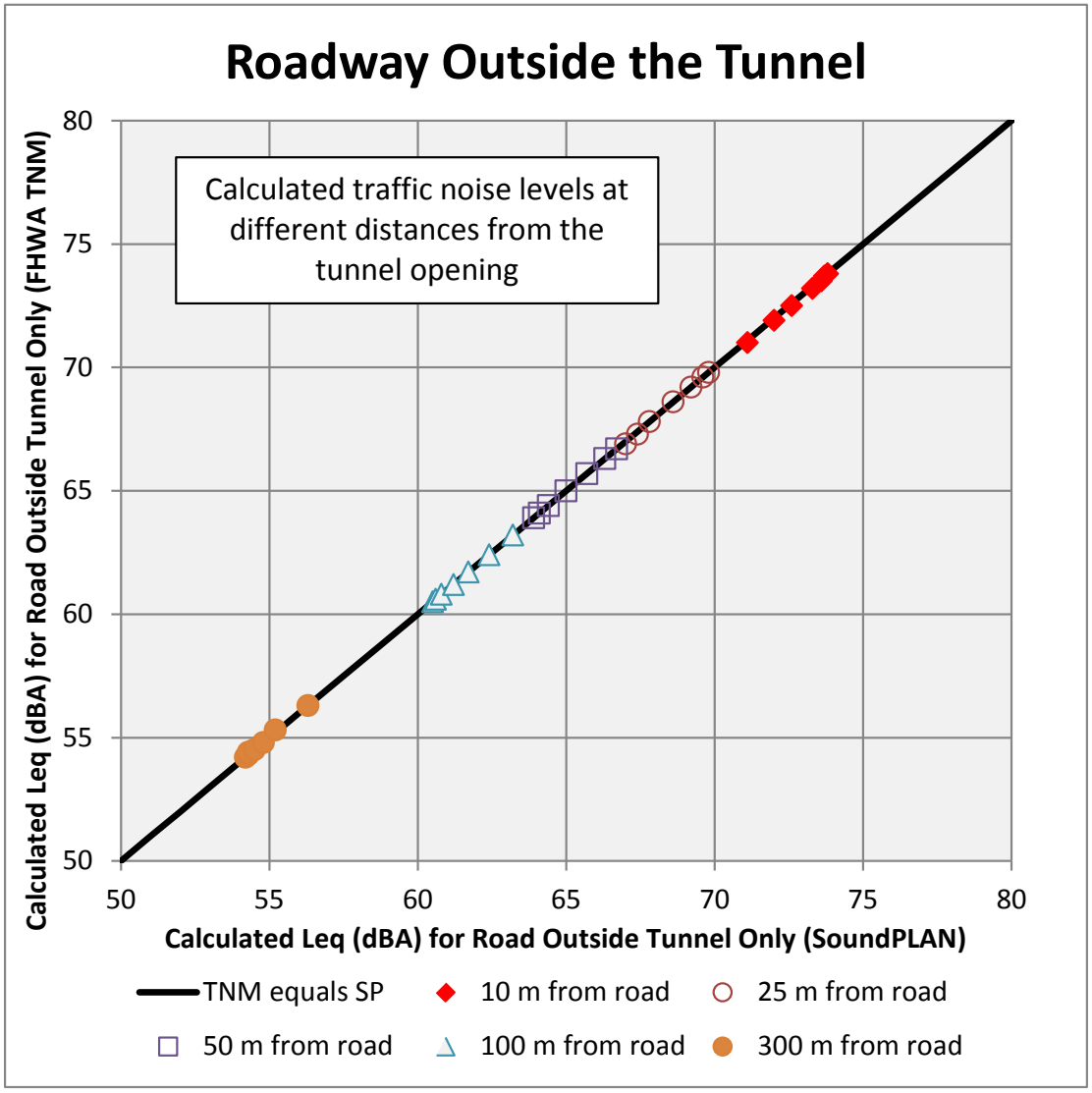
Tunnel Openings
Plan View of Modeled Geometry in TNM



