Peer Review of May 2015 Vehicle Population and Activity Update Report

September 28, 2015

Prepared for
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Acronyms and Abbreviations

Acronym / Abbreviation	Stands For
EPA	U.S. Environmental Protection Agency
ICF	ICF International
LDV	Light-Duty Vehicle
NMHC	Non-Methane Hydrocarbon Emissions
NMOG	Non-Methane Organic Gases
OTAQ	Office of Transportation and Air Quality
THC	Total Hydrocarbon
TOG	Total Organic Gas
VOC	Volatile Organic Compound
WAM	Work Assignment Manager

1. Introduction

The Office of Transportation and Air Quality (OTAQ) of the U.S. Environmental Protection Agency (EPA) is responsible for developing regulations to reduce the emissions of greenhouse gases (GHG) from light-duty vehicles (LDV) in the U.S. As new policy options are brought forth, there is a need to evaluate the soundness and utility of such policies. Modeling questions may yield approximations from smaller sets of real data when questions of policy tend to be too large to study directly. For example, models can provide insights into how drivers will change their vehicle operating patterns in response to a mandated increase in fuel economy across the light-duty vehicle fleet. EPA's MOVES2014 model is part of a comprehensive EPA approach to address the impacts of light- and heavy-duty vehicles on air quality and public health.

EPA documented changes to assumptions about the US national highway vehicle fleet population and activity data for the next version of the MOVES model. Fleet population and activity data is used to convert emission rates into emission inventory values and then is used to weight individual values into aggregated emission rates. The techniques and methods used to map and distribute population and activity data into the categories used by the MOVES model were also documented.

This report details the peer review of the subject report, *Vehicle Population and Activity Update Report (May 2015)*. A number of independent subject matter experts were identified and the process managed to provide reviews and comments on the methodology of the report. This peer review process was carried out under EPA's peer review guidelines[1].

This report is organized as follows:

- Chapter 2 details the selection of the peer reviewers
- Chapter 3 details the peer review process
- Appendix A provides resumes and conflict of interest statements for the two selected reviewers
- Appendix B provides the charge letter sent to the selected reviewers
- Appendix C and D provide the actual reviews submitted by the two selected reviewers

[1] U.S. Environmental Protection Agency, Peer Review Handbook, 3rd Edition with appendices. Prepared for the U.S. EPA by Members of the Peer Review Advisory Group, for EPA's Science Policy Council, EPA/100/B-06/002. Available at http://www.epa.gov/peerreview

2. Selection of Peer Reviewers

The EPA and ICF International (ICF) Work Assignment Manager (WAM) compiled a list of 6 reviewers who would be capable of reviewing the subject report. They are listed in Table 2-1. ICF contacted these potential reviewers to determine their availability to participate and obtain a CV.

Table 2-1. Potential Reviewers

Potential Reviewer	Affiliation	Availability	Degree	Depth of Experience	Recency of Contributions
Bai, Song	Sonoma Technology, Inc. Air Quality Scientist/Project Manager, Transportation Policy and Planning	Yes	PhD, Civil and Environmental Engineering, UC Davis MS, Statistics, UC Davis MS, Civil Engineering, Tsinghua University BS, Civil Engineering, Tsinghua University	Med	Med
Boriboonsomsin, Kanok	UC Riverside, CE-CERT Associate Research Engineer and Associate Adjunct Professor	Yes	Ph.D., Transportation Engineering, University of Mississippi M.Eng., Infrastructure Engineering Asian Institute of Technology B.Eng., Civil Engineering Chulalongkorn University	High	High
Chamberlin, Robert	Resource Systems Group	Yes, but did not send resume	n/a	n/a	n/a
Farzaneh, Mohamadreza	Texas Transportation Institute, Associate Research Engineer	Yes	Ph.D., Civil Engineering, Virginia Tech M.S., Civil Engineering, University of Tehran B.S., Civil Engineering, University of Tehran	Med	High
Guensler, Randall	Georgia Institute of Technology Professor - School of Civil and Environmental Engineering	Yes	UC Davis - Ph.D., Civil Engineering, M.S., Civil Engineering, B.S., Individualized Engineering	High	High

Potential Reviewer	Affiliation	Availability	Degree	Depth of Experience	Recency of Contributions
Pournazeri, Sam	California Air Resources Board, Air Resources Engineer	Yes	Ph.D., Mechanical Engineering, UC Riverside, M.S., Mechanical Engineering, UC Riverside, B.S., Mechanical Engineering, Sharif University of Technology	High	High

The two selected reviewers are listed in Table 2-2. Each had the necessary expertise, were available to review the report in a timely manner and had no conflict of interest. All were agreed upon by the EPA WAM.

Table 2-2. Final Reviewers

Reviewer	Contact Information	Necessary Expertise	Conflict of Interest
Kanok Boriboonsomsin	UC Riverside Center for Environment Research and Technology (CE-CERT P: xxx-xxx-xxxx EMAIL	Yes	No
Randall Guensler	Georgia Institute of Technology School of Civil and Environmental Engineering P: xxx-xxx-xxxx EMAIL	Yes	No

Resumes and conflict of interest statements for the two reviewers can be found in Appendix A.

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3. Peer Review Process

Once the two reviewers had been decided upon and approved by the EPA WAM, a charge letter (see Appendix B) and supporting materials for the peer review were distributed. Each reviewer provided a written peer review in accordance with the charge letter. These were sent to ICF who forwarded them directly to the EPA WAM.

ICF managed the peer review process to ensure that each peer reviewer had sufficient time to complete their review of the data analysis by the deliverable date. Extensions were requested by the reviewers in order to accommodate TRB and summer schedules. ICF adhered to the provisions of EPA's Peer Review Handbook guidelines to ensure that all segments of the peer review conformed to EPA peer review policy.

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Appendix A. Resumes and Conflict of Interest Statements

Kanok Boriboonsomsin, Ph.D., P.E.

College of Engineering – Center for Environmental Research and Technology
University of California, Riverside
1084 Columbia Ave, Riverside, CA 92507, USA
Phone: +1 951 781 5792, Fax: +1 951 781 5790, Email: kanok@cert.ucr.edu

EDUCATION

2004	Ph.D., Transportation Engineering University of Mississippi, Oxford, Mississippi
2001	M.Eng., Infrastructure Engineering Asian Institute of Technology, Bangkok, Thailand
1999	B.Eng., Civil Engineering Chulalongkorn University, Bangkok, Thailand

APPOINTMENTS

2012 – Present	Associate Research Engineer College of Engineering-Center for Environmental Research and Technology University of California, Riverside, CA
2012 – Present	Associate Adjunct Professor Department of Chemical and Environmental Engineering University of California, Riverside, CA
2007 – 2012	Assistant Research Engineer College of Engineering-Center for Environmental Research and Technology University of California, Riverside, CA
2005 – 2007	Postdoctoral Scholar College of Engineering-Center for Environmental Research and Technology University of California, Riverside, CA
2004 – 2005	Visiting Assistant Professor Department of Civil Engineering Ohio Northern University, Ada, OH

PROFESSIONAL LICENSURES

2008 – Present	Professional Traffic Engineer, State of California
2008 – Present	Professional Civil Engineer, State of Michigan
1999 – Present	Civil Engineer, Thailand

PROFESSIONAL MEMBERSHIPS

Member — Institute of Electrical and Electronics Engineers (IEEE)
- IEEE Intelligent Transportation Systems Society

Member — Transportation Research Board (TRB)
- ADC20: Transportation and Air Quality Committee
- Planning & Environment Group's Young Member Council

Member — Institute of Transportation Engineers (ITE)

RESEARCH INTERESTS

- Sustainable transportation
- Intelligent transportation systems
- Traffic simulation
- Traffic operations
- Vehicle energy and emissions modeling
- Vehicle activity analysis
- GIS applications in transportation
- Transportation modeling

GRANT ACTIVITIES

1. Co-Principal Investigator (with G. Wu as PI and M. Barth as Co-PI). "Eco-routing navigation system for electric vehicles." California Energy Commission; $94,714; Oct 2012 – Sep 2013.

2. Co-Principal Investigator (with M. Barth as PI and M. Todd as Co-PI). "Development and evaluation of ECO-ITS technology to support off-cycle CO2 reductions: Phase 2 research." Nissan Motor Company; $109,996; Jun 2012 – Mar 2013.

3. Co-Principal Investigator (with M. Barth as PI). "Near-Term Transportation Energy and Climate Change Strategies." California Department of Transportation (through subcontract with University of California Berkeley); $10,000; Aug 2011 – Jul 2014.

4. Principal Investigator (with M. Barth and G. Wu as Co-PI). "Reducing uncertainty in modeling vehicle emissions at high speed in California." California Department of Transportation; $199,999; Jul 2012 – Jun 2013.

5. Principal Investigator (with M. Barth and G. Wu as Co-PI). "Deployment of prior HOV lanes research results in developing analysis tools for new managed lanes projects." California Department of Transportation; $199,992; May 2012 – Apr 2014.

6. Co-Principal Investigator (with T. Durbin as PI and K. Johnson as Co-PI). "National deployment of portable emissions and activity measurement systems in support of the development and improvement of mobile source emission factors and emission inventories." U.S. Environmental Protection Agency (through subcontract with Eastern Research Group, Inc.); $298,934; Oct 2011 – Sep 2014.

7. Co-Principal Investigator (with M. Barth as PI). "Identification and evaluation of transformative environmental applications and strategies." U.S. Department of Transportation (through subcontract with Booz Allen Hamilton, Inc.); $849,937; Nov 2011 – Oct 2014.

8. Co-Principal Investigator (with M. Barth as PI). “Next generation environmentally friendly driving feedback systems research and development.” U.S. Department of Energy; $1,210,235 (plus $665,472 in-kind contribution from various research partners); Oct 2011 – Sep 2014.

9. Principal Investigator (with M. Barth as Co-PI). “High occupancy vehicle (HOV) system analysis tools: District 8 HOV facility performance analysis.” California Department of Transportation; $62,884; Dec 2011 – Nov 2012.

10. Co-Principal Investigator (with M. Barth as PI). “Advanced traffic signal control algorithms.” Federal Highway Administration (through subcontract with University of California Berkeley); $72,698; Aug 2010 – Jun 2012.

11. Principal Investigator. “Development and evaluation of intelligent energy management strategies for plug-in hybrid electric vehicles.” University of California Transportation Center; $72,020; Jan 2011 – Mar 2012.

12. Principal Investigator (with M. Barth as Co-PI). “High occupancy vehicle (HOV) system analysis tools: District 8 HOV facility performance analysis.” California Department of Transportation; $209,612; Dec 2008 – Nov 2011.

13. Co-Principal Investigator (with M. Barth as PI). “ECO-ITS: ITS applications to improve environmental performance.” U.S. Department of Transportation; $40,000; Oct 2010 – Sep 2011.

14. Principal Investigator. “Real-time energy/emission estimation and management system for heavy-duty trucks.” U.S. Department of Transportation (through subcontract with Calmar Telematics); $15,967; Feb 2011 – Jun 2011.

15. Principal Investigator (with M. Barth as Co-PI). “Improving vehicle fleet, activity, and emissions data for on-road mobile sources emissions inventories.” Federal Highway Administration; $340,000 (plus $140,000 in-kind contribution from California Air Resources Board and another $370,000 from Calmar Telematics); Nov 2009 – Apr 2011.

16. Principal Investigator (with M. Barth as Co-PI). “Development of TRANSIMS synthetic population data for Riverside County.” County of Riverside, California; $160,000; Jan 2008 – Nov 2009.

17. Principal Investigator. “Eco-driving: pilot evaluation of behavior changes in U.S. drivers.” University of California Transportation Center; $53,620; Oct 2008 – Sep 2009.

18. Principal Investigator (with M. Barth as Co-PI). “Improving greenhouse gas emissions inventory estimation of heavy-duty trucks.” Federal Highway Administration; $99,260 (plus $25,000 matching fund from California Air Resources Board); Sep 2008 – Sep 2009.

19. Co-Principal Investigator (with F. Reza as PI). “High albedo and environment-friendly concrete for smart growth and sustainable development.” U.S. Environmental Protection Agency; $10,000; Oct 2005 – May 2006.

20. Co-Principal Investigator (with F. Reza as PI and S. Bazlamit as Co-PI). “Development of a composite pavement performance index.” Ohio Department of Transportation; $10,085; Sep 2004 – Aug 2005.

21. Principal Investigator. "Enhancing civil engineering curriculum with geographic information system technology." Ohio Northern University; $5,000; Dec 2004 – May 2005.

PUBLICATIONS

Journal Articles

1. Wu, G., **Boriboonsomsin, K.**, and Barth, M. (2015). "Comparative analysis of empirical capacities between freeways with different types of high-occupancy vehicle access control." *Transportation Research Record*, in press.

2. **Boriboonsomsin, K.**, Wu, G., Hao, P., and Barth, M. (2015). "Fusion of vehicle weight and activity data for improved vehicle emission modeling." *Transportation Research Record*, in press.

3. **Boriboonsomsin, K.**, Dean, J., and Barth, M. (2014). "Examination of attributes and value of ecologically friendly route choices." *Transportation Research Record*, 2427, 13-25.

4. Wu, G., Xia, H., **Boriboonsomsin, K.**, and Barth, M. (2014). "Supplementary benefits from partial vehicle automation in an eco-approach/departure application at signalized intersections." *Transportation Research Record*, 2424, 66-75.

5. Wu, G., **Boriboonsomsin, K.**, and Barth, M. (2014). "Development and evaluation of intelligent energy management strategy for plug-in hybrid electric vehicle." *IEEE Transactions on Intelligent Transportation Systems*, 15(3), 1091-1100.

6. Du, Y., Wu, G., **Boriboonsomsin, K.**, and Chan, C.-Y. (2013). "Empirical study on lane changing behavior along different types of high-occupancy vehicle facilities in California." *Transportation Research Record*, 2396, 143-150.

7. Xia, H., **Boriboonsomsin, K.**, and Barth, M. (2013). "Dynamic ECO-driving for signalized arterial corridors and its indirect network-wide energy/emissions benefits." *Journal of Intelligent Transportation Systems*, 17(1), 31-41.

8. **Boriboonsomsin, K.**, Barth, M., Zhu, W., and Vu. A. (2012). "ECO-routing navigation system based on multi-source historical and real-time traffic information." *IEEE Transactions on Intelligent Transportation Systems*, 13(4), 1694-1704.

9. **Boriboonsomsin, K.**, Sheckler, R., and Barth, M. (2012). "Generating heavy-duty truck activity data inputs for MOVES based on large-scale truck telematics data." *Transportation Research Record*, 2270, 49-58.

10. **Boriboonsomsin, K.**, Zhu, W., and Barth, M. (2011). "A statistical approach to estimating truck traffic speed and its application to emission inventory modeling." *Transportation Research Record*, 2233, 110-119.

11. Wu, G., Du, Y., Jang, K., Chan, C.-Y., and **Boriboonsomsin, K.** (2011). "Preliminary evaluation of operational performance between different types of HOV facilities in California: Continuous-access vs. limited-access." *Transportation Research Record*, 2229, 93-101.

12. **Boriboonsomsin, K.**, Scora, G., and Barth, M. (2010). "Analysis of heavy-duty diesel truck activity and fuel economy based on electronic control module data." *Transportation Research Record*, 2191, 23-33.

13. Wu, G., **Boriboonsomsin, K.**, Zhang, W.-B., Li, M., and Barth, M. (2010). "Energy and emission benefit comparison between stationary and in-vehicle advanced driving alert systems." *Transportation Research Record*, 2189, 98-106.

14. Zhu, W., **Boriboonsomsin, K.**, and Barth, M. (2010). "Defining a freeway mobility index for roadway navigation." *Journal of Intelligent Transportation Systems*, 14(1), 37-50.

15. **Boriboonsomsin, K.**, Barth, M., and Xu, H. (2009). "Improvements to on-road mobile emissions modeling of freeways with high-occupancy vehicle facilities." *Transportation Research Record*, 2123, 109-118.

16. **Boriboonsomsin, K.** and Barth, M. (2009). "Impacts of road grade on fuel consumption and carbon dioxide emissions evidenced by use of advanced navigation systems." *Transportation Research Record*, 2139, 21-30.

17. Barth, M. and **Boriboonsomsin, K.** (2009). "Energy and emissions impacts of a freeway-based dynamic eco-driving system." *Transportation Research Part D*, 14(6), 400-410.

18. Li, M., **Boriboonsomsin, K.**, Wu, G., Zhang, W.-B., and Barth, M. (2009). "Traffic energy and emission reductions at signalized intersections: a study of the benefits of advanced driver information." *International Journal of Intelligent Transportation Systems Research*, 7(1), 49-58.

19. Barth, M. and **Boriboonsomsin, K.** (2008). "Real-world carbon dioxide impacts of traffic congestion." *Transportation Research Record*, 2058, 163-171.

20. **Boriboonsomsin, K.** and Barth, M. (2008). "Impacts of freeway high-occupancy vehicle lane configuration on vehicle emissions." *Transportation Research Part D*, 13(2), 112-125.

21. Reza, F., **Boriboonsomsin**, **K.**, and Bazlamit, S. (2007). "The development of a pavement quality index for the Ohio Department of Transportation." *International Journal of Pavements*, 6(1), 1-12.

22. **Boriboonsomsin, K**. and Barth, M. (2007). "Evaluating air quality benefits of freeway high occupancy vehicle lanes in Southern California." *Transportation Research Record*, 2011, 137-147.

23. **Boriboonsomsin, K**. and Reza, F. (2007). "Mix design and benefit evaluation of high solar reflectance concrete for pavements." *Transportation Research Record*, 2011, 11-20.

24. **Boriboonsomsin, K**. and Uddin, W. (2006). "Simplified methodology to estimate emissions from mobile sources for ambient air quality assessment." *Journal of Transportation Engineering*, 132(10), 817-828.

25. Uddin, W., **Boriboonsomsin, K.**, and Garza, S. (2005). "Transportation related environmental impacts and societal costs for life-cycle analysis of costs and benefits." *International Journal of Pavements*, 4(1-2), 92-104.

Conference Proceedings (Full Paper Reviewed)

1. Hao, P., **Boriboonsomsin, K.**, Wu, G., and Barth, M. (2014). "Probabilistic model for estimating vehicle trajectories using sparse mobile sensor data." *Proceedings of the 17th International IEEE Conference on Intelligent Transportation Systems*, Qingdao, China, October 8-11.

2. Qi, X., Wu, G., **Boriboonsomsin, K.**, and Barth, M. (2014). "An on-line energy management strategy for plug-in hybrid electric vehicles using an estimation distribution algorithm." *Proceedings of the 17th International IEEE Conference on Intelligent Transportation Systems*, Qingdao, China, October 8-11.

3. **Boriboonsomsin, K.** and Barth, M. (2014). "Context-sensitive eco-driving scores." *Proceedings of the 21st World Congress on Intelligent Transportation Systems*, Detroit, MI, September 7-11.

4. Jin, Q., Wu, G., **Boriboonsomsin, K.**, and Barth, M. (2014). "Improving traffic operations using real-time optimal lane selection with connected vehicle technology." *Proceedings of the 2014 Intelligent Vehicles Symposium*, Dearborn, MI, June 8-11.

5. **Boriboonsomsin, K.**, Dean, J., and Barth, M. (2014). "An examination of the attributes and value of eco-friendly route choices." *Proceedings of the 93rd Annual Meeting of the Transportation Research Board*, Washington, DC, January 12-16.

6. Wu, G., Xia, H., **Boriboonsomsin, K.**, and Barth, M. (2014). "Supplementary benefits from partial vehicle automation in an eco-approach/departure application at signalized intersections." *Proceedings of the 93rd Annual Meeting of the Transportation Research Board*, Washington, DC, January 12-16.

7. Barth, M., **Boriboonsomsin, K.**, and Wu, G. (2013). "The potential role of vehicle automation in reducing traffic-related energy and emissions." *Proceedings of the 2nd International Conference on Connected Vehicles & Expo*, Las Vegas, NV, December 2-7.

8. Xia, H., Wu, G., **Boriboonsomsin, K.**, and Barth, M. (2013). "Development and evaluation of an enhanced eco-approach traffic signal application for connected vehicles." *Proceedings of the 16th International IEEE Conference on Intelligent Transportation Systems*, The Hague, Netherlands, October 6-9.

9. Jin, Q., Wu, G., **Boriboonsomsin, K.**, and Barth, M. (2013). "Platoon-based multi-agent intersection management for connected vehicles." *Proceedings of the 16th International IEEE Conference on Intelligent Transportation Systems*, The Hague, Netherlands, October 6-9.

10. Yang, Q., Wu, G., **Boriboonsomsin, K.**, and Barth, M. (2013). "Arterial roadway travel time distribution estimation and vehicle movement classification using a modified Gaussian mixture model." *Proceedings of the 16th International IEEE Conference on Intelligent Transportation Systems*, The Hague, Netherlands, October 6-9.

11. Wu, G., **Boriboonsomsin, K.**, and Barth, M. (2013). "Development and evaluation of intelligent energy management strategy for plug-in hybrid electric vehicle." *Proceedings of the 92nd Annual Meeting of the Transportation Research Board*, Washington, DC, January 13-17.

12. Barth, M., **Boriboonsomsin, K.**, Todd, M., Ishisaka, T., and Williams, N. (2013). “A generalized methodology for establishing CO2 off-cycle credits as part of light-duty vehicle greenhouse gas emission standards.” *Proceedings of the 92nd Annual Meeting of the Transportation Research Board*, Washington, DC, January 13-17.

13. Scora, G., **Boriboonsomsin, K.**, and Barth, M. (2013). “Eco-friendly navigation system development for heavy-duty trucks.” *Proceedings of the 92nd Annual Meeting of the Transportation Research Board*, Washington, DC, January 13-17.

14. Martin, E., **Boriboonsomsin, K.**, Chan, N., Williams, N., Shaheen, S., and Barth, M. (2013). “Dynamic eco-driving in northern California: A study of survey and vehicle operations data from an eco-driving feedback device.” *Proceedings of the 92nd Annual Meeting of the Transportation Research Board*, Washington, DC, January 13-17.

15. Du, Y., Wu, G., **Boriboonsomsin, K.**, and Chan, C.-Y. (2013). “Empirical study on lane changing behavior along different types of high-occupancy vehicle facilities in California.” *Proceedings of the 92nd Annual Meeting of the Transportation Research Board*, Washington, DC, January 13-17.

16. Jin, Q., Wu, G., **Boriboonsomsin, K.**, and Barth, M. (2012). “Multi-agent intersection management for connected vehicles using an optimal scheduling approach.” *Proceedings of the 1st International Conference on Connected Vehicles & Expo*, Beijing, China, December 12-16.

17. Wu, G., **Boriboonsomsin, K.**, Zhang, L., and Barth, M. (2012). “Simulation-based benefit evaluation of dynamic lane grouping strategies at isolated intersections.” *Proceedings of the 15th International IEEE Conference on Intelligent Transportation Systems*, Anchorage, AK, September 16-19.

18. Xia, H., **Boriboonsomsin, K.**, Schweizer, F., Winckler, A., Zhou, K., Zhang, W.-B., and Barth, M. (2012). “Field operational testing of ECO-approach technology at a fixed-time signalized intersection.” *Proceedings of the 15th International IEEE Conference on Intelligent Transportation Systems*, Anchorage, AK, September 16-19.

19. Jin, Q., Wu, G., **Boriboonsomsin, K.**, and Barth, M. (2012). “Advanced intersection management for connected vehicles using a multi-agent systems approach.” *Proceedings of the 2012 Intelligent Vehicles Symposium*, Alcalá de Henares, Spain, June 3-7.

20. **Boriboonsomsin, K.**, Sheckler, R., and Barth, M. (2012). “Generating heavy-duty truck activity data inputs for MOVES based on large-scale truck telematics data.” *Proceedings of the 91st Annual Meeting of the Transportation Research Board*, Washington, DC, January 22-26.

21. Tadi, R., **Boriboonsomsin, K.**, and Barth, M. (2011). “Role of high occupancy vehicle (HOV) lanes in combating congestion and emissions – California case study.” *Proceedings of the 1st Conference of Transportation Research Group of India*, Bangalore, India, December 7-10.

22. Yang, Q., **Boriboonsomsin, K.**, and Barth, M. (2011). “Arterial roadway energy/emissions estimation using modal-based trajectory reconstruction.” *Proceedings of the 14th International IEEE Conference on Intelligent Transportation Systems*, Washington, DC, October 5-7.

23. Xia, H., **Boriboonsomsin, K.**, and Barth, M. (2011). "Indirect network-wide energy/emissions benefits from dynamic ECO-driving on signalized corridors." *Proceedings of the 14th International IEEE Conference on Intelligent Transportation Systems*, Washington, DC, October 5-7.

24. Barth, M., Mandava, S., **Boriboonsomsin, K.**, and Xia, H. (2011). "Dynamic ECO-driving for arterial corridors." *Proceedings of the 1st IEEE Forum on Integrated and Sustainable Transportation Systems*, Vienna, Austria, June 29 – July 1.

25. **Boriboonsomsin, K.**, Wu, G., Scora, G., and Barth, M. (2011). "Impacts of goods movement pricing on traffic congestion and air pollution: A case study of the ports of Los Angeles and Long Beach." *Proceedings of the 52nd Annual Transportation Research Forum*, Long Beach, CA, March 10-12.

26. **Boriboonsomsin, K.**, Vu, A., and Barth, M. (2011). "Evaluation of driving behavior and attitude towards eco-driving: A Southern California case study." *Proceedings of the 90th Annual Meeting of the Transportation Research Board*, Washington, DC, January 23-27.

27. **Boriboonsomsin, K.**, Zhu, W., and Barth, M. (2011). "A statistical approach to estimating truck traffic speed and its application to emission inventory modeling." *Proceedings of the 90th Annual Meeting of the Transportation Research Board*, Washington, DC, January 23-27.

28. Wu, G., Du, Y., Jang, K., Chan, C.-Y., and **Boriboonsomsin, K.** (2011). "Preliminary evaluation of operational performance between different types of HOV facilities in California: Continuous-access vs. limited-access." *Proceedings of the 90th Annual Meeting of the Transportation Research Board*, Washington, DC, January 23-27.

29. Vu, A., **Boriboonsomsin, K.**, and Barth, M. (2010). "Vehicle parameterization and tracking from traffic videos." *Proceedings of the 13rd International IEEE Conference on Intelligent Transportation Systems*, Madeira Island, Portugal, September 19-22.

30. Boskovich, S., **Boriboonsomsin, K.**, and Barth, M. (2010). "A developmental framework towards dynamic incident rerouting using vehicle-to-vehicle communication and multi-agent systems." *Proceedings of the 13rd International IEEE Conference on Intelligent Transportation Systems*, Madeira Island, Portugal, September 19-22.

31. **Boriboonsomsin, K.**, Barth, M., Zhu, W., and Vu. A. (2010). "ECO-routing navigation system based on multi-source historical and real-time traffic information." *Proceedings of the 13th International IEEE Conference on Intelligent Transportation Systems*, in Workshop on Emergent Cooperative Technologies in Intelligent Transportation Systems, Madeira Island, Portugal, September 19-22.

32. **Boriboonsomsin, K.**, Scora, G., and Barth, M. (2010). "Analysis of heavy-duty diesel truck activity and fuel economy based on electronic control module data." *Proceedings of the 89th Annual Meeting of the Transportation Research Board (DVD)*, Washington, DC, January 10-14.

33. Zhu, W., **Boriboonsomsin, K.**, and Barth, M. (2010). "Estimating truck traffic speed from single-loop detector data." *Proceedings of the 89th Annual Meeting of the Transportation Research Board (DVD)*, Washington, DC, January 10-14.

34. Scora, G., **Boriboonsomsin, K.**, and Barth, M. (2010). "Effects of operational variability on heavy-duty truck greenhouse gas emissions." *Proceedings of the 89th Annual Meeting of the Transportation Research Board (DVD)*, Washington, DC, January 10-14.

35. Wu, G., **Boriboonsomsin, K.**, Zhang, W.-B., Li, M., and Barth, M. (2010). "Energy and emission benefit comparison between stationary and in-vehicle advanced driving alert systems." *Proceedings of the 89th Annual Meeting of the Transportation Research Board (DVD)*, Washington, DC, January 10-14.

36. Mandava, S., **Boriboonsomsin, K.**, Barth, M. (2009). "Arterial velocity planning based on traffic signal information under light traffic conditions." *Proceedings of the 12th International IEEE Conference on Intelligent Transportation Systems*, St. Louis, MO, October 3-7.

37. Barth, M. and **Boriboonsomsin, K.** (2009). "Environmentally beneficial intelligent transportation systems." *Proceedings of the 12th IFAC Symposium on Control in Transportation Systems*, Redondo Beach, CA, September 2-4.

38. **Boriboonsomsin, K.**, Barth, M., and Xu, H. (2009). "Improvements to on-road mobile emissions modeling of freeways with high-occupancy vehicle facilities." *Proceedings of the 88th Annual Meeting of the Transportation Research Board (DVD)*, Washington, DC, January 11-15.

39. **Boriboonsomsin, K.** and Barth, M. (2009). "Fuel and CO_2 impacts from advanced navigation systems that account for road grade." *Proceedings of the 88th Annual Meeting of the Transportation Research Board (DVD)*, Washington, DC, January 11-15.

40. Zhu, W., **Boriboonsomsin, K.**, and Barth, M. (2008). "Mobility index-based navigation for mandatory re-routing scenarios." *Proceedings of the 11th International IEEE Conference on Intelligent Transportation Systems*, Beijing, China, October 12-15.

41. Zhu, W., **Boriboonsomsin, K.**, and Barth, M. (2008). "A new methodology for processing time-varying traffic data in multiple states." *Proceedings of the 11th International IEEE Conference on Intelligent Transportation Systems*, Beijing, China, October 12-15.

42. Barth, M. and **Boriboonsomsin, K.** (2008). "Real-world carbon dioxide impacts of traffic congestion." *Proceedings of the 87th Annual Meeting of the Transportation Research Board (DVD)*, Washington, DC, January 13-17.

43. **Boriboonsomsin, K.** and Barth, M. (2008). "Impacts of freeway high-occupancy vehicle lane configuration on vehicle emissions." *Proceedings of the 87th Annual Meeting of the Transportation Research Board (DVD)*, Washington, DC, January 13-17.

44. Servin, O., **Boriboonsomsin, K.**, and Barth, M. (2008). "A preliminary design of speed control strategies in dynamic intelligent speed adaptation system for freeways." *Proceedings of the 87th Annual Meeting of the Transportation Research Board (DVD)*, Washington, DC, January 13-17.

45. **Boriboonsomsin, K.**, Servin, O., and Barth, M. (2007). "Selection of control speeds in dynamic intelligent speed adaptation system: a preliminary analysis." *Proceedings of the 14th International Conference – Road Safety on Four Continents (CD-ROM)*, Bangkok, Thailand, November 14-16.

46. Barth, M., **Boriboonsomsin, K.**, and Vu, A. (2007). "Environmental-friendly navigation." *Proceedings of the 10th International IEEE Conference on Intelligent Transportation Systems (CD-ROM),* Seattle, WA, September 30 – October 3.

47. Zhu, W., **Boriboonsomsin, K.**, and Barth, M. (2007). "Microscopic analysis of traffic flow quality." *Proceedings of the 10th International IEEE Conference on Intelligent Transportation Systems (CD-ROM),* Seattle, WA, September 30 – October 3.

48. **Boriboonsomsin, K**. and Barth, M. (2007). "Evaluating air quality benefits of freeway high occupancy vehicle lanes in Southern California." *Proceedings of the 86th Annual Meeting of the Transportation Research Board (CD-ROM)*, Washington, DC, January 21-25.

49. **Boriboonsomsin, K**. and Reza, F. (2007). "Mix design and benefit evaluation of high solar reflectance concrete for pavements." *Proceedings of the 86th Annual Meeting of the Transportation Research Board (CD-ROM)*, Washington, DC, January 21-25.

50. Servin, O., **Boriboonsomsin, K.**, and Barth, M. (2006). "An energy and emission impact evaluation of intelligent speed adaptation." *Proceedings of the 9th International IEEE Conference on Intelligent Transportation Systems (CD-ROM)*, Toronto, Canada, September 17-20.

51. **Boriboonsomsin, K**. and Uddin, W. (2006). "A consideration of heat-island effect in ground-level ozone forecasting model and its application in rural areas of Northern Mississippi." *Proceedings of the 85th Annual Meeting of the Transportation Research Board (CD-ROM),* Washington, DC, January 22-26.

52. Reza, F., **Boriboonsomsin, K.**, and Bazlamit, S. (2006). "Development of a pavement quality index for the State of Ohio." *Proceedings of the 85th Annual Meeting of the Transportation Research Board (CD-ROM),* Washington, DC, January 22-26.

53. Reza, F., Bazlamit, S., and **Boriboonsomsin, K.** (2005). "Composite performance index for concrete pavement." *Proceedings of the 6th International Congress on Global Construction: Ultimate Concrete Opportunities*, Dundee, UK, July 5-7.

54. Uddin, W., **Boriboonsomsin, K.,** and Garza, S. (2005). "Transportation related environmental impacts and societal costs for life-cycle analysis of costs and benefits." **First Paper Award**, *Proceedings of the 2005 International Symposium on Pavement Recycling*, Sấo Paulo, Brazil, March 14-16.

55. Uddin, W. and **Boriboonsomsin, K.** (2005). "Air quality management using vehicle emission modeling and spatial technologies." *Proceedings of the Environment 2005: International Conference on Sustainable Transportation in Developing Countries*, Abu Dhabi, UAE, January 30 – February 2.

56. **Boriboonsomsin, K**. and Uddin, W. (2005). "Tropospheric ozone modeling considering vehicle emissions and point & aviation sources, validation, and implementation in rural areas." *Proceedings of the 84th Annual Meeting of the Transportation Research Board (CD-ROM),* Washington, DC, January 9-13.

57. Uddin, W., Garza, S., and **Boriboonsomsin, K.** (2003). "A 3D-FE simulation study of the effects of nonlinear material properties on pavement structural response analysis and design."

Proceedings of the 3rd International Symposium on Maintenance and Rehabilitation of Pavements and Technological Control, Guimarães, Portugal, July 7-10.

58. Uddin, W. and **Boriboonsomsin, K.** (2003). "A synthesis study and GIS database for bridge cathodic protection projects." *Proceedings of the 82nd Annual Meeting of the Transportation Research Board (CD-ROM),* Washington, DC, January 12-16.

59. Garza, S. and **Boriboonsomsin, K.** (2002). "Impact of traffic volume change on air quality." **Runner-up Award**, *Southern District ITE 2002 Graduate Student Paper Competition,* March.

60. **Boriboonsomsin, K**. and Herabat, P. (2001). "Suggested performance measures for traffic sign structures." *Proceedings of the 7th National Convention on Civil Engineering*, Bangkok, Thailand, May 17-18.

Conference Papers/Posters (Abstract Reviewed)

1. Wu, G., Jin, Q., and **Boriboonsomsin, K.** (2014). "Improve traffic operation at signalized intersections using four quadrant connection roadways." *The Transportation Research Board's 2014 Alternative Intersections & Interchanges Symposium*, Salt Lake City UT, July 20-23.

2. Wu, G., **Boriboonsomsin, K.**, and Barth, M. (2013). "Fusion of truck weight and activity data for improved estimation of emissions due to goods movement." *Sustainable Goods Movement: Maintaining the Environment, Economy and Equity*, Palm Desert, CA, November 21-22.

3. **Boriboonsomsin, K.**, Xia, H., Wu, G., and Barth, M. (2013). "Supplementary benefits from partial automation in energy and environment-focused connected vehicle applications." *The Transportation Research Board's 2nd Annual Workshop on Road Vehicle Automation*, Stanford, CA, July 16-19.

4. Wu. G., **Boriboonsomsin, K.**, and Barth, M. (2013). "Development and evaluation of intelligent energy management strategy for plug-in hybrid electric vehicle." *19th UCTC Student Conference*, Los Angeles, CA, February 28 – March 2.

5. Jin, Q., Wu. G., **Boriboonsomsin, K.**, and Barth, M. (2013). "Advanced intersection management for connected vehicles using optimal scheduling approach." *19th UCTC Student Conference*, Los Angeles, CA, February 28 – March 2.

6. Jarak, N. and **Boriboonsomsin, K.** (2013). "Method for self-constructing/updating vehicle fuel consumption models based on real-time fuel consumption data." *19th UCTC Student Conference*, Los Angeles, CA, February 28 – March 2.

7. Xia, H., **Boriboonsomsin, K.**, and Wu, G. (2013). "Calibration of traffic microsimulation models for microscopic vehicle emission modeling." *19th UCTC Student Conference*, Los Angeles, CA, February 28 – March 2.

8. Xia, H., Barth, M., and **Boriboonsomsin, K.** (2012). "Dynamic eco-driving on signalized corridors." *18th UCTC Student Conference*, Davis, CA, April 20.

9. Jin, Q., Barth, M., and **Boriboonsomsin, K.** (2012). "Advanced intersection management for connected vehicles using a multi-agent systems approach. *18th UCTC Student Conference*, Davis, CA, April 20.

10. Nelson, J., **Boriboonsomsin, K.**, and Barth, M. (2010). "A comparison of vehicle usage patterns of residents in New Urbanism communities and conventional communities." *16th UCTC Student Conference*, Irvine, CA, April 1-2.

11. Scora, G., **Boriboonsomsin, K.**, and Barth, M. (2010). "The effects of operational variability on heavy-duty truck greenhouse gas emissions." *16th UCTC Student Conference*, Irvine, CA, April 1-2.

12. Scora, G., **Boriboonsomsin, K.**, and Barth, M. (2009). "The importance of road grade and vehicle speed on heavy-duty truck fuel economy and emissions." *19th CRC On-Road Vehicle Emissions Workshop*, San Diego, CA, March 23-25.

13. Barth, M., **Boriboonsomsin, K.**, Zhu, W., Vu, A., Gerdes, A., Lee, C., and Rosario, D. (2008). "Environmental-friendly navigation: technology description and field operational testing plan." *15th World Congress on Intelligent Transportation Systems*, New York City, NY, November 16-20.

14. Wu, G., Zhang, W.-B., Li, M., Barth, M., **Boriboonsomsin, K.**, Lee, C., Gerdes, A., and Rosario, D. (2008). "Traffic emission reduction at signalized intersections: a simulation study of benefits of advanced driver information." *15th World Congress on Intelligent Transportation Systems*, New York City, NY, November 16-20.

15. Zhu, W., **Boriboonsomsin, K.**, and Barth, M. (2008). "Mobility index-based navigation for mandatory re-routing scenarios." *2nd Annual California University Transportation Centers – PATH Conference*, Los Angeles, CA, November 6-7.

16. **Boriboonsomsin, K**. and Barth, M. (2007). "A simple screening tool for evaluating walkability/bikability of travel routes to schools." *4th Asian Regional Conference on Safe Communities*, Bangkok, Thailand, November 22-24.

17. Barth, M., **Boriboonsomsin, K**. and Vu, A. (2007). "Environmentally-friendly navigation." *1st Annual California University Transportation Centers – PATH Conference*, Berkeley, CA, October 29-31.

18. **Boriboonsomsin, K**., Barth, M., and Scora, G. (2007). "Estimating the emissions inventory of high-occupancy vehicle facilities." *17th CRC On-Road Vehicle Emissions Workshop*, San Diego, CA, March 26-28.

19. **Boriboonsomsin, K**. (2006). "Integrated transportation/emissions modeling: a microscopic approach." *Citilabs International User Conference*, Palm Springs, CA, November 5.

20. **Boriboonsomsin, K**. and Uddin, W. (2005). "Ground-level ozone forecasting model considering precursor emissions and heat-island effect." *NOAA/EPA Golden Jubilee Symposium on Air Quality Modeling and Its Application*, Durham, NC, September 20-21.

21. **Boriboonsomsin, K.** and Uddin, W. (2005). "Pavement surface type and vector map extraction using modern spaceborne remote sensing and spatial technologies." *Pavement Performance Data Analysis Forum*, Washington, DC, January 8.

22. **Boriboonsomsin, K**. and Uddin, W. (2004). "A Methodology for trend analysis of land development and commercial/residential growth in rural cities in Mississippi." *6th Annual Memphis Areas Engineering and Sciences Conference*, Memphis, TN, May 12.

Book Chapters

1. Reza, F. and **Boriboonsomsin, K.** (2015). "Pavements made of concrete with high solar reflectance." *Eco-efficient Materials for Mitigating Building Cooling Needs*, ISBN 9781782423805, Elsevier, F. Pacheco-Torgal, J. A. Labrincha, L. F. Cabeza, and C. G. Grandqvist (Eds.), 37-62.

2. **Boriboonsomsin, K.** (2014). "Emissions modeling." *Encyclopedia of Transportation*, ISBN 9781452267791, SAGE Publications, Inc, M. Garrett (Ed.), 491-493.

3. Barth, M., **Boriboonsomsin, K.**, and Wu, G. (2014). "Vehicle automation and its potential impacts on energy and emissions." *Road Vehicle Automation*, ISBN 978-3-319-05990-7, Springer, G. Meyer and S. Beiker (Eds.), 103-112.

4. Songchitruksa, P., **Boriboonsomsin, K.**, and Barth, M. (2009). "Impact of rising fuel prices on prevailing traffic speed on freeway in Houston, Texas." *Transportation Land Use, Planning, and Air Quality*, ISBN 978-0-7844-1059-2, American Society of Civil Engineers, S. Pulugurtha, R. O'Loughlin, and S. Hallmark (Eds.), 31-40.

5. **Boriboonsomsin, K**. and Barth, M. (2008). "A microscopic approach to modeling air quality impacts of HOV lane conversion." *Transportation Land Use, Planning, and Air Quality*, ISBN 978-0-7844-0960-2, American Society of Civil Engineers, S. Pulugurtha, R. O'Loughlin, S. Hallmark (Eds.), 338-344.

Research Project Reports

1. Wu, G., Barth, M., and **Boriboonsomsin, K.** (2014). Eco-Routing Navigation System for Electric Vehicles. Final report to California Energy Commission, August, 38 pp.

2. **Boriboonsomsin, K.**, Scora, G., and Barth, M. (2014). Reducing uncertainty in modeling vehicle emissions at high speed in California. Final report to California Department of Transportation, May, 52 pp.

3. **Boriboonsomsin, K.**, Scora, G., Wu, G., and Barth, M. (2014). Deployment of prior HOV lanes research results in developing analysis tools for new managed lanes projects. Final report to California Department of Transportation, May, 49 pp.