Tunnel Openings
Detail of Plan View in TNM



Tunnel Openings
TNM vs SoundPLAN for Road Outside Tunnel

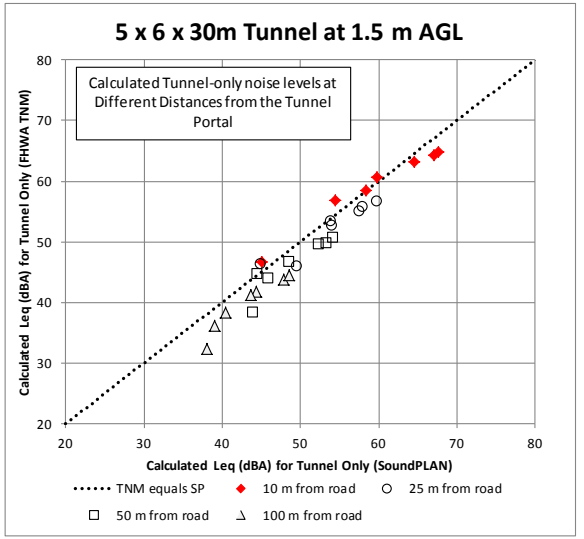


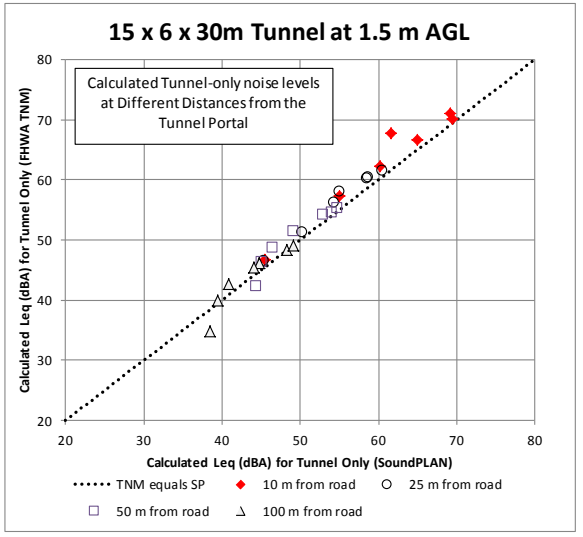
Tunnel Openings
Evaluation of Modeling Techniques

- **Test Cases for Tunnel-Radiated Noise within TNM**
  - 1 road inside the tunnel with:
    - 1 perpendicular road across and just outside the tunnel
    - 1 perpendicular road across and just inside the tunnel
  - 3 roads inside with 3X total volume outside
  - 3 roads inside with 7 to 8X total volume outside
  - 4 roads inside with 3X total volume outside
- **Focused on Tunnel Lengths of 30 and 150 meters**
  - Radiated noise increases with increasing tunnel length
    - From 30 to 150 m, additional length adds 0.03 dBA/m
    - From 150 m to 1 km, additional length adds 0.002 dBA/m

Tunnel Openings
Evaluation of Modeling Techniques

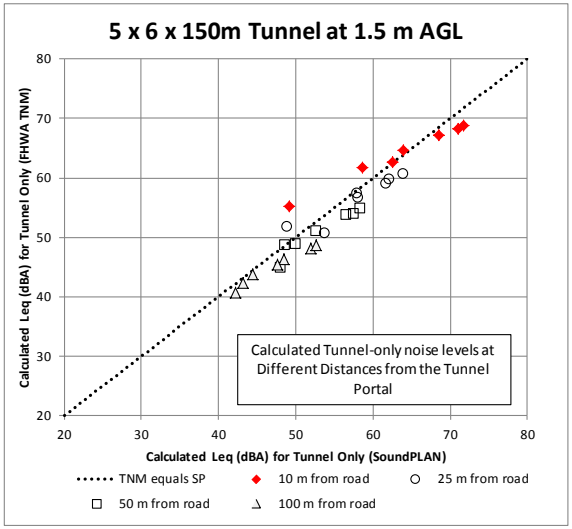
- Tunnel-Radiated Noise: TNM vs SP at 1.5 meters AGL
- Modeling Technique: 3 Roads Inside with 3X Total Volume Outside
- <u>Good agreement for 30-meter tunnel</u>