4. Luo, J. and **Boriboonsomsin, K.** (2014). Modeling Near-Road Concentration of Primary PM2.5 based on TRAN-LA's Model Outputs. Task report for the Virtual Co-Laboratory for Policy Analysis in the Greater Los Angeles Region Project, UC Multi Campus Research Initiative, May, 22 pp.

5. Luo, J. and **Boriboonsomsin, K.** (2014). Neighborhood Traffic and Air Pollution Modeling. Task report for the New Urbanism in Action – Creating Walkability Plans for Riverside Neighborhoods Project, California Department of Transportation, June, 26 pp.

6. Russell, R. and **Boriboonsomsin, K.** (2014). Analysis of high cube warehouse trip data. Technical memorandum to South Coast Air Quality Management District, August 7, 4 pp.

7. Russell, R. and **Boriboonsomsin, K.** (2013). Analysis of business survey data. Technical memorandum to South Coast Air Quality Management District, October 17, 5 pp.

8. **Boriboonsomsin, K.** and Barth, M. (2013). Next generation environmentally-friendly driving feedback systems research and development. Year 2 report to the Department of Energy, October, 30 pp.

9. Barth, M., **Boriboonsomsin, K.**, Todd, M., Ishizaka, T., and Williams, N. (2013). Research, development, and evaluation of ECO-ITS technology to support off-cycle CO2 reductions. Year 2 report to Nissan Motor Company, April, 59 pp.

10. Scora, G. and **Boriboonsomsin, K.** (2012). Building energy use: data review. Task report for the Virtual Co-Laboratory for Policy Analysis in the Greater Los Angeles Region Project, UC Multi Campus Research Initiative, October, 24 pp.

11. Scora, G. and **Boriboonsomsin, K.** (2012). Vehicle fuel use and emission factors. Task report for the Virtual Co-Laboratory for Policy Analysis in the Greater Los Angeles Region Project, UC Multi Campus Research Initiative, October, 22 pp.

12. Barth, M., **Boriboonsomsin, K.**, Todd, M., Ishizaka, T., and Williams, N. (2012). Research, development, and evaluation of ECO-ITS technology to support off-cycle CO2 reductions. Year 1 report to Nissan Motor Company, April, 53 pp.

13. **Boriboonsomsin, K.** and Durbin, T. (2012). Identification and evaluation of heavy-duty vehicle activity datasets. Technical memorandum to the U.S. Environmental Protection Agency, May, 20 pp.

14. **Boriboonsomsin, K.** and Barth, M. (2012). Next generation environmentally-friendly driving feedback systems research and development. Year 1 report to the Department of Energy, October, 43 pp.

15. Scora, G., **Boriboonsomsin, K.**, and Barth, M. (2012). Eco-friendly navigation system development for heavy-duty trucks. Final report to the University of California Transportation Center, June, 32 pp.

16. Wu, G., **Boriboonsomsin, K.**, and Barth, M. (2012). Development and evaluation of intelligent energy management strategies for plug-in hybrid electric vehicles. Final report to the University of California Transportation Center, April, 27 pp.

17. **Boriboonsomsin, K.**, Wu, G., and Barth, M. (2012). “High occupancy vehicle (HOV) system analysis tools - District 8 HOV facility performance analysis.” Final report to the California Department of Transportation, November, 201 pp.

18. **Boriboonsomsin, K.**, Wu, G., and Barth, M. (2011). “High occupancy vehicle (HOV) system analysis tools - District 8 HOV facility performance analysis.” Interim report to the California Department of Transportation, November, 136 pp.

19. **Boriboonsomsin, K.**, Scora, G., Wu, G., and Barth, M. (2011). “Improving vehicle fleet, activity, and emissions data for on-road mobile sources emissions inventories.” Final report to the Federal Highway Administration, September, 165 pp.

20. Barth, M. and **Boriboonsomsin, K.** (2011). “ECO-ITS: Intelligent transportation system applications to improve environmental performance.” Final report to the U.S. Department of Transportation, August, 39 pp.

21. **Boriboonsomsin, K.**, Vu, A., and Dean, J. (2011). “Calculation of GHG emissions from UCR commuting.” Technical memorandum to UCR Campus Sustainability Coordinator, June 15, 9 pp.

22. **Boriboonsomsin, K.,** Sheckler, R., and Barth, M. (2011). “Research on intelligent transportation system application to improve environmental performance.” Final report to the U.S. Department of Transportation, May, 47 pp.

23. Skabardonis, A., Shladover, S., Zhang, W.-B., Zhang, L., Li, J.-Q., Zhou, K. Barth, M., **Boriboonsomsin, K.**, Winckler, A., Liccardo, D., Argote, J., Christofa, E., Xuan, Y. (2011). “Advanced traffic control signal algorithms.” Interim report to the Federal Highway Administration, March, 119 pp.

24. Barth, M., **Boriboonsomsin, K.**, Wu, G., Scora, G., and Todd, M. (2010). “Congestion and air quality evaluation of goods movement pricing.” Final report to the Federal Highway Administration, September, 50 pp.

25. Li, M., **Boriboonsomsin, K.**, Kohut, N., Wu, G., Song, M. K., Vu, A., Misener, J., Zhang, W.-B., Barth, M., Hedrick, J. K., and Borrelli, F. (2010). “Audi ‘Clean Air, A Viable Planet’ Research Initiative.” Final report to Volkswagen Group of America, May, 77 pp.

26. Allison, J. E., Johnson, M. Barth, M., McLaughlin, J., **Boriboonsomsin, K.**, and Medina, X. (2010). “The hope of New Urbanism: Energy conservation and sustainability through urban design.” Final report to The John Randolph and Dora Haynes Foundation, July.

27. **Boriboonsomsin, K.**, Vu, A., and Barth, M. (2010). “Eco-Driving: Pilot evaluation of driving behavior changes among U.S. drivers.” Working paper to the University of California Transportation Center, February, 17 pp.

28. **Boriboonsomsin, K.**, Zhu, W., Scora, G., and Barth, M. (2009). “Improving greenhouse gas emissions inventory estimation of heavy-duty trucks.” Final report to the Federal Highway Administration, November, 70 pp.

29. Barth, M., **Boriboonsomsin, K.**, and Scora, G. (2009). “Evaluation and validation of CO2 estimates of EMFAC and OFFROAD through vehicle activity analysis.” Final report to the California Air Resources Board, November, 120 pp.

30. **Boriboonsomsin, K.** and Barth, M. (2009). “Implementation and evaluation of adaptive transit signal priority along El Camino Real – energy and emission evaluation.” Technical report to the California Partners for Advanced Transit and Highways, May, 10 pp.

31. **Boriboonsomsin, K.** and Barth, M. (2009). “Development of TRANSIMS synthetic population data for Riverside County.” Final report to the Transportation and Land Management Agency, County of Riverside, March, 70 pp.

32. **Boriboonsomsin, K.** and Barth, M. (2009). "Development of advanced ECO-driving strategies: Phase II research." Final report to Nissan Technical Center North America, Inc., March, 61 pp.

33. Barth, M., **Boriboonsomsin, K.,** and Scora, G. (2008). "Evaluation and validation of CO2 estimates of EMFAC and OFFROAD through vehicle activity analysis: Phase II - industry and other agencies survey." Technical report to the California Air Resources Board, January, 69 pp.

34. **Boriboonsomsin, K.** and Barth, M. (2008). "Paints and Architectural Coatings Environmental Study (PACES) – Task 3: Coating application activity analysis." Phase I final report to the National Paint & Coatings Association, September, 40 pp.

35. Barth, M., **Boriboonsomsin, K.**, Vu, A., and Scora, G. (2008). "Development of advanced ECO-driving strategies Phase I." Final report to Nissan Technical Center North America, Inc., March, 38 pp.

36. Barth, M., **Boriboonsomsin, K.,** and Scora, G. (2007). "Evaluation and validation of CO2 estimates of EMFAC and OFFROAD through vehicle activity analysis: Phase I – literature and data review." Technical report to the California Air Resources Board, November, 42 pp.

37. Barth, M., Zhu, W., **Boriboonsomsin, K.**, and Ordonez, L. (2007). "Analysis of GPS-based data for light-duty vehicles." *Contract No. 04-327 UCR*, Final report to the California Air Resources Board, January, 211 pp.

38. **Boriboonsomsin, K.** and Barth, M. (2006). "Modeling the effectiveness of HOV lanes at improving air quality." *Contract No. RTA 65A0196*, Final report to the California Department of Transportation, December, 122 pp.

39. **Boriboonsomsin, K.** and Barth, M. (2006). "Evaluating air quality benefits of proposed network improvements on Interstate 10 in the Coachella Valley." Final report to the Coachella Valley Association of Governments, August, 25 pp.

40. **Boriboonsomsin, K.** and Barth, M. (2006). "Evaluating air quality benefits of proposed network improvements on Interstate 10 in the Coachella Valley." Final report to the Environmental Research Institute, University of California, Riverside, July, 26 pp.

41. Reza, F. and **Boriboonsomsin, K.** (2006). "High albedo and environment-friendly concrete for smart growth and sustainable development." Final report to the U.S. Environmental Protection Agency, *Report No. SU832477*, April, 42 pp.

42. Reza, F., **Boriboonsomsin, K.**, and Bazlamit, S. (2005). "Development of a composite pavement performance index." Final report to the Ohio Department of Transportation, *Report No. ST/SS/05-001*, September, 92 pp.

43. Uddin, W., **Boriboonsomsin, K.**, and Garza, S. (2004). "NCRST-E air quality project: air quality modeling, analysis, and implementation in northern Mississippi." *Report No. UM-CAIT/2004-01*, Final report to U.S. DOT Research and Special Program Administration, June, 169 pp.

44. Uddin, W. and **Boriboonsomsin, K.** (2002). "A synthesis study and GIS database for bridge cathodic protection projects." *Report No. UM-CAIT/2002-01*, Final report to Innovative Business Solutions inc., July, 36 pp.

Others

1. Barth, M. and **Boriboonsomsin, K.** (2012). "Traffic congestion and greenhouse gas emissions (translated to Chinese by Ling, S.)" *Urban Transport of China*, 10(1), 89-94.

2. Barth, M. and **Boriboonsomsin, K.** (2010). "Intelligent transportation systems as a way to reduce greenhouse gas emissions." *UCTC Policy Brief*, Issue 2010-03.

3. Barth, M. and **Boriboonsomsin, K.** (2010). "Traffic congestion and greenhouse gases." *TR News*, Issue 268, May, p. 26.

4. Barth, M. and **Boriboonsomsin, K.** (2009). "Traffic congestion and greenhouse gases." *ACCESS* Magazine, 35, 2-9.

SERVICES

Journal Manuscript Reviews

Energies	2010[a] (1[b])
Environmental Science & Technology	2010 (1), 2009 (1)
European Journal of Operational Research	2012 (1)
IEEE Transactions on Intelligent Transportation Systems	2014 (1), 2013 (1), 2011 (3), 2010 (4)
International Journal of Sustainable Transportation	2013 (1), 2008 (1)
Journal of Intelligent Transportation Systems	2012 (1)
Journal of Planning Literature	2012 (1)
Journal of Transportation Engineering	2013 (1), 2011 (1)
Simulation Modelling Practice and Theory	2012 (1)
The Open Transportation Journal	2009 (1)
Transport Policy	2012 (1)
Transportation	2013 (1)
Transportation Letters	2014 (1)
Transportation Research Part A: Policy and Practice	2008 (1), 2007 (1)
Transportation Research Part B: Methodological	2010 (1)
Transportation Research Part C: Emerging Technologies	2014 (2), 2013 (1), 2012 (1)
Transportation Research Part D: Transport and Environment	2014 (2)

[a] Year of review, [b] Number of manuscripts

Conference Paper Reviews

Annual Meeting of the Transportation Research Board	2014[a] (3[b]), 2013 (7), 2012 (4), 2011 (9), 2010 (5), 2009 (5), 2008 (6), 2007 (7), 2006 (5)
Eastern Asia Society for Transportation Studies Conference	2005 (2)
International Conference of Chinese Transportation Professionals	2011 (3)
International Conference on Automotive Engineering	2014 (1)
International Conference on Maintenance and Rehabilitation of Pavements and Technological Control	2009 (5)
International Conference on Transport Infrastructures	2010 (2)

International IEEE Conference on Intelligent Transportation Systems	2013 (4), 2011 (1), 2010 (3), 2009 (3), 2008 (3)
IEEE Forum on Integrated and Sustainable Transportation Systems	2011 (7)
IEEE Intelligent Vehicle Symposium	2015 (2), 2014 (1), 2012 (1), 2011 (1)
IEEE International Conference on Communications	2010 (1)
Transportation, Land Use, Planning, and Air Quality Conference	2007 (1)
World Congress of the International Federation of Automatic Control	2014 (1), 2010 (2)

[a] Year of review, [b] Number of papers

Research Proposal Reviews

National Center for Sustainable Transportation	2014[a] (1[b])
National Institute for Transportation & Communities	2012 (7)
National Science Foundation	2012 (1), 2010 (17)
New Zealand Ministry of Science and Innovation	2012 (2)
Oregon Transportation Research & Education Consortium	2013 (1), 2009 (1), 2007 (1)

[a] Year of review, [b] Number of proposals

Others

2012 – Present
Member, Transportation Working Group
Chancellor's Committee on Sustainability
University of California, Riverside

2011 – Present
Associate editor, IEEE Intelligent Transportation System Magazine

2008 – Present
Editorial board member, The Open Transportation Journal

2010 – 2012
Paper review co-chair, Transportation and Air Quality Committee
Transportation Research Board

2008 – 2011
Technical advisory committee member, Truck Trip Generation Study
National Association of Industrial and Office Properties

June 2010
Organizing committee member, 2010 IEEE Intelligent Vehicles Symposium

June 2010
Thesis committee member for Sindhura Mandava
Master of Science (Electrical Engineering)
University of California, Riverside

August 2009
Peer reviewer for the U.S. Environmental Protection Agency on the report "Draft MOVES2009 highway vehicle population and activity data"

March 2009
Dissertation committee member for Weihua Zhu
Ph.D. (Electrical Engineering)
University of California, Riverside

June 2008	Thesis committee member for Henry Chen Master of Science (Electrical Engineering) University of California, Riverside
March 2008	Thesis committee member for Oscar Servin Master of Science (Electrical Engineering) University of California, Riverside
2007 – Present	Member, Academic Committee College of Engineering-Center for Environmental Research and Technology University of California, Riverside
December 2006	Thesis committee member for Angelo Ledesma Master of Science (Electrical Engineering) University of California, Riverside
2004 – 2005	Advisor for Ohio Northern University team Ohio Student Asphalt Mixture Design Competition
December 2004	Instructor of Engineering Pathways Project for middle school students Ohio Northern University
2003 – 2004	Graduate student senator of Department of Civil Engineering University of Mississippi
March 2004	Judge in 16th Annual Region VII Science and Engineering Fair University of Mississippi
March 2003	Judge in 15th Annual Region VII Science and Engineering Fair University of Mississippi
March 2002	Judge in 14th Annual Region VII Science and Engineering Fair University of Mississippi

HONORS, AWARDS, AND SCHOLARSHIPS

January 2013	Excellent service as a paper review co-chair Transportation and Air Quality Committee, Transportation Research Board
February 2007	Pyke Johnson Award Nominee Transportation and Air Quality Committee, Transportation Research Board
May 2006	Honorable mention, National P3 Design Competition for Sustainability U.S. Environmental Protection Agency
March 2005	First paper award, 2005 International Symposium on Pavement Recycling Conference Organizing Committee
May 2004	The National Dean’s List

April 2004	Chi Epsilon National Civil Engineering Honor Society
Spring 2004	Dissertation fellowship University of Mississippi
Summer 2003	Summer research fellowship University of Mississippi
July 2003	Graduate student scholarship Air & Waste Management Association, Mississippi Chapter
March 2003	Phi Kappa Phi Honor Society
March 2002	Runner-up award, 2002 Graduate Student Paper Competition Institute of Transportation Engineers, Southern District
September 1999	Academic scholarship Asian Institute of Technology

TEACHING EXPERIENCE

2008 – Present	Invited Lecturer Department of Electrical Engineering, University of California, Riverside EE246: Intelligent Transportation Systems
Aug 2004 – Apr 2005	Visiting Assistant Professor Department of Civil Engineering, Ohio Northern University CE351: Transportation Systems and Highway Engineering CE352: Traffic Engineering CE353: Pavement Engineering CE415: CE Senior Design Project CE471: Urban and Transportation Planning CE203: Surveying
Aug 2004 – Apr 2005	Instructor Department of Civil Engineering, University of Mississippi ENGR207: Engineering Graphics
Jan 2002 – May 2004	Graduate Teaching Assistant Department of Civil Engineering, University of Mississippi CE481: Transportation Engineering CE315: Civil Engineering Materials CE417: Construction Engineering and Management ENGR207: Engineering Graphics CE455: Senior Design I CE456: Senior Design II

ORGANIZATIONAL CONFLICT OF INTEREST CERTIFICATE

Customer: U.S. Environmental Protection Agency

Contractor: ICF Incorporated, LLC, 9300 Lee Highway, Fairfax, VA 22031

Prime Contract: EP-C-12-011

Subcontract/Peer Reviewer: Kanok Boriboonsomsin

In accordance with EPAAR 1552.209-70 through 1552.209-73, Subcontractor/Consultant certifies to the best of its knowledge and belief, that:

___x____ No actual or potential conflict of interest exists.

_______ An actual or potential conflict of interest exists. See attached full disclosure.

Subcontractor/Consultant certifies that its personnel, who perform work on this contract, have been informed of their obligations to report personal and organizational conflict of interest to Contractor and Subcontractor/Consultant recognizes its continuing obligation to identify and report any actual or potential organizational conflicts of interest arising during performance under referenced contract.

____
Subcontractor/Consultant

______6/24/2015______________
Date

RANDALL GUENSLER, Ph.D.
Professor
Georgia Institute of Technology
School of Civil and Environmental Engineering

I. EARNED DEGREES

Ph.D.	1993	University of California, Davis	Civil Engineering
M.S.	1989	University of California, Davis	Civil/Environmental Engineering
B.S.	1985	University of California, Davis	Individualized Engineering

II. EMPLOYMENT

2005-Present	Professor	Georgia Institute of Technology Civil and Environmental Engineering
2014-Present	Associate Director	National Center for Sustainable Transportation University Transportation Center
2013-Present	Adjunct Professor	Georgia Institute of Technology City and Regional Planning
1996-2012	Adjunct Professor	Georgia Institute of Technology Public Policy
1999-2005	Associate Professor	Georgia Institute of Technology Civil and Environmental Engineering
1994-1999	Assistant Professor	Georgia Institute of Technology Civil and Environmental Engineering
1992-1993	Lecturer	University of California, Davis Civil Engineering
1991-1994	Post Graduate Researcher	University of California, Davis Institute of Transportation Studies
1989-1993	Air Resources Eng. Assoc.	California Air Resources Board Executive Office, Transportation Programs
1987-1992	Teaching Assistant	University of California, Davis Civil Engineering
1989-1991	Graduate Research Asst.	University of California, Davis Civil Engineering
1987-1989	Air Resources Eng. Assoc.	California Air Resources Board Compliance Division, Compliance Assistance
1985-1987	Air Resources Engineer	California Air Resources Board Compliance Division, Program Evaluation

III. TEACHING

A. INDIVIDUAL STUDENT GUIDANCE

Ph.D. Student Guidance

Graduated:

C. Toth
Co-advisor with Dr. Jorge Laval
Completion: Fall 2014
Starting Semester: Fall 2009
Research: Empirical Study of the Effect of Offramp Queues on Freeway Mainline Traffic Flow

V. Elango
Co-advisor with Dr. Michael Rodgers
Completion: Fall 2014
Starting Semester: Spring 2003
Research: Modeling Activity Participation Using Longitudinal Travel Variability and Spatial Activity Extent

S. Khoeini
Co-advisor with Dr. Michael Hunter
Completion: Spring 2014
Starting Semester: Spring 2011
Research: Demographic Modeling of HOT System Users and Non-users
Current Position: Post-Doc Researcher, Georgia Tech

Y. Xu
Completion: Spring 2010
Starting Semester: Fall 2006
Research: Estimating Effective Sample Size for Longitudinal Travel Behavior Studies
Current Position: Research Engineer II, Georgia Tech

C. Feng
Completion: Spring 2007
Starting Semester: Fall 2001
Research: Transit Bus Load-Based Modal Emission Rate Model Development
Current Position: Transportation Engineer. Massachusetts DOT

J. Jun
Completion: Fall 2006
Starting Semester: Winter 2002
Research: Potential Crash Exposure Measures Based on GPS-Observed Driver Behavior Activity Metric
Current Position: Transportation Engineer. Virginia DOT

J. Ko
Co-Advisor with Michael Hunter
Completion: Summer 2006
Starting Semester: Fall 2001
Research: Measurement of Freeway Traffic Quality Using GPS-Equipped Vehicles
Current Position: Director, Megacity Research Center, The Seoul Institute

S. Yoon
Co-Advisor with Dr. Michael O. Rodgers
Completion: Summer 2005
Starting Semester: Fall 2002
Research: Development of Heavy-Duty Vehicle and Bus Activity and Estimation Methods for Real-World Emissions Rates
Current Position: Air Resources Engineering Associate. California Air Resources Board

H. Li
Completion: Fall 2004
Starting Semester: Fall 2000
Research: Morning Commute Route Choice Behavior using Global Positioning Systems and Multi-Day Travel Data
Current Position: Manager, United Parcel Service

J. Granell
Completion: Fall 2002
Starting Quarter: Winter 1997
Research: Model Year Distribution and Vehicle Technology Composition of the Onroad Fleet as a Function of Vehicle Registration Data and Site Location Characteristics
Current Position: Transportation Engineer. Federal Transit Administration

H. Ikwut-Ukwa
Completion: Spring 2001
Starting Quarter: Fall 1996
Research: Advances in Vehicle Emissions Modeling: Development of a Methodology for the Kinematic Acquisition of Roadway Grade Data
Current Position: Transportation and Environmental Specialist, Parsons Transportation Group, Inc.

J. Wolf
Completion: Summer 2000
Starting Quarter: Fall 1996
Research: Using GPS Data Loggers to Replace Travel Diaries in the Collection of Travel Data
Current Position: President, GeoStats Consulting Inc.

M. Thornton
Completion: Summer 2000
Starting Quarter: Fall 1996
Research: Modal Vehicle Activity on Freeways and Freeway On-Ramps: An Assessment of the Oxides of Nitrogen Emissions Impacts Resulting from Changes in Vehicle Operating Mode Due to Ramp Metering Systems
Current Position: Senior Engineer, National Renewable Energy Laboratory

S. Hallmark
Completion: Fall 1999
Starting Quarter: Fall 1995
Research: Analysis and Prediction of Individual Vehicle Activity for Microscopic Traffic Modeling
Current Position: Associate Professor, Iowa State University

D. Ahanotu
Completion: Summer 1999
Starting Quarter: Spring 1995
Research: Heavy-Duty Vehicle Weight and Horsepower Distributions: Measurement of Class-Specific Temporal and Spatial Variability
Current Position: Consultant, Cambridge Systematics

C. Grant
Completion: Summer 1998
Starting Quarter: Fall 1994
Research: Modeling Speed/Acceleration Profiles on Freeways
Current Position: Professor and Associate Dean, Embry-Riddle University

W. Bachman
Co-advisor with Dr. Wayne Sarasua
Completion: Fall 1997
Starting Quarter: Winter 1995
Research: A GIS-Based Modal Emissions Model
Current Position: Principal, GeoStats Consulting Inc.

O. Tomeh
Completion: Summer 1996
Starting Quarter: Fall 1994
Research: Source Apportionment of the On-Road Fleet
Current Position: Consultant, Booz Allen & Hamilton Inc.

In Process:

A. Sheikh
Scheduled Completion: Spring 2015
Starting Semester: Fall 2011
Research: High Occupancy Toll Lane Demand Elasticity

F. Castrillon
Co-advisor with Dr. Jorge Laval
Scheduled Completion: Spring 2015
Starting Semester: Fall 2011
Research: Bus Network Performance and Mode Choice

G. Schwaiger
Co-advisor with Dr. Michael Hunter
Scheduled Completion: Spring 2015 (part-time)
Starting Semester: Fall 2007
Research: Vehicle-to-Vehicle Communications Efficiency

A. Grossman
Scheduled Completion: Spring 2016
Starting Semester: Fall 2012
Research: Demographic and Land Use Considerations in Sidewalk Infrastructure Management

H. Liu
Co-advisor with Dr. Michael Rodgers
Scheduled Completion: Fall 2016
Starting Semester: Fall 2013
Research: MOVES-Matrix Implementation for Transportation Project-Level Evaluation

R. Donahey
Scheduled Completion: Spring 2017
Starting Semester: Fall 2014
Research: TBD

H. Li
Scheduled Completion: Spring 2017
Starting Semester: Fall 2014
Research: TBD

<u>Research Engineer Supervision</u>

Y. Xu	Development of a GHG Emissions Calculator Incorporating Electric Vehicle Options (FTA) Analysis of High-Resolution Instrumented Vehicle and Travel Diary Data (GDOT) Research Engineer II (2012-Present)
V. Elango	Commuter Choice and Value Pricing Insurance Incentive Program (Commute Atlanta) Research Engineer I (2007-Present)
H. Li	Commuter Choice and Value Pricing Insurance Incentive Program (Commute Atlanta) Research Engineer II (2004-2007)
S. Yoon	RARE Heavy Duty Diesel Vehicle Modal Emissions Model (HDDV-MEM) Research Engineer II (2005)
J. Ogle	Commuter Choice and Value Pricing Insurance Incentive Program (Commute Atlanta) Research Engineer II (2004-2005), Research Engineer I (2001-2004)

Service as a Dissertation Opponent:

E. Ericsson	Urban Driving Patterns - Characterisation, Variability, and Environmental Implications Lund Institute of Technology. Lund, Sweden. September 2000

Post-Doctoral Fellow Guidance

G. Macfarlane	Sustainable Transportation Education Program Development, 2014
S. Khoeini	Socio-spatial Analysis of Carpool Activity, 2014
Y. Xu	School Bus Emissions Reductions and Traffic Count Accuracy Assessments, 2011-2012
Z. Peng	Refinement of Parking Turnover Study Methods, 1996

M.S. Thesis Students:

Y. Aurora	Recycling of Lithium Ion Batteries, Environmental Engineering, Fall 2014
K. Colberg	Bluetooth Work Zone Applications, Spring 2013
D. Duarte	Change in Vehicle Characteristics Following the I-85 HOV-to-HOT Conversion, Spring 2013
K. Kamiya	Vision-Based Detection-Tracking Surveillance Systems for Counting Vehicles, Fall 2012
S. Zinner	Bluetooth Systems Integration, Fall 2012
K. Smith	Carpool Vehicle Occupancy by Vehicle Type, Fall 2011
C. Rome	School Bus Anti-Idle Intervention Effectiveness, Summer 2011
K. D'Ambrosio	HOV-to-HOT Occupancy Data Collection Methods, Summer 2011
G. Shafi	CALINE-Grid Link Screening Criteria for Conformity Analysis, Spring 2008
J. Lee	Comparison of GPS-Equipped Vehicles and ITS Data for Estimation of Freeway Speed, Spring 2007
T. Udell	Cost-Effectiveness of Market Niche Natural Gas Conversion, Winter 1998
D. Drake	Trip Generation and Parking Turnover at Five Urban Malls, Spring 1997

M.S. Dual Degree Thesis Students:

G. Maier	Mixed-use Development Impacts on MARTA Rail Transit Demand, Scheduled Completion Fall 2014
G. Li	BRT Implementation in Atlanta, Summer 2014
A. Frackelton	Automated Sidewalk Quality Assessment System, Fall 2013
M. Roell	Transit Operation Efficiency on HOT Lanes, Fall 2012
L. Zuyeva	Equity Issues in HOV-to-HOT Conversion on I-85N in Atlanta, Spring 2009
D. Kall	MOBILE-Matrix Element of the Project-Level Conformity Screening Tool, Summer 2008
T. Trudell	Issues in Transit and 'Affordable' Housing for Metro Atlanta's Aging Population, Summer 2008
K. Zuehlke	Spatial Analysis of Employer-Based Commute Options Program Participation, Fall 2007
C. Pastore	Impact of School Schedules on Travel Behavior, Spring 2005
S. Lee	Residential Density Effects on Atlanta Tripmaking, Spring 2003
R. Hartz	Lessons in Adapting United States I&M Programs in Mexico City, Summer 2001
J. Pritchett	A Comparison of STAMINA and TNM (Traffic Noise Model), Fall 1999

M.S. Special Research Problems

J. Cruz	Sustainable Transportation Curricula Development, Fall 2014
A. Grossman	Demographic and Land Use Considerations for Sidewalks, Summer 2014
A. Wang	Sidewalk Outreach Planning, Spring 2014
G. Cernjul	MOVES-Matrix Emissions Modeling, Fall 2013
J.H. Hong	Estimating Induced Travel Using the SMITE-ML Model, Spring 2011
G. Chu	Potential for Urban Scale Vehicles in Metropolitan Atlanta, Spring 2011
S. Vedala	HOV-to-HOT Changes in Use Demographic Characteristics, Spring 2011
N. Wood	Commercial Instrumented Vehicle Activity, Spring 2010
P. Blaiklock	Design of a Portable Loop Detector, Spring 2010
V. Pandey	CALINE-Grid Module of the Georgia Project Conformity Screening Tool, Spring 2008
J.I. Nelson	Accessibility Analysis of Parking, Transit, and Pedestrian Facilities at Georgia Tech, Spring 2007
S. Mergelsberg	Acceptable Commute Times, Fall 2002
J. Williams	Current State Regulatory Support for Pay-as-You-Drive Insurance, Spring 2002
T. Orawan	Consumer Response Issues with OBD Systems, Fall 2001
P. Ovasith	Link Screening in Regional Applications of Microscale Dispersion, Summer 2001
S. Desai	LabVIEW Code for a Comprehensive Vehicle Test Package, Fall 2000
R. Thittai	Spatial and Temporal Accuracy Issues in GPS, Fall 1999
A. Ma	GIS, Spatial Data Analysis, and Wetlands Management, Spring 1998
M. Tai	Video/GPS Integration for Land Use Classification, Spring 1998

B. McHugh	A Comparison of Parking Turnover Data Collection Methods, Spring 1998
A. Ammer	MEASURE Website Development, Winter 1998
C. Heggen	Agency Guidance on Implementing NEPA, Winter 1998
E. Pihl	Integrating Land Use Models into a GIS Framework, Spring 1997
B. Curls	Implementation of the TransNet Service, Fall 1996
A. Pickard	A MOBILE5a Sensitivity Analysis of Bus Emissions, Fall 1996
W. Bain	Weigh-in-Motion Equipment Operations, Spring 1996
D. Kasbo	Parking Turnover Study Methodology, Fall 1995

MBA Special Projects

R. Langdale	Transportation Telematics Market Analysis, Spring 2009
S. Kauffman	Transportation Telematics Market Analysis, Spring 2009

Undergraduate Thesis Students

K. Edwards	Error Analysis of Undergraduate-Collected Field Data, Spring 2013

Undergraduate Research Students

H. Chen	Cost Effectiveness of Heavy-duty Truck Control Strategies, Fall 2014-present
R. Liu	Tree Encroachment (and assistance with Pedestrian Count Methods), Fall 2013 - present
C. Paton	Sidewalk Sentry Tablet Testing and Performance Assessment, Spring 2014 -Spring 2014
R. Guissou	Tree Encroachment (and assistance with Pedestrian Count Methods), Fall 2013 -Spring 2014
B. Lempke	Sidewalk Sentry Pedestrian Count Methods and Tree Encroachment, Fall 2013
S. Williams	Sidewalk Sentry Pedestrian Count Methods and Tree Encroachment, Fall 2013
R.J. Daniell	Sidewalk Sentry Pedestrian Count Methods and Tree Encroachment, Fall 2013
V. Kemmegni	Sidewalk Sentry Outreach, Summer 2013
M. Cosner	Sidewalk Sentry Outreach, Summer 2013
R. Thamm	Sidewalk Sentry Machine Shop Activities, Summer 2013 - Fall 2013
K. Randall	Sidewalk Sentry Data Collection Manual Development, Summer 2013
A. Wang	Sidewalk Sentry Survey Data, Fall 2013
G. Amir	Positive Identification of Vehicle Occupancy, Fall 2012
E. Ingles	Assessment of Automated License Plate Reader Angle on Decoding Accuracy, Fall 2012
M. Thumaty	Bluetooth Technology Assessment, Summer 2012 to Fall 2012
Z. Drakhshandeh	Instrumented Bus Systems Management, Spring, Summer, Fall 2011 to Spring 2012
G. Rodgers	Vehicle Fleet Turnover in the Commute Atlanta Program, Spring 2008
C. Russell	Water Quality Modeling Lecture Material Development, Summer 2004
J. Davis	CORSIM Model Development for North Atlanta, Summer 2004
M. Williamson	Analysis of Employer Commute Options Survey Data, Fall 2003
D. Changeau	Analysis of Employer Commute Options Survey Data, Summer 2003
J. Swanson	Legal/Privacy Issues in Remote Vehicle ID and Instrumented Vehicle Data, Spring 2003
R. Lund	Web System for Transportation Journal Publications, Spring 2002
E. Cooper	NEPA Permitting Systems Evaluation, Fall 1999
J. Powell	Ramp Metering Speed/Acceleration Profile Research Plan, Spring 1999
K. Seo	Analysis of Douglas County Weigh Station Truck Surveys, Winter 1999
C. Conklin	EIS Multimedia Course Development, Spring 1997
K. Leopard	Annotated Bibliography of EIS Case Law, Spring 1997
A. Morales	Parking Data Collection Strategies, Fall 1996
S. Lopez	Parking Research, Fall 1996
S. Patel	Parking Research, Fall 1996
M. Gooseff	Transportation/Air Quality Conformity, Spring 1996
P. Sepulveda	Transportation/Air Quality Research, Fall 1995
A. Smith	Introduction to GIS and ARC/INFO, Winter 1994

Programmer Guidance

Ravikant Gupta	Fuel and Emissions Calculator (Python), CS, 2014-Present
Alper Akanser	Commute Warrior App (Android), COC, 2014-Present
Komal Poddar	Commute Warrior App (iOS), ECE, 2014
Ramik Sadana	Commute Warrior App (Android), COC, 2012-2014

B. OTHER TEACHING ACTIVITIES

Curriculum Development

CE4803, Boulevard of Broken Sidewalks (2014) - This is a new undergraduate honors course that explores how sidewalks, as transportation infrastructure, affect urban life. This course couples literature review and class discussion with field research and data analysis to explore the importance of sidewalks within the context of planning, engineering, and public policy. Students investigate sidewalk conditions, usage, and accessibility in the City of Atlanta by collecting data on sidewalk conditions and conducting manual and automated pedestrian counts. The class focuses on accessibility and equity in transportation while also learning about trip making and transportation mode choice modeling methods.

CE6625, Transportation Energy and Air Quality (1996-Present) - This course focuses on the energy air quality impacts of transportation, from vehicle activity, fuel consumption, and emissions estimation. Students use case studies to explore relationships between transportation demand, greenhouse gas and pollutant emissions, and air quality and learn to use the latest analytical techniques and models.

CE4620, Environmental Impact Assessment (1994-present) - The Environmental Impact Assessment course offered serves as an undergraduate service course on environmental policy. This course overviews environmental law, agency regulation, and policy-making fundamentals, but also focuses on policy and technical analysis. Students learn fundamental principles and scientific limitations of impact assessment modeling (air quality, noise, etc.).

CE8102, Publishing Transportation Research on the Internet (1996-1999) - Drs. Leonard and Guensler developed a two-unit graduate course that provides students with a comprehensive overview on World Wide Web publishing. The course explored basic tools used in Internet publication. Students created their own home pages and published research papers on the Web. The course was discontinued when web development tools advanced to the point where specialized training was no longer necessary.

Multimedia Courseware

Guensler, R. (2004). TRANS/AQ. Transportation and Air Quality. Courseware CD-ROM. Georgia Institute of Technology. August (1996-2004, replaced by Internet site).

Guensler, R. (2004). EIA 2002. Environmental Impact Assessment. Courseware CD-ROM. Georgia Institute of Technology. April (1998-2004, replaced by Internet site).

Participation in Teaching Development Programs

Class of 1969 Teaching Fellow (1996) - Dr. Guensler participated in the Georgia Institute of Technology Class of 1969 Teaching Fellows program to learn more about effective teaching and to develop improved classroom techniques.

C-SPAN in the Classroom Fellow (1996) - Dr. Guensler was the first engineer selected to participate in the C-SPAN in the Classroom Fellowship Program. The program focused on the use of C-SPAN video materials (such as congressional testimony and debate) in classroom teaching exercises.

Continuing Education Courses

Air Quality Impacts of Urban Transportation (1997-2002). Dr. Guensler developed a three-day continuing education course on transportation and air quality. The course focused on vehicle activity and emission rates, emission modeling, emission inventory development, regional air quality modeling, and microscale impact analysis. Hands-on modeling in the computer lab included an exercise in microscale dispersion analysis). The course was offered at the University of California, Davis, in February 1997, and at Georgia Tech in September 1997, 1998, 1999, 2000, and 2002.

IV. SCHOLARLY ACCOMPLISHMENTS

A. PUBLISHED BOOKS AND PARTS OF BOOKS

1. Suh, W., D. Henclewood, A. Guin, R. Guensler, M. Hunter, and R. Fujimoto (submitted 2014). “Dynamic Data Driven Transportation Systems.” *Dynamic Data Driven Application Systems*, Springer-Verlag.
2. Bachman, W., W. Sarasua, S. Hallmark, and R. Guensler (2000). “Modeling Regional Mobile Source Emissions in a Geographic Information System Framework.” Geographic Information Systems in Transportation Research. Elsevier Science. New York, NY. 2000.
3. Guensler, R. (2000). “Motor Vehicle Emissions Control.” Macmillan Encyclopedia of Energy. 2000.
4. Guensler, R. (2000). “Traffic Flow Improvement.” Macmillan Encyclopedia of Energy. 2000.

5. Fomunung, I., S. Washington, and R. Guensler (1999). "Comparison of MEASURE, and MOBILE5a Predictions with Laboratory Measurements of Vehicle Emission Factors." Transportation Planning and Air Quality IV. Arun Chatterjee, Ed. American Society of Civil Engineers. New York, NY. 1999.
6. Guensler, R. (1998). "Increasing Vehicle Occupancy in the United States." L'Avenir Des Deplacements en Ville (The Future of Urban Travel). Odile Andan, et al., Eds. Laboratoire d'Economie des Transports. Lyon, France. Tome 2. pp. 127- 155. 1998.
7. Guensler, R., W. Bachman and S. Washington (1998). "An Overview of the MEASURE GIS-Based Modal Emissions Model." Transportation Planning and Air Quality III. Tom Wholley, Ed. American Society of Civil Engineers. New York, NY. pp. 51-70. 1998.
8. Guensler, R., and D. Sperling (1994). "Congestion Pricing and Motor Vehicle Emissions: An Initial Review." Curbing Gridlock: Peak Period Fees to Relieve Traffic Congestion, Volume 2, pp. 356-379. National Academy Press. Washington, DC. 1994.
9. Guensler, R. (1993). "Data Needs for Evolving Motor Vehicle Emission Modeling Approaches." Transportation Planning and Air Quality II. Paul Benson, Ed. American Society of Civil Engineers. New York, NY. 1993.
10. Washington, S., R. Guensler, and D. Sperling (1993). "Emission Impacts of Intelligent Vehicle Highway Systems." Transportation Planning and Air Quality II. Paul Benson, Ed. American Society of Civil Engineers. New York, NY. 1993.

B. REFEREED PUBLICATIONS

Articles in Refereed Archival Journals

1. Liu, H., Y. Xu, M.O. Rodgers, and R. Guensler (submission pending). A Comparative Analysis of Life-cycle Energy and Emissions for Intercity Passenger Transportation in the U.S. for Regional Aviation, Intercity Bus, and Personal Vehicles. Transport Policy.
2. Xu, Y., H. Liu, and R. Guensler (submission pending). Emissions Impact of HOV to HOT Lane Conversions: An Atlanta, Georgia Case Study. Journal of the Air and Waste Management Association.
3. Xu, Y., F. Gbologah, D. Lee, H. Liu, M.O. Rodgers, and R. Guensler (submitted). Assessment of Alternative Fuel and Powertrain Transit Bus Options using Real-world Operations Data: Life-cycle Fuel and Emissions Modeling. Applied Energy.
4. Guensler, R., F. Castrillon, K. D'Ambrosio, D. Duarte, V. Elango, A. Guin, M. Hunter, S. Khoeini, J. Laval, L. Peesapati, M. Roell; A. Sheikh, K. Smith, and C. Toth (submitted). Vehicle and Person Throughput Analysis for the Atlanta I-85 HOV-to-HOT Conversion. Case Studies on Transportation Policy.
5. Pearre, N., W. Kempton, R. Guensler, and V. Elango (submitted). "Electric Vehicle Battery Size, Recharge Rate, and Charging Locations: Jointly Meeting Travel Requirements." Transportation Research C.
6. Liu, H., Y. Xu, R. Guensler, and M.O. Rodgers (in Press). A Proposed Method for Developing Vehicle Classification Input for Project-Level MOVES Analysis. Transportation Research Record. Number xxxx. pp. xx-xx. National Academy of Sciences. Washington, DC. 2015.
7. Sheikh, A., A. Misra, and R. Guensler (in Press). High Occupancy Toll Lane Decision Making: Income Effects on Atlanta's I-85 Express Lanes. Transportation Research Record. Number xxxx. pp. xx-xx. National Academy of Sciences. Washington, DC. 2015.
8. Elango, V. and R. Guensler (2014). "Collection, Screening, and Evaluation of Vehicle Occupancy Data." Transportation Research Record. Number 2470. pp. 142-151. National Academy of Sciences. Washington, DC. 2014.
9. Sheikh, A., A. Guin, and R. Guensler (2014). "Value of Travel Time Savings: Evidence from Atlanta's I-85 Express Lanes." Transportation Research Record. Number 2470. pp. 161-168. National Academy of Sciences. Washington, DC. 2014.
10. Castrillon, F., M. Roell, S. Khoeini, and R. Guensler (2014). "The I-85 HOT Lane's Impact on Atlanta's Commuter Bus and Vanpool Occupancy." Transportation Research Record. Number 2470. pp. 169-177. National Academy of Sciences. Washington, DC. 2014.
11. Palinginis, E., M.W. Park, K. Kamiya, J. Laval, I. Brilakis, and R. Guensler (2014). "Full-Body Occlusion Handling and Density Analysis in Traffic Video-Surveillance Systems." Transportation Research Record. Number 2460. pp. 58-65. National Academy of Sciences. Washington, DC. 2014.