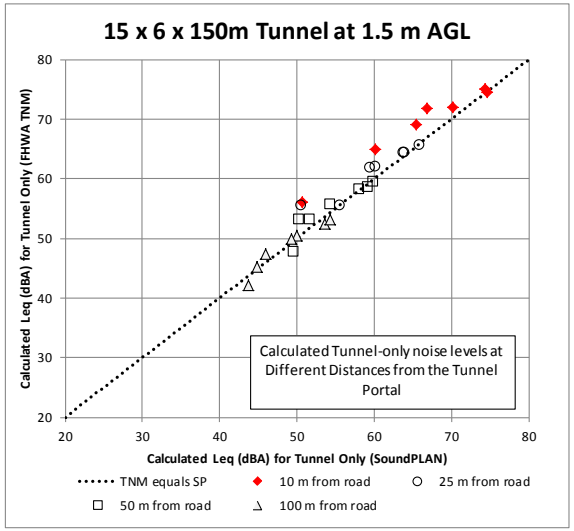




Tunnel Openings
Evaluation of Modeling Techniques

- Tunnel-Radiated Noise: TNM vs SP at 1.5 meters AGL
- Modeling Technique: 3 Roads Inside with 7 to 8X Total Volume Outside
- <u>Good Agreement for 150-meter Tunnel</u>

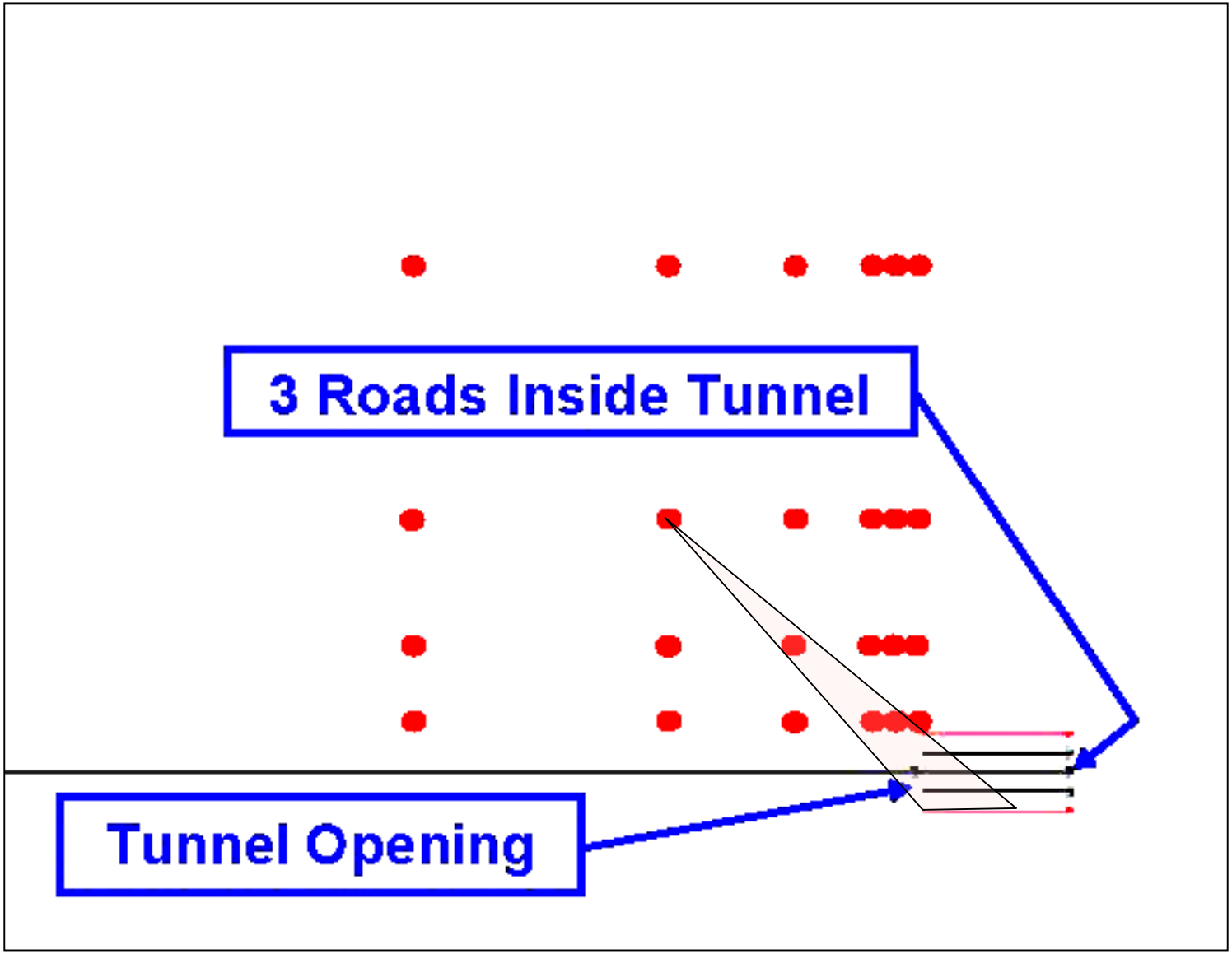




Tunnel Openings
Recommended Best Practices for Modeling in TNM

- **Use a Look-up Table of Pre-calculated Adjustments for the "Tunnel Effect"**
- **Model Tunnel Openings in TNM**
  - Tunnel length < 15 meters: do not consider "tunnel effects"
  - 15 < tunnel length < 60 meters:
    - 3 or 4 parallel evenly-spaced roads along the full length
    - With 30-meter tall noise barriers for the tunnel walls
    - Total volume (inside) = 3 X total volume (outside)
  - Tunnel length > 60 meters
    - 3 or 4 roads up to a maximum length of 300 meters
    - Total volume (inside) = 7 to 8 X total volume (outside)
- **Consider other Software Applications (FHWA approval)**

Tunnel Openings
Detail of Plan View in TNM



Tunnel Openings
"Tunnel Effect" in dBA to be Added to TNM LAeq

Distance (meters) from		Single Lane		2+ Lanes	
Road Centerline	Tunnel Opening	Short Tunnel	Long Tunnel	Short Tunnel	Long Tunnel
10	10	1	3	2	4
	25	1	1	1	2
	50	0	0	0	1
	100	0	0	0	0
25	10	0	1	1	2
	25	1	1	1	2
	50	0	1	0	1
	100	0	0	0	0
50	10	0	0	0	0
	25	0	1	0	1
	50	0	1	0	1
	100	0	0	0	1

Tunnel Openings
Limitations of the Recommended Best Practices

- Barrier at 30-meter Height AGL – Contributions from Diffracted Sound Path
- Receptor Heights Limited to 15 Meters AGL
- Most Suitable for Receptors within 150 Meters of Road
- Receptors with Direct Lines of Sight to the Tunnel Opening / Portal
- Best Practices Were Developed for Reflective Tunnel – for Absorptive Tunnels Consider other Commercially Available Models (with FHWA Approval)

Tunnel Openings
Team Members & Acknowledgements

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  - Christopher Bajdek, HMMH – evaluation of modeling techniques and development of Best Practices
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