12. Khoeini, S. and R. Guensler (2014). “Socioeconomic Assessment of the Atlanta I-85 HOV-to-HOT Conversion.” Transportation Research Record. Number 2450. pp. 52-61. National Academy of Sciences. Washington, DC. 2014.

13. Colberg, K., W. Suh, J. Anderson, S. Zinner, A. Guin, M. Hunter, and R. Guensler (2014). “Lane Bias Issues in Work Zone Travel Time Measurement and Reporting.” Transportation Research Record. Number 2458. pp. 78-87. National Academy of Sciences. Washington, DC. 2014.

14. Gbologah, F., Y. Xu, M. Rodgers, and R. Guensler (2014). “Demonstrating a Bottom-up Framework for Evaluating Energy and Emission Performance of Various Electric Rail Transit Options.” Transportation Research Record. Number 2428. pp. 10-17. National Academy of Sciences. Washington, DC. 2014.

15. Suh, W., A. Guin, S. Zinner, K. Colberg, M. Hunter, and R. Guensler (2014). “Marginal Benefit of Adding Antennas to Bluetooth Sensor Arrays in Freeway Travel Time Data Collection.” Journal of Transportation Engineering. Volume 140, Issue 12. December 2014.

16. Khoeini, S., and R. Guensler (2014). “Using Vehicle Value as a Proxy for Income: A Case Study on Atlanta’s I-85 HOT Lane.” Research in Transportation Economics. Volume 44. Issue C. pp. 33-42. June 2014.

17. Toth, C., W. Suh, V. Elango, R. Sadana, A. Guin, M. Hunter, and R. Guensler (2013). “Tablet-Based Traffic Counting Application Designed to Minimize Human Error.” Transportation Research Record. Number 2339. pp. 39-46. National Academy of Sciences. Washington, DC. 2013.

18. Elango, V., S. Khoeini, Y. Xu, and R. Guensler (2013). “Longitudinal GPS Travel Data and Breach of Privacy via Enhanced Spatial and Demographic Analysis.” Transportation Research Record. Number 2354. pp. 86-98. National Academy of Sciences. Washington, DC. 2013.

19. Xu, Y., V. Elango, and R. Guensler (2013). “Idle Monitoring, Real-time Intervention, and Emissions Reductions from Cobb County School Buses.” Transportation Research Record. Number 2340. pp. 59-65. National Academy of Sciences. Washington, DC. 2013.

20. Frackelton, A., A. Grossman, E. Palinginis, F. Castrillon, V. Elango, R. Guensler (2013). “Measuring Walkability: Development of an Automated Sidewalk Quality Assessment Tool.” Journal of Suburban Sustainability. Volume 1, Number 1, Article 4. March 2013.

21. Suh, W., D. Henclewood, A. Greenwood, A. Guin, R. Guensler, M. Hunter (2013). “Modeling Pedestrian Crossing Activities in an Urban Environment using Microscopic Traffic Simulation.” Simulation: Transactions of the Society for Modeling and Simulation International. Volume 89, Number 2, pp. 213-224. February 2013.

22. Jeon, C., A. Amekudzi, and R. Guensler (2013). Sustainability Assessment at the Transportation Planning Level: Performance Measures and Indexes. Transport Policy, Volume 25, pp. 10-21. January 2013.

23. Castrillon, F., A. Guin, R. Guensler, and J. Laval (2012). “Comparison of Modeling Approaches for the Imputation of Intelligent Transportation System VDS Data.” Transportation Research Record. Number 2308, pp. 138-147. National Academy of Sciences. Washington, DC. 2012

24. Khoeini, S., R. Guensler, M.O. Rodgers, and V. Elango (2012). “Sensitivity of Commuters’ Demographic Characteristics to License Plate Data Collection Specifications: A Case Study of the I-85 HOV-to-HOT Project in Atlanta, GA.” Transportation Research Record. Number 2308, pp. 37-46. National Academy of Sciences. Washington, DC. 2012.

25. Jun, J., J. Ogle, and R. Guensler (2012). “A Pilot Study to Compare the Driving Habits of Crash-Involved Versus Non-Crash Involved Older Drivers from GPS-Instrumented Vehicles.” ITE Journal. pp. 42-47. July 2012.

26. Seshasayee, B., M. Hunter, R. Fujimoto, R. Guensler, K. Schwan, H.K. Kim, J. Sirichoke, and W. Suh (2011). “On the Resilience of Ad Hoc Distributed Simulation of Surface Transportation Systems with Unreliable Communications.” Journal of Algorithms and Computation Technology, Special Issue on Dynamic Data-Driven Application Systems. Volume 5, Number 4, pp. 531-544. December 2011.

27. Pearre, N., W. Kempton, R. Guensler, and V. Elango (2011). “Electric Vehicles: How Much Range is Required for a Day’s Driving?” Transportation Research C. Volume 19, Issue 6, pp. 1171-1184. December 2011.

28. Jun, J., J. Ogle, and R. Guensler (2011). “An Enhanced Method to Compare the Driving Habits of Crash-Involved versus Non-Crash-Involved Older Drivers.” Transportation Research C. Volume 19, Issue 4, pp. 569-578. August 2011.

29. Ko, J., Guensler, R., and Hunter, M. (2010). “Analysis of Effects of Driver/Vehicle Characteristics on Acceleration Noise Using GPS-Equipped Vehicles.” Transportation Research Part F. Volume 13, Issue 1, pp. 21-31. January 2010.

30. Jeon, C.M., A. Amekudzi, R. Guensler (2010). "Evaluating Plan Alternatives for Transportation System Sustainability: Atlanta Metropolitan Region." International Journal of Sustainable Transportation. Volume 4, Number 4, pp. 227-247. July 2010.
31. Kall, D., R. Guensler, M.O. Rodgers, and V.S. Pandey (2009). "Effect of High Occupancy Toll Lanes on Mass Vehicle Emissions: Application to I-85 in Atlanta, Georgia." Transportation Research Record. Number 2123. pp. 88-96. National Academy of Sciences. Washington, DC. 2009.
32. Jun, J., and R. Guensler (2009). "Freeway Speed Stability Patterns Based on Instrumented Vehicle Data." ITE Journal on the Web. http://www.ite.org/itejournal/webarticles.asp. June 2009.
33. Ko, J., R. Guensler, and M. Hunter (2009). "Exploring the Relationship between Roadway Characteristics and Speed Variation." Transportation Research Record. Number 2092. pp. 1-10. National Academy of Sciences. Washington, DC. 2009.
34. Ko, J., M. Hunter and R. Guensler (2008). "Measuring Control Delay Components Using Second-by-Second GPS Speed Data." ASCE Journal of Transportation Engineering. Volume 134, Number 8. pp. 338-346. August 2008.
35. Guin, A., R. Guensler, and M. Hunter (2008). "Analysis of Reduction in Effective Capacities on High-Occupancy-Vehicle Lanes Related to Traffic Behavior." Transportation Research Record. Number 2065. pp. 47-53. National Academy of Sciences. Washington, DC. 2008.
36. Nelson, J.I., R. Guensler, and H. Li (2008). "A Geographic and Demographic Profile of Morning Rush Hour Commuters in Metropolitan Atlanta." Transportation Research Record. Number 2067, pp. 26-37. National Academy of Sciences. Washington, DC. 2008.
37. Jun, J., J. Ogle, and R. Guensler (2007). "Relationships between Crash Involvement and Temporal-Spatial Driving Behavior Activity Patterns: Use of Data for Vehicles with Global Positioning Systems." Transportation Research Record. Number 2019. pp. 246-255. National Academy of Sciences. Washington, DC. 2007.
38. Elango, V., R. Guensler, and J. Ogle (2007). "Day-To-Day Travel Variability in the Commute Atlanta Study." Transportation Research Record. Number 2014. pp. 39-49. National Academy of Sciences. Washington, DC. 2007.
39. Zuehlke, K. and R. Guensler (2007). "Employer Perceptions and Implementation of Commute Alternatives Strategies." Journal of Public Transportation. Volume 10, Number 4, pp. 171-194. 2007.
40. Ko, J., R. Guensler, and M. Hunter (2006). "Variability in Traffic Flow Quality Experienced by Drivers: Evidence from Instrumented Vehicles." Transportation Research Record. Number 1988. pp. 1-9. National Academy of Sciences. Washington, DC. 2006.
41. Jun, J., R. Guensler, and J. Ogle (2006). "Smoothing Methods Designed to Minimize the Impact of GPS Random Error on Travel Distance, Speed, and Acceleration Profile Estimates." Transportation Research Record. Number 1972. pp. 141-150. National Academy of Sciences. Washington, DC. 2006.
42. Yoon, S., H. Li, J. Jun, J. Ogle, R. Guensler, and M. Rodgers (2005). "Methodology for Developing Transit Bus Speed-Acceleration Matrices for Load-Based Mobile Source Emissions Models." Transportation Research Record. 1941. pp. 26-33. National Academy of Sciences. Washington, DC. 2005.
43. DeHart-Davis, L, and R. Guensler (2005). "Employers as Mediating Institutions for Public Policy: The Case of Commute Options Programs." Policy Studies Journal, Volume 33, Number 4, pp. 675-697. 2005.
44. Ogle, J., Guensler, R., and V. Elango (2005). "Commute Atlanta Value Pricing Program: Recruitment Methods and Travel Diary Response Rates." Transportation Research Record. Number 1931. pp. 28-37. National Academy of Sciences. Washington, DC. 2005.
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2. Akanser, A., Elango, V., A. Grossman, Y. Xu, and R. Guensler (abstract accepted). Sidewalk Scout: Crowdsourcing Android Application for Collecting Sidewalk Condition Data. 2015 Transportation Research Forum. Atlanta, GA. March 2015.

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23. Guensler, R. and M. Oliveira (2001). “Proposed 2001-2002 Vehicle Activity Monitoring Plan: Jefferson Street Particulate Matter Monitoring Station.” Prepared Under Contract for Louis Berger Associates. Trans/AQ, Inc. Atlanta, GA. September2001.
24. Lee, H., A. Russell, and R. Guensler (2001). “Receptor Modeling of Atlanta Supersite and Associated Particulate Matter Measurements.” Prepared Under Contract for Louis Berger Associates. Trans/AQ, Inc. Atlanta, GA. September2001.
25. Guensler, R. and M. Oliveira (2001). “Vehicle Activity Data Sources and Emissions Estimates for the Jefferson Street Particulate Matter Monitoring Site.” Prepared Under Contract for Louis Berger Associates. Trans/AQ, Inc. Atlanta, GA. September2001.
26. Guensler, R., A. Russell, and M. Oliveira (2001). “Atlanta Metropolitan Area Particulate Matter Monitoring Stations: Site Characterization.” Prepared Under Contract for Louis Berger Associates. Trans/AQ, Inc. Atlanta, GA. September2001.
27. Guensler, R., A. Russell, and H. Holm (2001). “Atlanta's Particulate Matter Monitoring Equipment and Data Collection.” Prepared Under Contract for Louis Berger Associates. Trans/AQ, Inc. Atlanta, GA. September2001.
28. Guensler, R. (2001). “Taxi-Transit Integration in the Atlanta Region: Analysis of Taxi Regulations across 40 Jurisdictions in the Atlanta Metropolitan Area.” Prepared Under Contract for the Georgia Regional Transportation Authority. Trans/AQ, Inc. Atlanta, GA. June 2001.
29. Guensler, R. (2001). “Taxi-Transit Integration in the Atlanta Region: Taxi Industry Participation in the Transportation Planning Process in Major Metropolitan Areas.” Prepared Under Contract for the Georgia Regional Transportation Authority. Trans/AQ, Inc. Atlanta, GA. June 2001.
30. Guensler, R. (2001). “Taxi-Transit Integration in the Atlanta Region: Review of Taxi/Transit Trips in the 1990 Onboard Transit Ridership Survey Data.” Prepared Under Contract for the Georgia Regional Transportation Authority. Trans/AQ, Inc. Atlanta, GA. April 2001.
31. Guensler, R., M. Thornton, M. O. Rodgers, K. Dixon, J. Pearson, W. Bachman, J. Leonard, and J. Daniel (2001). “Evaluation of Ramp Metering Impacts on Air Quality: The Atlanta I-75 Case Study.” Georgia Transportation Institute. Georgia Institute of Technology. Atlanta, GA. January 2001.
32. School of CEE Computer Committee (2001). “CEE Computing and Network Policy.” Georgia Transportation Institute. Georgia Institute of Technology. Atlanta, GA. February 2001.
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36. Wolf, J., R. Guensler, S. Washington, W. Sarasua, C. Grant, S. Hallmark, M. Oliveira, M. Koutsak, R. Thittai, R. Funk, J. Hsu (1999). “Development of a Comprehensive Vehicle Instrumentation Package for Monitoring Individual Tripmaking Behavior - Test Plans and Results” (GTI - R - 99004). Georgia Transportation Institute. Georgia Institute of Technology. Atlanta, GA. March 1999.
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41. Grant, C.D., R. Guensler and M. D. Meyer (1996). "Variability of Heavy-Duty Vehicle Operating Mode Frequencies for Prediction of Mobile Emissions." Environmental Protection Agency, Office of Research and Development. Research Triangle Park, NC.

42. Guensler, R., and L. Platte (1996). "Summary of the Activity of the Modeling Workgroup of the Office of Mobile Sources Technical Advisory Subcommittee" [of the Clean Air Act Advisory Committee]. US Environmental Protection Agency. Washington, DC. October 1996.

43. Guensler, R., and S. Washington, and D. Sperling (1994). "Modeling IVHS Emission Impacts, Volume 1, Background Issues and Modeling Capabilities" (UCD-ITS-RR-94-017). Institute of Transportation Studies. University of California, Davis. Davis, CA. August 1994.

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45. Koenig, B., C. Yee, R. Guensler, and P. P. Jovanis (1994). "Incidents, Lane Closures, and Rapid Incident Response: Congestion and Emissions Analysis" (UCD-ITS-RR-94-2). Prepared for the Mobile Sources Air Pollution Reduction Review Committee under the AB2766 Program. Institute of Transportation Studies, University of California, Davis, California 95616, March 1994.

46. Guensler, R. (1993). "Vehicle Emission Rates and Average Vehicle Operating Speeds." Dissertation. Department of Civil and Environmental Engineering, University of California, Davis. Davis, CA. 1993.

47. Guensler, R, S. Washington and D. Sperling (1993). "A Weighted Disaggregate Approach to Modeling Speed Correction Factors" (UCD-ITS-RR-93-6). Institute of Transportation Studies. University of California, Davis. Davis, CA. April 1993.

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51. Guensler, R., D. Sperling, and P. P. Jovanis (1991). "Uncertainty in the Emission Inventory for Heavy-Duty Diesel Powered Trucks" (UCD-ITS-RR-91-02). Institute of Transportation Studies, University of California, Davis. Davis, CA. June 1991.

52. AB2595 Heavy-Duty Truck Technical Advisory Group (1990). "Guidelines for Local Air Districts Considering Transportation Control Measures Directed at Heavy-Duty Truck Operations." California Air Resources Board, California Department of Business Transportation and Housing, and California Highway Patrol. Sacramento, CA. August 1990.

53. Guensler, R., V. Boothe, D. Lo, and J. Ungvarsky, U.S. Environmental Protection Agency Region IX, California Air Resources Board, South Coast Air Quality Management District, Bay Area Air Quality Management District, and San

Diego County Air Pollution Control District (1990). “Phase III State Implementation Plan Strategy Effectiveness Report for California Aerospace Coating Regulations”. USEPA, Region IX, Air Division. San Francisco, CA. June 1990.

54. Guensler, R. (1989). “Measuring Emissions of Potentially Toxic Organic Compounds from Municipal Wastewater Treatment Plants.” Thesis submitted in partial satisfaction of the requirements for the degree of Masters of Science in Civil/Environmental Engineering. Advisor: Daniel Chang. Department of Civil Engineering, University of California, Davis. Davis, CA. December 1989.

55. Guensler, R. (1987). “The Application of Bar Codes to Compliance Inspections (ARB/CD-87-01).” California Air Resources Board, Compliance Division, Sacramento, CA. September 1987.

Co-Authored California Air Resources Board Reports

1. California Air Resources Board, Office of Air Quality Planning and Liaison (1990). “California Clean Air Act Cost-Effectiveness Guidance.” Sacramento, CA. September 1990.

2. California Air Resources Board, Compliance Assistance Program (1990). “Surface Coating Operations, Aerospace Components, Technical Manual.” Sacramento, CA. August 1990.

3. California Air Resources Board, Compliance Assistance Program (1990). “Self-Inspection Handbook for Surface Coating of Aerospace Components.” Sacramento, CA. August 1990.

4. California Air Resources Board, Office of Strategic Planning (1990). “California Clean Air Act Transportation Requirements Guidance” (CCAA Guidance Paper #2). Sacramento, CA. February 1990.

5. California Air Resources Board, Compliance Division (1989). “An Evaluation of the San Diego County Air Pollution Control District Program.” Sacramento, CA. October 1989.

6. California Air Resources Board, Compliance Assistance Program (1989). “Self-Inspection Handbook for Solvent Cleaners.” Sacramento, CA. October 1989.

7. California Air Resources Board, Compliance Assistance Program (1989). “Self-Inspection Handbook for Surface Coating of Metal and Plastic Parts and Products.” Sacramento, CA. July 1989.

8. California Air Resources Board, Compliance Assistance Program (1989). “Solvent Cleaning Degreasing Applications, Technical Manual.” Sacramento, CA. July 1989.

9. California Air Resources Board, Compliance Assistance Program (1989). “Surface Coating Operations, Metal Parts and Products, Technical Manual.” Sacramento, CA. July 1989.

10. California Air Resources Board, Compliance Assistance Program (1988). “Self-Inspection Handbook for Gasoline Facilities.” Sacramento, CA. July 1988.

11. California Air Resources Board, Compliance Division (1988). “An Evaluation of the Bay Area Air Quality Management District Program.” Sacramento, CA 1988.

12. California Air Resources Board, Compliance Division (1987). “An Evaluation of the South Coast Air Quality Management District Program.” Sacramento, CA. 1987

13. California Air Resources Board, Compliance Division (1986). “An Evaluation of the Yolo-Solano County Air Pollution Control District Program.” Sacramento, CA. 1986

14. California Air Resources Board, Compliance Division (1986). “An Evaluation of the San Joaquin County Air Pollution Control District Program.” Sacramento, CA. 1986.

15. California Air Resources Board, Compliance Division (1985). “An Evaluation of the Fresno County Air Pollution Control District Program.” Sacramento, CA. 1985.

D. PRESENTATIONS (WITHOUT PROCEEDINGS)

1. Guensler, R., Y. Xu, A. Sheikh, H. Li, S. Khoeini, R. Donahey (2015) Atlanta I-85 HOT Lane Carpool Survey: Initial Analysis of Individual Questions. Presentation to the managed Lanes Committee at the 94th Annual Meeting of the Transportation Research Board. Washington, DC (60 attendees). January 2015.

2. Guensler, R. (2014). Transportation and the Five Pillars of Research and Industry. A Virtual Chat with Engineering Students of the South Carolina Governor's School for Science and Math (12 attendees). October 29, 2014

3. MacFarlane, G, J. Cruz, Y. Xu, and R. Guensler (2014). Education Development in Sustainable Transportation. TRB Committee for Waste Management and Resource Efficiency in Transportation (ADC60) Summer Workshop (30 attendees). New York, NY. June 18, 2014.
4. Hunter, M. and R. Guensler (2014). "GDOT Partnership with University Transportation Centers." Georgia Department of Transportation Lunch and Learn Series (10 attendees). Atlanta, GA. April 1, 2014.
5. Guensler, R. et al., (2014). "Atlanta's Managed Lane Experience." Congestion Pricing and Managed Lanes: 20 Years of Learning – Where have we been, where are we now, and where are we going? Presentation P14-7024, Workshop 164 (85 attendees). Washington, DC. January 12, 2014.
6. Guensler, R. et al., (2013). "Beyond Average Speeds and Travel Time: ITS and Real-Time High-Resolution Data." University of California, Davis Seminar (15 attendees). September 24, 2013.
7. Guensler, R. et al., (2013). "Atlanta's I-85 HOT Lane: Additional Items for Discussion." Transportation Research Board Congestion Pricing Summer Committee Meeting and Conference (25 attendees). Seattle, WA. July 11, 2013.
8. Guensler, R. et al., (2013). "Atlanta's I-85 HOT Lane: Performance Assessment." Transportation Research Board Congestion Pricing Summer Committee Meeting and Conference (40 attendees). Seattle, WA. July 10, 2013.
9. Guensler, R. (2013). "An Overview of the Automated Sidewalk Quality Assessment Program." Presentation to the CDC Built Environment Workgroup (10 attendees). Atlanta, GA, June 4, 2013.
10. Guensler, R. et al., (2013). "Beyond Average Speeds and Travel Time: ITS and Real-Time High-Resolution Data." Georgia Institute of Technology Transportation Research Seminar (40 attendees). April 3, 2013.
11. Guensler, R. (2013). "An Overview of the Automated Sidewalk Quality Assessment Program." Presentation to the Atlanta Regional Commission (15 attendees). Atlanta, GA, March 15, 2013.
12. Guensler, R. et al., (2013). I-85 HOV-to-HOT Corridor Performance Assessment. Transportation Research Board Freeway & Managed Lanes Operations Meeting and Conference (40 attendees). Atlanta, GA. June 2013.
13. Guensler, R. (2013). "An Overview of the Automated Sidewalk Quality Assessment Program." Presentation to the Midtown Neighborhood Association (10 attendees). Atlanta, GA, February 11, 2013.
14. Guensler, R. (2013). "An Overview of the Automated Sidewalk Quality Assessment Program." Presentation to Neighborhood Planning Unit F (25 attendees). Atlanta, GA, February 11, 2013.
15. Guensler, R. (2012). "An Update on HOV-to-HOT Research in Atlanta." Presentation to the US Environmental Protection Agency, Region IV (10 attendees). Washington, DC, January 26, 2012.
16. Guensler, R., P. Vu, et al. (2012). "Early Findings from Atlanta's I-85 Managed Lanes (P12-5914)." 91st Annual Meeting of the Transportation Research Board, Washington DC. January 2012.
17. Guensler, R. (2011). "An Update on HOV-to-HOT Research in Atlanta." Presentation to the Federal Highway Administration (20 attendees). Atlanta, GA, September 13, 2011.
18. Guensler, R. (2009). "An Overview of HOV-to-HOT Research in Atlanta." Presentation to the Transportation Research Board, Managed Lanes Committee, Research Subcommittee (15 attendees). Washington, DC, January 24, 2009.
19. Guensler, R. (2009). "Monitoring the Effectiveness of HOV-to-HOT Conversions." Presentation to the University of Minnesota Warren Lecture Series (40 attendees). Atlanta, GA, April 10, 2009.
20. Guensler, R. (2009). "HOT Lanes for Atlanta." Presentation to the Georgia Institute of Technology City Planning Seminar Series (20 attendees). Atlanta, GA, April 10, 2009.
21. Guensler, R. (2008). "Instrumented Vehicle Data for Transportation Planning, Operations, Safety, Emissions, and Health Impact Assessment." Presentation to the Atlanta Regional Commission Model Users Group (50 attendees). Atlanta, GA, May 30, 2008.
22. Guensler, R. (2008). "The Role of Instrumented Vehicle Activity Data in Transportation Planning, Operations, Safety, and Health Impact Assessment." Presentation to the Emory Rollins School of Public Health (50 attendees). Atlanta, GA, January 17, 2008.
23. Zumerchik, J., M. Grace, and R. Guensler (2008). "Improving Freight Terminal Operations to Reduce Emissions." Presentation to the US Environmental Protection Agency SmartWay Program. Washington, DC, January 16, 2008.
24. Guensler, R. (2007). "National Environmental Policy Act Overview." Presentation to the US Environmental Protection Agency Region IV, Permitting, Mobile Sources, and NEPA Sections (20 attendees). Atlanta, GA, September 19, 2007.

25. Guensler, R., V. Elango, and P. Blaiklock (2007). "Intermodal Research Applications of GPS Tracking. Presentation to the Transportation Research Board Intermodal Freight Transport Committee (AT045) Meeting. Chicago, IL, July 7, 2007.
26. Guensler, R. (2006). "Vehicle Technology and Travel Behavior." Hot Nights in the City: Urban Planning Responses to Climate Change, Atlanta, GA, November 2006.
27. Guensler, R. (2006). "Vehicle and Driver Monitoring in Public and Private Fleets." Oral Testimony Delivered to the Georgia General Assembly, Business Incentives Study Committee. Atlanta, GA. October 25, 2006.
28. Guensler, R. (2006). "Traffic, Traffic, Everywhere - The Commute Atlanta Instrumented Vehicle Program: Emission Rate and Activity Modeling Issues." Air Resources Engineering Center, Georgia Air Quality and Climate Summit, Atlanta, GA, May 4, 2006.
29. Yoon, S. and R. Guensler (2006). "Heavy-Duty Diesel Vehicle Modal Emission Model: Model Development." California Air Resources Board Chairman's Seminar, Sacramento, CA, March 2006.
30. Guensler, R. (2006). "Instrumented Vehicle Data and Modeling Activities in Atlanta." Natural Resources Canada/Office of Energy Efficiency, Windsor, ON, Canada, February 2006.
31. Guensler R. (2005). "Georgia's Transportation and Air Quality Linkage". Georgia Air Policy Symposium, Georgia Department of Natural Resources, Environmental Protection Division, Atlanta, GA, December 19, 2005.
32. Guensler R. (2005). "Commute Atlanta GPS Data". Time-Geography Meeting. Center for Spatially Integrated Social Science, UC Santa Barbara, Santa Barbara, CA, October 10, 2005.
33. Guensler R. (2005). "Commute Atlanta Instrumented Vehicle Value Pricing Study". Georgia Tech School of Civil and Environmental Engineering External Advisory Board. Atlanta, GA, October 6, 2005.
34. Guensler R. (2005). "Commute Atlanta Research Activities". Chi Epsilon Chapter of the Georgia Tech School of Civil and Environmental Engineering. Atlanta, GA, September 22, 2005.
35. Guensler, R. and S. Yoon (2005). "Capture of Transit Bus Operating Data with a GT Trip Data Collector". Gwinnett Transit Advisory Board. Lawrenceville, GA. May 2, 2005.
36. Guensler, R. (2005). "Use of Instrumented Vehicle Data in Insurance Underwriting". Computer Science Corporation's Future Focus Conference for the Insurance Industry. Charleston, SC. October 18, 2005.
37. Li, H., and R. Guensler (2005). "GPS-Based Vehicle Activity Data in the Commute Atlanta Route Choice Study". 10th Annual TRB Transportation Planning Applications Conference, Portland, OR, April 24-28, 2005.
38. Yoon, S, C. Feng, J. Jun, H. Li, V. Elango, and R. Guensler (2005). "Heavy-Duty Diesel Vehicle Modal Emissions Model: Transit Bus Emissions Simulations". ITE Georgia Chapter Monthly Meeting. Georgia Institute of Technology, Atlanta, GA. April 21, 2005
39. Guensler, R. (2005). "Technology in the Dugout: The Latest in Motor Vehicle Telematics, Commute Atlanta". Property Casualty Insurers Association of America Joint Underwriting Seminar. Saint Petersburg, FL. April 19, 2005.
40. Guensler, R. (2005). "Commute Atlanta Research: Commuter Choice Value Pricing Pilot Program". Association of Metropolitan Planning Organizations Annual Meeting. Atlanta, GA. March 22, 2005.
41. Guensler, R. (2005). "Commute Atlanta Overview: Commuter Choice Value Pricing Pilot Program". Transport Canada. Ottawa. March 8, 2005.
42. Guensler, R. (2004). "Value Pricing in Transportation: The Commute Atlanta Project." Pricing & Revenue Management Initiative Workshop. Georgia Institute of Technology, Business School. Atlanta, GA. November 2004.
43. Guensler, R. and J. Ogle (2004). "Atlanta's Vehicle Instrumentation and Activity Monitoring Programs: 2004 Status Report." sponsor approval not received in time for proceedings publication. 14th Annual On-Road Vehicle Emissions Workshop, San Diego, CA. Coordinating Research Council. Atlanta, GA. March 2004.
44. Ogle, J., and Guensler, R. (2004). "Commute Atlanta: Arterial Congestion Modeling Techniques." ITE Georgia Section Summer Seminar. St. Simons Island, GA.
45. Guensler, R., S. Yoon, C. Feng, H. Li, and J. Jun (2004). Heavy-Duty Diesel Vehicle Load-Based Modeling Framework. USEPA Region IV. Atlanta, GA, October 15, 2004.
46. Guensler, R. (2004). An Overview of the Model Emissions Modeling Approach for Heavy-Duty Diesel Vehicles. USEPA Region IV. Atlanta, GA, February 2004.

47. Guensler, R. (2003). The MACOC Mobile Source Control Strategy Delphi Panel. Air Quality Issue Forum. Metropolitan Atlanta Chamber of Commerce. Atlanta, GA. May 2003.
48. Guensler, R. (2003). Innovations in Transportation: Intelligent Transportation Systems, Variable Speed Limits, and Bus Rapid Transit. Emerging Issues in Mobile Sources Workshop. US Environmental Protection Agency, Region IV. Atlanta, GA. May 2003.
49. Guensler, R. and J. Ogle (2003). Analytical Potential in the DRIVE-Atlanta Instrumented Vehicle Data Sets. US Environmental Protection Agency. Washington, DC. March 2003.
50. Guensler, R. (2003). Air Quality and Transportation in Georgia: Where Are We and Where Are We Going?." Georgia Crushed Stone Association Management Workshop. Atlanta, GA. February 2003.
51. Guensler, R. (2002). Three Technology-Based TCMs: Speed Management, Value Pricing, and Emissions Fees. Atlanta Regional Commission, Air Quality Planning Team. Atlanta, GA. December 2002.
52. Guensler, R. and J. Ogle (2002). Instrumented Vehicles, Risk, and Pay-as-You-Drive Insurance. ISOTech Conference. Orlando, FL. November 2002.
53. Guensler, R. and J. Ogle (2002). "Drive Atlanta: Instrumented Vehicles Providing a Wealth of Planning Data. Imperial College Seminar Series. London, England. November 2002.
54. Guensler, R. (2002). "The Atlanta Instrumented Vehicle Programs: Providing Critical Data for Driver Behavior, Safety, Travel Demand, and Vehicle Emissions Modeling." UC Davis Transportation Seminar Series. Davis, CA. May 2002.
55. Guensler, R. (2002). "The Atlanta Instrumented Vehicle Programs: Providing Critical Data for Driver Behavior, Safety, Travel Demand, and Vehicle Emissions Modeling." UC Berkeley Transportation Seminar Series. Davis, CA. April 2002.
56. Guensler, R. (2002). "The Atlanta Value Pricing Insurance Initiative." USEPA Pay as You Drive Workshop. Reno, NV. March 2002.
57. Guensler, R. (2002). "GPS Issues in Automated Travel Data Collection." USEPA Pay as You Drive Workshop. Reno, NV. March 2002.
58. Guensler, R. (2002). "Applications of Technology in Future Survey Methods." Workshop on the National Household Travel Survey. Washington, DC. February 2001.
59. Guensler, R. (2001). "The Commuter Choice and Value Pricing Insurance Incentive Program." The GRTA/FHWA Value Pricing Workshop. Atlanta, GA. October 2001.
60. Guensler, R. (2001). "Onboard Diagnostic System Data and Vehicle Emissions Modeling." Meeting of the Truck and Bus Electronic Data Recorder Working Group, National Highway Transportation and Safety Administration. Atlanta, GA. October 2001.
61. Guensler, R and J. Ogle (2001). "The Atlanta Instrumented Vehicle Intensive." Meeting of the Mobile Source Technical Review Subcommittee, Clean Air Act Advisory Committee, US Environmental Protection Agency. Dearborn, MI. October 2001.
62. Guensler, R., W. Bachman, and M. Rodgers (2001). "MOBILE/MEASURE, Meeting of the Mobile Emission Assessment System for Urban and Regional Evaluation." Modeling Workgroup, Mobile Source Technical Review Subcommittee, Clean Air Act Advisory Committee, US Environmental Protection Agency. Dearborn, MI. October 2001.
63. Guensler, R. (2001). "New Air Quality Standards and the Mining Industry." Annual Meeting of the Georgia Mining Industry Academic Initiative. Atlanta, GA. March 2001.
64. Guensler, R. (2001). "Using Poster Sessions to Enhance Technical Outreach." Transportation Research Board Annual Meeting, All Chairs Dinner. Washington, DC. January 2001.
65. Wolf, J., R. Guensler, S. Washington, and L. Frank (2000). The Use of Electronic Travel Diaries and Vehicle Instrumentation Packages in the Year 2000 Atlanta Regional Household Travel Survey: Final Test Results and Implementation Plans. 9th International Association of Travel Behaviour Research Conference. Gold Coast, Queensland, Australia, July 2000.
66. Guensler, R. (1999). "Linking Modal Emissions Models with Vehicle Activity Estimates." Society of Automotive Engineers, Future Technology Toptec. Costa Mesa, CA. August 1999.

67. Guensler, R. (1999). "The Role of TRB Committees in the National Research Agenda." Transportation Research Board, New Committee Chair Orientation Meeting. Washington, DC. January 1999.
68. Guensler, R. (1998). "Considerations in Developing Future Emissions Models." National Research Council. Committee to Review EPA's Mobile Source Emissions Factor (MOBILE) Model. Washington, DC. December 1998.
69. Guensler, R. and J. Wolf (1998). "Travel Behavior and Air Quality." North American Travel Monitoring Exhibition and Conference. Charlotte, NC. May 1998.
70. Guensler, R. (1998). "Future Improvements to Motor Vehicle Emissions Models. EPA State and Local Transportation and Air Quality Planning Meeting." US Environmental Protection Agency, Region IV. Atlanta, GA. March 1998.
71. Guensler, R. (1997). "Evolving Motor Vehicle Emissions Models: Toward Analysis of ITS Impacts." Invited Speaker, Spring Civil Engineering Lecture Series. University of California, Berkeley. May 1997.
72. Guensler, R., W. Bachman, and S. Washington (1997). "Engine Start and Hot Stabilized Components of the GIS-Based Modal Emissions Model." 7th Annual On-Road Vehicle Emissions Workshop, San Diego, CA. Coordinating Research Council. Atlanta, GA. April 1997.
73. Grant, C., R. Guensler, K. Dixon and J. Metarko (1997). "Use of Video Systems for Collection of Vehicle Activity Data in Emissions Modeling." 7th Annual On-Road Vehicle Emissions Workshop, San Diego, CA. Coordinating Research Council. Atlanta, GA. April 1997.
74. Guensler, R. (1997). "High Emitters and Incremental Engine Starts." World Car Conference '97. University of California, Riverside. January 1997.
75. Guensler, R. (1997). "Overview of the Georgia Tech GIS-Based Modal Emissions Model." World Car Conference '97. University of California, Riverside. January 1997.
76. Guensler, R. (1996). "Air Quality Research Needs Statements. Environmental Research Needs in Transportation." Invitational Conference. National Research Council, Transportation Research Board. Washington, DC. November 1996.
77. Guensler, R. (1996). "Presentation and Discussion of the Draft Subcommittee Report Chapter on the Modeling Workgroup." Office of Mobile Sources Technical Advisory Subcommittee [of the Clean Air Act Advisory Committee] Meeting. US Environmental Protection Agency. Washington, DC. October 1996.
78. Guensler, R. (1996). "Electronic Communications, TransNet Project. Transferring Research Results into Practice: Methods and Tools." A Presentation at the Council of University Transportation Centers Workshop. Gainesville, FL. June 1996.
79. Guensler, R. (1995). "Modeling Efforts of the Georgia Tech Research Partnership." National Academy of Sciences, National Cooperative Research Program, Workshop on "Quantifying Air Quality and Other Benefits and Costs of Transportation Control Measures." La Jolla, CA. October 1995.
80. Guensler, R. (1995). "An Overview of the ASCE Home Page." ASCE Technical Activities Committee. ASCE Transportation Congress. San Diego, CA. October 1995.
81. Guensler, R. (1995). "TREAD: The ASCE Urban Transportation Division Home Page." Annual Meeting of the ASCE Urban Transportation Division. ASCE Transportation Congress. San Diego, CA. October 1995.
82. Guensler, R. (1995). "Time-Based Modeling within a GIS-Based Modal Model Framework." The Emission Inventory: Programs and Progress. A Specialty Conference Sponsored by the US Environmental Protection Agency and the Air and Waste Management Association. Research Triangle Park, NC. October 1995.
83. Ross, C., R. Guensler, S. Washington, and D. LeBlanc (1995). "Temporal Distributions of Engine Starts, Hot Soaks, and Modal Operating Fractions across Three Cities." The Emission Inventory: Programs and Progress. A Specialty Conference Sponsored by the US Environmental Protection Agency and the Air and Waste Management Association. Research Triangle Park, NC. October 1995.
84. Guensler, R. (1995). "Motor Vehicle Emission Inventory Models: Problems and Solutions." Keynote Speaker. Institute of Transportation Engineers, Georgia Section. Spring Meeting. Atlanta, GA. May 1995.
85. Guensler, R. (1995). "Remote Sensing: Perception and Reality." Invited Keynote Speaker. 1995 Annual Meeting of the Alliance Petroleum Corporation. San Francisco, CA. April 1995.
86. Guensler, R. (1995). "Transportation Resources Available through the Internet." Invited Speaker, A Presentation to the Transportation Research Board's Committee on Transportation and Air Quality (A1F03). January 1995.

87. Guensler, R., D. LeBlanc, and S. Washington (1994). "Jekyll and Hyde Emitters." 1994 Air and Waste Management Association International Conference on the Emission Inventory. November 1994.
88. Guensler, R. (1994). "Next Generation Motor Vehicle Emissions Model." Alliance for Transportation Research, Research Associates Conference. New Mexico Engineering Research Institute. November 1994.
89. Guensler, R. (1993). "The Impact of Speed Correction Factors on Uncertainty in the South Coast AQMD Emission Inventory." The Emission Inventory, Perception and Reality. Air and Waste Management Association International Conference. October 1993.
90. Guensler, R., S. Washington, and D. Sperling (1993). "Mobile Source Speed Correction Factors, Phase 1: Evaluation of the EMFAC7F Speed Correction Factors." Preprint Made Available at the 72nd Annual Meeting of the Transportation Research Board. Washington, DC. January 1993.
91. Guensler, R. (1992). "Uncertainty in Estimating Heavy Duty Truck Emissions." Cooperative Clean Air Technology Conference. Air and Waste Management Association International Conference. April 1992.
92. Guensler, R., D. Sperling, and P. P. Jovanis (1992). "Heavy Duty Truck Emissions: Research Agenda." A Paper Presented at the Transportation Research Board Transportation/Air Quality Committee Meeting. 71st Annual Meeting of the Transportation Research Board. Washington, DC. January 1992.
93. Guensler, R., D. Sperling, and P. P. Jovanis (1991). "Disaggregate Diesel Emission Database for California." Session 171B. 70th Annual Meeting of the Transportation Research Board. Washington, DC. January 1991.
94. Guensler, R. (1989). "Compliance Perspectives on Transportation Control Measures: South Coast AQMD Regulation XV." 68th Annual Meeting of the Transportation Research Board. Washington, DC. January 1989.

E. OTHER SCHOLARLY ACCOMPLISHMENTS

Patents and Patent Applications

1. Guensler, R., V. Elango, and P. Blaiklock (2010). Automatic Anti-idle Warning and Shutoff System and Method. Provisional Patent Application 61/349,284. May, 2010. Final Patent Application 2011/0295486, May 2011.
2. Vu, P., J. Miller, R. Guensler, T. Slack, and J. Breedlove (2008). Electronic Barrier Enforcement System and Method. Patent 8,044,824. July, 2008.

Software

1. Guensler, R., A. Akanser, and V. Elango (2013-2014). Sidewalk Scout: Pedestrian Infrastructure Inventory App. Google Play Store. Android. School of Civil and Environmental Engineering. Georgia Institute of Technology.
2. Xu, Y., R. Guensler, G. Cernjul, and V. Elango (2013-2014). Federal Transit Administration, Transit Greenhouse Gas Calculator. Excel. School of Civil and Environmental Engineering. Georgia Institute of Technology and Oak Ridge National Laboratory.
3. Guensler, R., H. Liu. Y. Xu, G. Cernjul, and V. Elango (2013-2014). MOVES-Matrix CALINE-Grid Project-Level Emission Impact Assessment Tool. MOVES, CALINE4, Perl Scripts, and Visual Basic. School of Civil and Environmental Engineering. Georgia Institute of Technology.
4. Guensler, R., Y. Xu, H. Liu, and V. Elango (2013-2014). MOVES-Matrix Cluster Computer Processor. MOVES and Perl Scripts for the PACE Cluster. School of Civil and Environmental Engineering. Georgia Institute of Technology.
5. Guensler, R., V. Elango, et al. (2010-2014). Commute Warrior: Personal Activity Tracking Application for Handheld Devices, Map Interface to Commute Warrior Activity Data, and Personal Electronic Travel Diary. Google Play Store. Android. School of Civil and Environmental Engineering. Georgia Institute of Technology.
6. Guensler, R., and R. Sadana (2012-2014). Sidewalk Sentry; Automated Sidewalk Quality Assessment App. Android. School of Civil and Environmental Engineering. Georgia Institute of Technology.
7. Guensler, R., M. Hunter, A. Guin, and R. Sadana (2011-2014). Traffic Counting Video App. Android. School of Civil and Environmental Engineering. Georgia Institute of Technology.
8. Guensler, R., M. Hunter, V. Elango, and R. Sadana (2012-2013). Interactive Survey Creator. HTML/PHP. School of Civil and Environmental Engineering. Georgia Institute of Technology.
9. Guensler, R., and V. Elango (2008-2009). Internet Travel Diary for Instrumented Vehicles. PHP, HTML, and Perl. School of Civil and Environmental Engineering. Georgia Institute of Technology.

10. Guensler, R., V. Elango, and J.C. Wren (2007). In-vehicle Travel Diary for Instrumented Vehicles. C and Terminal Code. School of Civil and Environmental Engineering. Georgia Institute of Technology.
11. Guensler, R., A. Guin, D. Kall, V. Pandey, V. Elango, and G. Shafi (2007). MOBILE-Matrix CALINE-Grid Project-Level Emission Impact Assessment Tool. MOBILE, CALINE4, Perl Scripts, and Visual Basic. School of Civil and Environmental Engineering. Georgia Institute of Technology.
12. Yoon, S., V. Elango, and R. Guensler (2005). Heavy-Duty Vehicle Modal Emission Model (HDV-MEM) Framework. Excel, Perl Scripts, and C. RARE Research Effort. School of Civil and Environmental Engineering. Georgia Institute of Technology.
13. Guensler, et al., (2003). Onboard Vehicle and Personal Activity Monitoring Software. GTRC Invention Disclosure 3222. Georgia Institute of Technology.
14. Elango, V., S. Yoon, and R. Guensler (2003). CALINE-Grid: Grid-Based CALINE Dispersion Model. CALINE4 and Perl Scripts.
15. Elango, V., S. Yoon, R. Guensler, J. Leonard, and W. Bachman (2003). MOBILE-Matrix: MOBILE6 Emission Rate Matrix Generator. MOBILE6 and Perl Scripts.
16. Leonard, J., R. Guensler, M. Oliveira, W. Bachman, (1999). Microscale Air Quality Impact Assessment System for Large Scale Transportation Projects. CALINE4 and Perl Scripts.
17. Guensler, R. (1998). Georgia Tech Electronic Travel Diary. OVAL for Psion Workabout.
18. Bachman, W., R. Guensler, S. Washington, W. Sarasua, and J. D. Leonard (1996-1999). Mobile Emissions Assessment System for Urban and Regional Evaluation (MEASURE). ARC/INFO and FORTRAN for Sun Workstation. Georgia Tech Research Partnership. School of Civil and Environmental Engineering. Georgia Institute of Technology.
19. Leonard, J., and R. Guensler (1995). MOBILE5m, Version 1.0. A Monte Carlo Version of the USEPA MOBILE5a Motor Vehicle Emissions Model. FORTRAN for DOS. School of Civil and Environmental Engineering. Georgia Institute of Technology.

Poster Sessions

1. Shaw, A., A. Grossman, P. Pratyaksa, A. Greenwood, Y. Xu, M.P. Hunter, and R. Guensler (accepted). Engaging in Transportation Engineering Initiatives with K-12 Students. Georgia Tech ASEE Expo. Atlanta, GA. February 2015.
2. Li, H., Y. Xu, S., Khoeini, and R. Guensler (2015). I-85 HOV to HOT Carpool Survey Preliminary Results (P15-6550). 94th Annual Meeting of the Transportation Research Board, Washington DC. January 2015.
3. Toth, C. and R. Guensler (2015). Lane Choice and HOT Egress Behavior Analysis of Peach Pass Drivers (P15-5756). 94th Annual Meeting of the Transportation Research Board, Washington DC. January 2015.
4. Watkins, K., S. Handy, A. Grossman, and R. Guensler (2014). Environmental Sustainability through Bicycle and Pedestrian Research. National UTC Poster Session on Bicycle and pedestrian Research. Research and Innovative Technology Administration. Washington, DC. September 29, 2014.
5. Guensler, R., Y. Xu, V. Elango, A. Grossman, K. Poddar, A. Akanser, and R. Sadana (2014). "Commute Warrior: An Android Application to Collect Longitudinal Travel Survey Data." Georgia Department of Transportation and Georgia Transportation Institute Research Poster Session. Atlanta, GA. September 23, 2014.
6. Grossman, A., A. Frackelton, R. Guensler (2014). "Benefits of Sidewalk Sentry Android App Data." Georgia Department of Transportation and Georgia Transportation Institute Research Poster Session. Atlanta, GA. September 23, 2014.
7. Khoeini, S., V. Elango, R. Guensler (2014). "Generating Sidewalk Networks from Roadway Network and Parcel Data." Georgia Department of Transportation and Georgia Transportation Institute Research Poster Session. Atlanta, GA. September 23, 2014.
8. Xu, Y., H. Liu, R. Guensler (2014). "Emissions Impact of HOV to HOT Lane Conversions in I-85, Atlanta." Georgia Department of Transportation and Georgia Transportation Institute Research Poster Session. Atlanta, GA. September 23, 2014.
9. Sheikh, A., A. Misra, R. Guensler (2014). "High Occupancy Toll Lane Decision Making: Income Effects on Atlanta's I-85 Express Lanes." Georgia Department of Transportation and Georgia Transportation Institute Research Poster Session. Atlanta, GA. September 23, 2014.

10. Khoeini, S., R. Guensler (2014). "HOV-to-HOT Conversion Socioeconomic Assessment: Atlanta I-85 HOV-to-HOT Conversion." Georgia Department of Transportation and Georgia Transportation Institute Research Poster Session. Atlanta, GA. September 23, 2014.
11. Toth, C., R. Guensler, J. Laval (2014). "An Empirical Data-Driven Macroscopic Lane Changing Model." Georgia Department of Transportation and Georgia Transportation Institute Research Poster Session. Atlanta, GA. September 23, 2014.
12. Xu, Y., M. Hunter, R. Guensler, A. Grossman, A. Shaw, P. Pratyaksa, A. Greenwood (2014). "Engaging in Transportation Engineering Initiatives with K-12 Students." Georgia Department of Transportation and Georgia Transportation Institute Research Poster Session. Atlanta, GA. September 23, 2014.
13. Liu, R., R. Guissou, A. Grossman, and R. Guensler (2014). Sidewalks and Tree Encroachment. 9th Annual Undergraduate Research Symposium. Georgia Institute of Technology. April 2014.
14. Xu, Y., R. Guensler, M. Rodgers, D. Lee, F. Gbologah (2014). "Transit Fleet GHG Management Using the Fuel and Emissions Calculator." Poster presentation at the 24th CRC Real Work Emissions Workshop, San Diego, CA, March 31 to April 2, 2014.
15. Sheikh, A., and R. Guensler (2014). "HOT Lane Decision Making: Operational and Demographic Factors." University Transportation Center (UTC) Conference for the Southeastern Region, Atlanta, GA. March 24, 2014.
16. Palinginis, E., F. Castrillon, A. Akanser, A. Grossman, V. Elango, and R. Guensler (2014). "A Technology Overview of the Sidewalk Sentry Application." University Transportation Center (UTC) Conference for the Southeastern Region, Atlanta, GA. March 24, 2014.
17. Grossman, A., E. Palinginis, A. Frackelton, F. Castrillon, V. Elango, A. Akanser, and R. Guensler (2014). "Estimation of Sidewalk Data Variables in Development of a Sidewalk Quality Rating." GTRIC 2014 Poster Session. February 11, 2014.
18. Guensler, R., M. Hunter, A. Guin, V. Elango, S. Khoeini, A. Sheikh, et al. (2014). Atlanta I-85 HOV-to-HOT Conversion: Analysis of Vehicle and Person Throughput (P14-5870). 93rd Annual Meeting of the Transportation Research Board, Washington DC. January 2014.
19. Grossman, A., Frackelton, A. E. Palinginis, A. Akanser, R. Sadana, F. Castrillon, V. Elango, Y. Xu, K. Watkins, Guensler, R. (2014) "Sidewalk Quality Assessment." STRIDE Reception at the 93rd Annual Transportation Research Board Meeting, Washington, DC., January 2014
20. Khoeini, S., and R. Guensler (2014). Atlanta I-85 HOV-to-HOT Conversion: Household-Level Sociospatial Impact Assessment (P14-6591). 93rd Annual Meeting of the Transportation Research Board, Washington DC. January 2014.
21. Grossman, A., A. Frackelton, E. Palinginis, A. Akanser, R. Sadana, F. Castrillon, V. Elango, and R. Guensler (2013). "Innovative Technology for Sidewalk Assessment: Development and Field Deployment." Association of Pedestrian and Bicycle Professionals Professional Development Seminar. Best Poster Award. Boulder, CO. September, 2013.
22. Guensler, R., W. Suh, M. Hunter, A. Guin, J. Teizer, J. Anderson, K. Colberg, S. Zinner (2013). "Work Zone Technology Testbed Development." Georgia Department of Transportation and Georgia Transportation Institute Transportation Research Poster Session. Atlanta, GA. September, 2013.
23. Akanser, A., F. Castrillon, V. Elango, and R. Guensler (2013). "Estimation of Sidewalk Grade and Roughness using Accelerometers on Wheelchairs." Georgia Department of Transportation and Georgia Transportation Institute Transportation Research Poster Session. Atlanta, GA. September, 2013.
24. Khoeini, S., and R. Guensler (2013). "Socio-Economic Study on Atlanta I-85 HOV to HOT Conversion." Georgia Department of Transportation and Georgia Transportation Institute Transportation Research Poster Session. Atlanta, GA. September, 2013.
25. Grossman, A., V. Elango, A. Frackelton, and R. Guensler (2013). "The Use of a Sidewalk Quality Assessment Survey in Developing Sidewalk Ratings." Georgia Department of Transportation and Georgia Transportation Institute Transportation Research Poster Session. Atlanta, GA. September, 2013.
26. Sheikh, A., A. Guin, and R. Guensler (2013). "Value of Travel Time Savings: Evidence from Atlanta's I-85 Express Lanes." Georgia Department of Transportation and Georgia Transportation Institute Transportation Research Poster Session. Atlanta, GA. September, 2013.

27. Toth, C., and R. Guensler (2013). "Analysis of Variables that Affect HOT Speeds on I-85 Express Lanes in Atlanta." Georgia Department of Transportation and Georgia Transportation Institute Transportation Research Poster Session. Atlanta, GA. September, 2013.
28. Palinginis, E., K. Kamiya, J. Laval, I. Brilakis, and R. Guensler (2013). "Full-Body Occlusion Handling and Density Analysis in Traffic Video-Surveillance Systems." Georgia Department of Transportation and Georgia Transportation Institute Transportation Research Poster Session. Atlanta, GA. September, 2013.
29. Castrillon, F., M. Roell, S. Khoeini, and R. Guensler (2013). "The I-85 HOT Lane's Impact on Atlanta's Commuter Bus and Vanpool Occupancy." Georgia Department of Transportation and Georgia Transportation Institute Transportation Research Poster Session. Atlanta, GA. September, 2013.
30. Khoeini, S., and R. Guensler (2013). "Pricing Impact on Users Characteristics: Socio-economic Study on Atlanta I-85 HOV2+ to HOT3+ Conversion." Transportation Research Board Freeway & Managed Lanes Operations Meeting and Conference. Atlanta, GA. June 2013.
31. Sheikh, A., C. Toth, A. Guin, and R. Guensler (2013). "Weaving and Throughput in the I-85 Express Lanes. Transportation Research Board Freeway & Managed Lanes Operations Meeting and Conference. Atlanta, GA. June 2013."
32. Khoeini, S., R. Guensler, et al. (2013). Spatial and Demographic Changes of Atlanta I-85 Commutershed for the Managed Lane for the HOV-to-HOT Conversion (P13-6078). 92nd Annual Meeting of the Transportation Research Board, Washington DC. January 2013.
33. Frackelton, A., A. Grossman, K. Kamiya, R. Sadana, F. Castrillon, E. Palinginis, V. Elango, Y. Xu, K. Watkins, Guensler, R. (2013) "Development of an Automated Sidewalk Quality Assessment System." STRIDE Reception at the 92nd Annual Transportation Research Board Meeting, Washington, DC., January 2013
34. Elango, V., S. Khoeini, S., R. Guensler, et al. (2013). Evaluation of Changes in Person and Vehicle Throughput for the I-85 Corridor HOV-to-HOT Lane Conversion (P13-6068). 92nd Annual Meeting of the Transportation Research Board, Washington DC. January 2013.
35. Guensler, R., et al. (2012). Conversion of HOV to HOT Monitoring and Evaluation - Atlanta I-85. 14th International Managed Lanes Conference. Oakland, CA. May 22-24, 2012.
36. Guensler, R., et al. (2012). Atlanta HOV-to-HOT Corridor Performance Monitoring (P12-5606). 91st Annual Meeting of the Transportation Research Board, Washington DC. January 2012.
37. Guensler, R., M. Hunter, J. Laval, A. Guin, V. Elango, and P. Vu (2011). Atlanta HOV-to-HOT Corridor Performance Monitoring (P11-0548). 90th Annual Meeting of the Transportation Research Board, Session 559, Road Pricing and Managed Lanes Showcase: Lessons from Projects and Case Studies. Washington, DC. January 2011.
38. Wood, N., R. Guensler, and V. Elango (2011). Assessing the Marginal Cost of Freeway Congestion for Vehicle Fleets Using Passive GPS Data (P11-0530). 90th Annual Meeting of the Transportation Research Board, Session 560, Road Pricing and Managed-Lane Research: New Tools and Promise for the Future. Washington, DC. January 2011.
39. Toups, D., P. Vu, and R. Guensler, (2011). Pricing Implications of Combining User Fee and Credit Programs Across Multiple Transportation Modes (P11-0539). 90th Annual Meeting of the Transportation Research Board, Session 560, Road Pricing and Managed-Lane Research: New Tools and Promise for the Future. Washington, DC. January 2011.
40. Hunter, M., R. M. Fujimoto, C. Alexopoulos, R. Guensler, and F. Southworth (2009). Embedded Distributed Simulation for Transportation System Management. 2009 NSF EFRI Annual Grantees Conference. Arlington, VA. March 2009.
41. Barringer, J., C. Ross, R. Guensler, and L. Zuyeva (2009). "Perceptions of Equity Issues with Congestion Pricing in the Metropolitan Atlanta Region." 88th Annual Meeting of the Transportation Research Board. Session 623. Congestion Pricing Research: Laying the Foundation for the Future. Washington, DC. January 2009.
42. Kall, D., V. Pandey, J., and R. Guensler (2008). "MOBILE-Matrix and CALINE-Grid: Project-Level Conformity Screening and Microscale Air Quality Impact Assessment Tools." 18th Annual On-Road Vehicle Emissions Workshop, San Diego, CA. Coordinating Research Council. Atlanta, GA. March 2008.
43. Guensler, R., V. Elango, and P. Blaiklock (2008). "Reducing Emissions through Cargo Insulation: Shifting Refrigerated Freight to Dry Containers." Data for Goods Movement Impacts on Air Quality, Irvine, CA. National Academy of Sciences. March 2008.

44. Xu, Y., V. Elango, L. Zuyeva, R. Guensler, and J. Ogle (2008). “Commute Atlanta Pricing Response Trends.” 87th Annual Meeting of the Transportation Research Board, Session 251, Advancements in Congestion Pricing. Washington, DC. January 2008.

45. Hunter, M., R. M. Fujimoto, C. Alexopoulos, R. Guensler, and F. Southworth (2007). Embedded Distributed Simulation for Transportation System Management, *NSF EFRI Grantees Conference*, Arlington, VA, December 2007.

46. Kall, D., V. Pandey, J.I. Nelson, and R. Guensler (2007). “The Impact of Vehicle Fleet Characteristics on Emissions Outputs from MOBILE6.” 17th Annual On-Road Vehicle Emissions Workshop, San Diego, CA. Coordinating Research Council. Atlanta, GA. March 2007.

47. Li, H., R. Guensler, and J. Ogle (2006). “A Summary of Commute Atlanta Research Progress.” Congestion Pricing Poster Session. 85th Annual Meeting of the Transportation Research Board. Washington, DC. January 2006.

48. Kimbrough, S. D. Aspy, T. Baugh, R. Guensler, S. Yoon (2005). RARE Project – Heavy-Duty Diesel Truck Activity Factors Analysis. The EPA Science Forum 2005: Collaborative Science for Environmental Solutions, Washington, DC. USEPA Office of Research and Development. Research Triangle Park, NC. May 2005.

49. Yoon, S., J. Jun, H. Li, R. Guensler, M. Rodgers, and S. Kimbrough (2005). “Transit Bus Load-Based Modal Emissions Rate Simulation with Link-Specific Speed-Acceleration-Road Grade Matrices.” Georgia Tech Graduate Student Research Symposium. Atlanta, GA. April 2005.

50. Ko, J., and R. Guensler (2005). “Variability in Traffic Flow Quality Experienced by Drivers: Evidences from Instrumented Vehicles.” Georgia Tech Graduate Student Research Symposium. Atlanta, GA. April 2005.

51. Jun, J., S. Yoon, H. Li, and R. Guensler (2005). “Evaluation of Numerical Difference Formulations for Estimating Accelerations in Transportation Research.” Georgia Tech Graduate Student Research Symposium. Atlanta, GA. April 2005.

52. Guensler, R., S. Yoon, and C. Feng (2005). “Heavy-Duty Diesel Vehicle Modal Emissions Modeling Framework”, 15th Annual On-Road Vehicle Emissions Workshop, San Diego, CA. Coordinating Research Council. Atlanta, GA. April 2005.

53. Yoon, S., R. Guensler, and M. Rodgers (2005). “Transit Bus Load-Based Modal Emissions Rate Simulation with Speed-Acceleration Matrices by Time and by Roadway Facility Type”, 15th Annual On-Road Vehicle Emissions Workshop, San Diego, CA. Coordinating Research Council. Atlanta, GA. April 2005.

54. Yoon, S., R. Guensler, and M. Rodgers (2005). “A New Heavy-Duty Vehicle VMT Estimation Method: Impact upon Regional Emissions Rates and Inventories”, 15th Annual On-Road Vehicle Emissions Workshop, San Diego, CA. Coordinating Research Council. Atlanta, GA. April 2005.

55. Guensler, R., S. Yoon, and H. Li (2004). “Soak Time Distributions for 400,000 Atlanta Vehicle Trips”, 14th Annual On-Road Vehicle Emissions Workshop, San Diego, CA. Coordinating Research Council. Atlanta, GA. March 2004.

56. Guensler, R., S. Yoon, J. Pearson, and M. Rodgers (2004). “Activity Pattern Differences between Older and Newer High- and Medium-Mileage Vehicles”, 14th Annual On-Road Vehicle Emissions Workshop, San Diego, CA. Coordinating Research Council. Atlanta, GA. March 2004.

57. Yoon, S., P. Zhang, J. Pearson, R. Guensler, M. Rodgers, and S. Kimbrough (2004). “Heavy-Duty VMT Translation for Mobile Source Emissions Inventories Using A New Heavy-Duty Vehicle Visual Classification Scheme”, 14th Annual On- Road Vehicle Emissions Workshop, San Diego, CA. Coordinating Research Council. Atlanta, GA. March 2004.

58. Guensler, R. (2003). Simulation-Based Test Bed for Networked Sensors in Surface Transportation Systems: Vehicle Activity Simulation. NSF Electrical and Communications Systems Division Workshop on Wireless Networked Sensor and Actuator Systems and Grantees Meeting. University of California, Los Angeles. September8-9, 2003

59. Fitzgibbons, B., R. Fujimoto, R. Guensler, and J. Leonard (2003). “Simulation-Based Operations Planning for Regional Transportation Systems.” Proceedings of the 2003 National Conference on Digital Government Research. Digital Government Research Center. National Academy of Sciences, pp. 175-176, Washington, DC. May 2003.

60. Guensler, R. and D. Ahanotu (2000). “Heavy-Duty Vehicle Weight and Horsepower Distributions: Measurement of Class-Specific Temporal and Spatial Variability.” 10th Annual On-Road Vehicle Emissions Workshop, San Diego, CA. Coordinating Research Council. Atlanta, GA. March 2000.

61. Rodgers, M. O., J. Pearson, and R. Guensler (2000). “Measurement of Facility-Level Emissions from an Interstate Highway by Atmospheric Flux Measurements.” Proceedings of the 10th Annual On-Road Vehicle Emissions Workshop, San Diego, CA. Coordinating Research Council. Atlanta, GA. April 2000.

62. Wolf, J. and R. Guensler (2000). "Electronic Capture of Personal Travel Activity and Vehicle Operating Conditions in the Year 2000 Atlanta Regional Household Travel Survey." 10th Annual On-Road Vehicle Emissions Workshop, San Diego, CA. Coordinating Research Council. Atlanta, GA. March 2000.

63. Thornton, M., R. Guensler, and K. Dixon (2000). "Emissions Impacts Of Ramp Metering Strategies On The Atlanta Freeway System." 10th Annual On-Road Vehicle Emissions Workshop, San Diego, CA. Coordinating Research Council. Atlanta, GA. March 2000.

64. Awuah-Baffour, R., W. Sarasua, C. Grant, W. Bachman, and R. Guensler (1995). "Applications of Global Positioning Systems in Mobile Source Emissions Inventories." The Emission Inventory: Programs and Progress. Specialty Conference Sponsored by the US Environmental Protection Agency and the Air and Waste Management Association. Research Triangle Park, NC. October 1995.

65. Guensler, R. (1990). "Diurnal Emission Patterns at a Wastewater Treatment Plant." 83rd Annual Meeting of the Air and Waste Management Association. Student Poster Competition. Third Prize. June 1990.

V. SERVICE

A. PROFESSIONAL CONTRIBUTIONS

Advisory Board Service

Institute of Transportation Studies, University of California, Davis (2014-Present)
Mortenson Center in Engineering for Developing Communities, University of Colorado (2012-Present)

Technical Committee Activities

Transportation Research Board - Member (1992-Date)
  Co-Chair (2014-Date): Managed Lanes Research Needs Subcommittee
  Committee Member (2014-2017): Managed Lanes (AHB35)
  Committee Member (2014-2017): Congestion Pricing Committee (ABE25)
  Committee Chairman (1997-2002): Transportation and Air Quality (A1F03)
  Committee Member (1992-2005): Transportation and Air Quality (A1F03)
Air and Waste Management Association - Member (1987-2004)
  Committee Member (1990-1999): Mobile Sources (AS-1)
  Committee Member (1990-1999): Land Use/Transportation Policies (EP-2)
American Society of Civil Engineers - Member (1987-2002)
  Member (1992-2000): Environmental and Energy Aspects of Transportation
  Committee Member (1994-1998): Urban Transportation Division Education Committee
  Transportation Planning and Air Quality IV Conference Committee (1999), Atlanta, GA. November
  Committee Secretary (1994-95): Environmental and Energy Aspects of Transportation
  Transportation Planning and Air Quality II Conference Committee (1993). Boston, MA. May
Society of Automotive Engineers – Member (1988-2002)

Organization and Chairmanship of Technical Sessions and Workshops

1. Guensler, R., (2002). "MOBILE6: Case Studies from Selected Urban Areas." Speaker and Moderator for the Specialty Workshop. 81st Annual Meeting of the Transportation Research Board. Washington, DC. January 2002.

2. Guensler, R., (2000). "A Look Inside EPA's MOBILE6 Mobile Source Emission Rate Model." Specialty Workshop. 79th Annual Meeting of the Transportation Research Board. Washington, DC. January 2000.

3. Guensler, R. (2000). "Ten Years after the CAAA of 1990: Where Have We Been; Where Are We Going?" Session 129. 79th Annual Meeting of the Transportation Research Board. Washington, DC. January 2000.

4. Guensler, R. (2000). "Impacts of the 1999 Circuit Court Rulings on Transportation and Air Quality Planning." Session 22. 79th Annual Meeting of the Transportation Research Board. Washington, DC. January 2000.

5. Guensler, R. (1999). "Assessment of Mobile Source Reformulated and Alternative Fuel Emissions." Session D8. 92nd Annual Meeting of the Air and Waste Management Association. Pittsburgh, PA. June 1999.

6. Guensler, R. (1999). "Advances in Mobile Source Emissions and Dispersion Modeling." Session D6. 92nd Annual Meeting of the Air and Waste Management Association. Pittsburgh, PA. June 1999.

7. Guensler, R. (1999). "Workshop on Microscale Air Quality Impact Assessment for Transportation Projects." Specialty Workshop. 78th Annual Meeting of the Transportation Research Board. Washington, DC. January 1999.

8. Guensler, R. (1998). "Heavy-Duty Truck Activity and Emissions." Session 206. 77th Annual Meeting of the Transportation Research Board. Washington, DC. January 1998.

9. Guensler, R. (1998). "One Stop Shopping for Electronic Transportation Resources: Utopia or Attainable Goal?" Specialty Workshop. 77th Annual Meeting of the Transportation Research Board. Washington, DC. January 1998.

10. Guensler, R. (1998). "Workshop on Emerging Transportation Air-Quality Analysis Methodologies." Specialty Workshop. 77th Annual Meeting of the Transportation Research Board. Washington, DC. January 1998.

11. Guensler, R. (1997). "Is Research Meeting Regulatory Needs?" Transportation Planning and Air Quality III. Granlibakken Conference Center. American Society of Civil Engineers. New York, NY. August 1997.

12. Guensler, R. (1997). "Current Emissions Factor Model Evaluations and Improvements." 7th Annual On-Road Vehicle Emissions Workshop, San Diego, CA. Coordinating Research Council. Atlanta, GA. April 1997.

13. Guensler, R. (1997). "Recent Developments in Motor Vehicle Emissions and Dispersion Modeling." Session 300. 76th Annual Meeting of the Transportation Research Board. Washington, DC. January 1997.

14. Guensler, R. (1996). "Air Quality Impact Assessment Studies." Session 114B. 75th Annual Meeting of the Transportation Research Board. Washington, DC. January 1996.

15. Guensler, R. (1995). "Mobile Source Emissions: Modeling. The Emission Inventory: Programs and Progress." Specialty Conference sponsored by the USEPA and the Air and Waste Management Association. Research Triangle Park, NC. October 1995.

16. Guensler, R. (1993). "Land Use/Transportation/Air Quality Modeling." Session 41A. 86th Annual Meeting of the Air and Waste Management Association. Pittsburgh, PA. June 1993.

17. Guensler, R. (1992). "Transportation and Air Quality." Session 140. 71st Annual Meeting of the Transportation Research Board. Washington, DC. January 1992.

<u>Invited Panel Discussant</u>

1. Guensler, R. et al., (2014). Congestion Pricing and Managed Lanes: 20 Years of Learning – Where have we been, where are we now and where are we going? Workshop 164. Washington, DC. January 12, 2014.

2. Guensler, R. (2011). Discussant. Experimental Economics Examination of Congestion Pricing. Center for Economic Analysis of Risk / FHWA Panel Review. Georgia State University. Atlanta, GA. December 5, 2011.

3. Guensler, R. (1998). Discussant. The Importance of Modal Modeling. Workshop on Emerging Transportation Air-Quality Analysis Methodologies. Specialty Workshop. 77th Annual Meeting of the Transportation Research Board. Washington, DC. January 1998.

4. Guensler, R. (1996). Panel Member. Expanding Metropolitan Highways: Implications for Air Quality and Energy Use (Special Report 245). Panel Discussion. Session 195. 75th Annual Meeting of the Transportation Research Board. Washington, DC. January 1996.

<u>Editorial Board Memberships</u>

Transportation Research D: Transport and Environment. Elsevier Publishing (1996-2008)

<u>Professional Peer Review Panels</u>

Member, National Academy of Sciences. ACRP Synthesis on Environmental Assessment of High Speed Rail v. Air Transport (ACRP 11-03/Topic S02-08), March 2012.
Member, National Science Foundation Proposal Review Panel. Resilient and Sustainable Infrastructures (EFRI/RESIN). Washington, DC, December 2007.
National Academy of Sciences, National Research Council, Board on Environmental Studies in Toxicology, Modeling Mobile Sources Emissions, January 2000.
US Environmental Protection Agency, Office of Transportation and Air Quality, Supplemental Federal Test Procedure Corrections to MOBILE6. February 2000.

<u>Other Local, State, and National Service</u>

Member, Grand Jury, Superior Court of Fulton County, Atlanta Judicial Circuit (January-February, 2007)
Member. Clean Air Campaign Advisory Committee. Atlanta, GA (2003, 2000-2001)
Member. Committee on Carbon Monoxide Episodes in Meteorological and Topographical Problem Areas. National Academy of Sciences, National Research Council, Board on Environmental Studies and Toxicology (2001-2002)

Member. Air Quality Planning Team Technical Subcommittee for the RTP/RDP Update. Atlanta Regional Commission (2001-2002)
Co-Facilitator, Environmental Research Needs in Transportation. Invitational Conference. Transportation and Air Quality Workgroup. National Research Council, Transportation Research Board (2002)
Member. GRTA Air Quality Blue Ribbon Panel Conference (2001)
Member and Co-Chair of the Modeling Working Group, USEPA Office of Mobile Sources Technical Advisory Committee, Sub-Committee to the Clean Air Act Advisory Committee (1995-2001)
Member. Committee on Aeronautics Research and Technology for Environmental Compatibility. National Academy of Sciences, National Research Council, Aeronautics and Space Engineering Board (2000)
Member, Mobile Source Sector Workgroup for On-Highway Vehicles. Southern Appalachian Mountain Initiative (SAMI). E. H. Pechan, Inc. (1998)
Co-Facilitator, Environmental Research Needs in Transportation. Invitational Conference. Transportation and Air Quality Workgroup. National Research Council, Transportation Research Board (1996)
Member, FHWA/ORNL Advisory Panel on Emissions Modeling (1993-1994)
Member, National Research Council, Transportation Research Board Workgroup: Transportation and Air Quality Research Needs (1991)
Member, South Coast AQMD Market Incentives Workgroup (1990)
Member, AB2595 Heavy-Duty Truck Technical Advisory Group (1990)
Expert Witness Designation, USEPA Headquarters (1990)
Member, California Technical Review Group, Subcommittees: Industrial, Aerospace, and Marine Coatings, Transfer Efficiency, VOC Content, and Vapor Pressure (1986-1989)

B. CAMPUS CONTRIBUTIONS

Program Development

In 2007, Dr. Guensler brokered a three-year Basic Ordering Agreement (BOA) between Georgia Tech and the State Road and Tollway Authority, which was extended through 2013.

Dr. Guensler worked with the College of Architecture City and Regional Planning Program to propose and develop a dual degree program in Transportation Engineering and City Planning. The dual degree program was established so that students could complete both degrees in two years. The dual-degree program requires students to complete a detailed written thesis that crosses both disciplines. Both schools approved the proposed program in 1996. An updated program was approved by the Board of Regents in 2010.

Institute and School Committees

Lead, School of CEE Transportation Group Graduate Admissions Ad-Hoc Committee (2014)
Member, School of CEE Construction Program Ad-Hoc Committee (2012-2014)
Group Leader, Transportation Affinity Group, School of CEE (2012-2013)
Member, School of CEE Promotion and Tenure Committee (2011-2013)
Member, School of CEE Graduate Committee (2012)
Member, School of CEE Reappointment, Promotion, and Tenure Committee (2008-2011)
Member, School of CEE Statutory Advisory Committee (2007-2010)
Member, Georgia Tech Academic Technologies Advisory Committee (2004)
Chair, School of CEE Computer Committee (2004, 2000-2001)
Member, School of CEE Interdisciplinary Research and International Programs Committee (2003-2004)
Chair, School of CEE Transportation Faculty Search Committee (2004)
Affinity Group Leader, Transportation Affinity Group, School of CEE (2002-2004)
Member, School of CEE Computer Committee (2000-2004)
Member, School of CEE Web Committee (2003)
Member, Georgia Tech Procurement Focus Group (1996-97)
Member, School of CEE Semester Conversion Task Force (1995-96)
Member, School of CEE Undergraduate Study Committee (1995-96)

C. OTHER CONTRIBUTIONS

Research Sabbaticals

University of California Berkeley, Institute of Transportation Studies (Spring and Summer 2002)

Consulting

Battelle Memorial Institute (2014-Present)
Resource Systems Group, Inc. (2014-Present)
Trans/AQ, Inc. (1998-Present)
Vehicle Monitoring Technologies, Inc., a Georgia Tech Venture Labs Company (2005-Present)
North Highland Co. (2009-2010)
Louis Berger Associates (2001-2006)
Cambridge Systematics, Inc. (1995-2006)
Metropolitan Atlanta Chamber of Commerce (2002-2003)
Georgia Regional Transportation Authority (2000-2001)
ICF Kaiser (1999-2000)
Hagler Bailly, Transportation Division (1998-1999)
Henry, Lowerre, Johnson, Hess & Frederick, Attorneys at Law (1998-1999)
Expert Witness in the field of Transportation and Air Quality (ACT v. NCTCOG, 1998)
The University of Tennessee, Knoxville (1994-1997)

VI. GRANTS AND CONTRACTS

A. AS PRINCIPAL AND CO-PRINCIPAL INVESTIGATOR

Funded

1. National Center for Sustainable Transportation (NCST), Year 2
US Department of Transportation, Research Innovation and Technology Administration, National UTC
Amount: $473,000 (2015-2016)
Co-Principal Investigator with Yanzhi Xu and Michael Rodgers

2. National Center for Sustainable Transportation (NCST)
Professional Education Course Development for Sustainable Transportation
Georgia Institute of Technology, Office of the Vice President for Research
Amount: $255,000 (2014-2016)

3. GHG Calculator for Heavy-Duty Vehicles
National Center for Sustainable Transportation Jump Start Project 3.2
US Department of Transportation, Research Innovation and Technology Administration, National UTC
Amount: $138,000 (2014-2015)
Co-Principal Investigator with Yanzhi Xu and Michael Rodgers

4. Improved Emissions Models for Project Evaluation
National Center for Sustainable Transportation Jump Start Project 4
US Department of Transportation, Research Innovation and Technology Administration, National UTC
Amount: $92,000 (2014-2015)
Co-Principal Investigator with Michael Rodgers, Yanzhi Xu, and Michael Hunter

5. Eco-driving for Transit Vehicles
National Center for Sustainable Transportation Jump Start Project 2.2
US Department of Transportation, Research Innovation and Technology Administration, National UTC
Amount: $55,000 (2014-2015)
Co-Principal Investigator with Vetri Elango and Yanzhi Xu

6. Innovative Data Collection to Improve Transit Service Assessment
National Center for Sustainable Transportation Jump Start Project 6.1
US Department of Transportation, Research Innovation and Technology Administration, National UTC
Amount: $103,000 (2014-2015)
Co-Principal Investigator with Yanzhi Xu, Vetri Elango, and Kari Watkins

7. Sustainable Transportation Education Program Development
National Center for Sustainable Transportation Jump Start Project 12
US Department of Transportation, Research Innovation and Technology Administration, National UTC
Amount: $83,000 (2014-2015)
Co-Principal Investigator with Yanzhi Xu, Adjo Amekudzi, and Catherine Ross

8. Macro and Micro Modeling Tools for Socioeconomic Evaluation and Pricing of Managed Lanes
Georgia Department of Transportation and NCTSPM University Transportation Center
Amount: $140,000 (2014-2015)
Principal Investigator

9. HOV to HOT Conversion Impacts on Carpooling
NCTSPM University Transportation Center
Amount: $150,500 (2013-2014)
Co-Principal Investigator with Yanzhi Xu

10. National Center for Sustainable Transportation
US Department of Transportation, Research Innovation and Technology Administration, National UTC
Amount: $5,656,000, $943,000 in CEE (2013-2017), 50% Federal and 50% State/Local
Lead University: UC Davis, D. Sperling Executive Director
Partner Universities: University of Southern California, UC Riverside, University of Vermont, Cal State Long Beach
Associate Directors: S. Handy, R. Guensler, M. Barth, G. Giuliano, L. Aultman-Hall

11. Sidewalk Quality Assessment Project Undergraduate Summer Research Program
Georgia Institute of Technology Office of Undergraduate Education
Amount: $1,000 (Summer 2013)

12. GRTA/GDOT Real-Time Tracking and Choice Data
University Transportation Center and Georgia Department of Transportation
Amount: $130,000 (2012-2013)

13. Evaluation of Innovative Weave Zone Striping
Georgia Department of Transportation
Amount: $75,000 (2012-2013)
Co-Principal Investigators (Drs. Michael Hunter and Angshuman Guin)

14. Development of a GHG Emissions Calculator Incorporating Electric Vehicle Options
Oak Ridge National Laboratory and Federal Transit Administration
Amount: $166,000 (2012-2013)
Co-Principal Investigator (Dr. Michael Rodgers)

15. Automated Sidewalk Quality and Safety Assessment System
STRIDE University Transportation Center and Georgia Department of Transportation
Amount: $400,000 (2012-2013)

16. Southeast Transportation Research, Innovation and Education Center (STRIDE)
US Department of Transportation, University Transportation Center Program
University of Florida, Georgia Institute of Technology, Mississippi State, University of North Carolina, North Carolina State University, Florida International University, University of Alabama Birmingham and Auburn University
Amount: $7,000,000, $1,095,000 in CEE (2012-2014)
Serving as STRIDE Principal Investigator Representing Georgia Tech

17. Effective Capacity Analysis and Traffic Data Collection for the I-85 HOV to HOT Conversion (Supplement)
Georgia Department of Transportation
Amount: $312,000 (2012-2013)
Co-Principal Investigators (Drs. Michael Hunter and Jorge Laval)

18. Value Pricing Data Analysis Fellowship Program. Phase II: Fellowship Support
Georgia Department of Transportation
Amount: $190,000 (2011-2013)

19. Work Zone Technology Testbed
Georgia Department of Transportation
Amount: $300,000 (2011-2013)
Co-Principal Investigators (Drs. Michael Hunter and Angshuman Guin)

20. HOT Corridor Manual Traffic Counts
State Road and Tollway Authority
Amount: $22,000 (2011-2012)

21. HOT Corridor Travel Time Data Collection
State Road and Tollway Authority
Amount: $40,000 (2011)

22. Effective Capacity Analysis and Traffic Data Collection for the I-85 HOV to HOT Conversion
Georgia Department of Transportation
Amount: $1,986,000 (2010-2012)
Co-Principal Investigators (Drs. Michael Hunter and Jorge Laval)

23. Cobb County School District School Bus Emissions Control and Anti-Idling Program
US Environmental Protection Agency, Southeast Diesel Collaborative, ARRA Funds
Amount: $1,100,000, $635,000 in CEE (2010-2011)

24. Value Pricing Data Analysis Fellowship Program. Phase I: Preliminary Data Processing
Georgia Department of Transportation
Amount: $95,000 (2009-2010)

25. Utility Factors for Atlanta Vehicle Activity
Emmeskay, Inc.
Amount: $30,000 (2009)

26. VMT Phase IIb Development Grant
Georgia Research Alliance
Amount: $50,000 (2009)

27. Managed Lane Air Quality and Environmental Justice Issues
State Road and Tollway Authority
Amount: $19,000 (2008-2009)

28. VMT Phase IIa Development Grant
Georgia Research Alliance
Amount: $50,000 (2008)

29. EFRI ARES-CI Embedded Distributed Simulation for Transportation System Management
National Science Foundation (Grant #0735991)
Amount: $1,976,114 (2007-2012)
Co-Principal Investigator (with Drs. Michael Hunter (PI), Richard Fujimoto, and C. Alexopoulos)

30. Scoping of Potential Congestion Pricing Impacts on Delivery Fleets and Commercial Vehicle Operations
Georgia Department of Transportation and Federal Highway Administration
Amount: $219,000 (2007-2009)

31. Evaluation of Public Acceptance of Atlanta Congestion Pricing Programs
Georgia Department of Transportation
Amount: $501,000, $240,000 in CEE (2007-2009)
Co-Principal Investigator (with Dr. Catherine Ross)

32. Managed Lane System Enforcement and Transition Issues
State Road and Tollway Authority
Amount: $25,000 (2007-2008)

33. Commuter Choice and Value Pricing Insurance Incentive Program
Federal Highway Administration/Georgia Department of Transportation
Amount: $2,770,000 (2001-2009)
Co-Principal Investigator (with Jennifer Ogle)

34. Dynamic, Simulation-Based Management of Surface Transportation Systems
National Science Foundation, Core Computing Division
Amount: $350,000 (2005-2007), $210,000 in CEE
Co-Principal Investigator (with Drs. Richard Fujimoto, Karsten Schwan, Michael Hunter, and John Leonard)

35. ITR: Simulation-Based Operations Planning for Regional Transportation Systems
National Science Foundation
Amount: $400,000 (2003-2006), $200,000 in CEE
Co-Principal Investigator (with Dr. Richard Fujimoto)

36. Analysis of Start and Soak Distributions in Atlanta
    Georgia Department of Transportation and US Environmental Protection Agency
    Amount: $45,000 (2005)
    Supplement to the Phase 1 Commuter Choice and Value Pricing Insurance Incentive Program

37. Analysis of Long Trips and Household Travel Space
    Georgia Department of Transportation and Federal Highway Administration
    Amount: $40,000 (2005)
    Supplement to the Phase 1 Commuter Choice and Value Pricing Insurance Incentive Program
    Co-Principal Investigator (with Dr. Jennifer Ogle)

38. Heavy Duty Diesel Truck Activity Analysis II
    RARE Project. US Environmental Protection Agency
    Amount: $98,000 (2004-2006)

39. Analysis of Commute Atlanta Speed and Activity Data
    Georgia Department of Transportation and Federal Highway Administration
    Amount: $147,000 (2004)
    Supplement to the Phase 1 Commuter Choice and Value Pricing Insurance Incentive Program
    Co-Principal Investigator (with Dr. Jennifer Ogle)

40. Preparation and Analysis of Instrumented Vehicle Data
    Sponsor name withheld under a non-disclosure agreement
    Amount: $35,000 (2004)

41. Heavy Duty Diesel Truck Activity Analysis
    RARE Project. US Environmental Protection Agency
    Amount: $100,000 (2004)

42. A Simulation-Based Test Bed for Networked Sensors in Surface Transportation Systems
    National Science Foundation
    Amount: $150,000 (2003-2004), $50,000 in CEE
    Co-Principal Investigator (with Dr. Richard Fujimoto)

43. Knoxville External Trip Survey
    NuStats International
    Amount: $40,000 (2000)
    Co-Principal Investigator (with Jim Pearson)

44. Assessing the Air Quality Impacts of Intelligent Transportation Systems in Georgia
    Georgia Department of Transportation
    Amount: $251,000 (1998-2003)
    Co-Principal Investigator (with Dr. John Leonard)

45. Evaluation of Ramp Metering Impacts on Air Quality
    Georgia Department of Transportation
    Amount: $439,000 (1998-2000)
    Co-Principal Investigator (with Dr. Karen Dixon)

46. Validation of the MEASURE GIS-Based Modal Emissions Model
    US Environmental Protection Agency
    Amount: $500,000 (1998-1999)
    Co-Principal Investigator (with Dr. Michael Meyer and Dr. Mike Rodgers)

47. Development of a Comprehensive Vehicle Instrument Package for Monitoring Individual Tripmaking Behavior (Phase I and II)
    Federal Highway Administration and Georgia DOT
    Amount: $140,000 (1997-1998)
    Principal Investigator

48. Refinement of the MEASURE GIS-Based Modal Emissions Model
    Georgia Tech Research Partnership
    Federal Highway Administration and USEPA

Amount: $250,000 (1997-1998)
Co-Principal Investigator (with Dr. Michael Meyer and Dr. Mike Rodgers)

49. Development of a Multimedia Semester Course in Environmental Impact Assessment
Faculty Development Grant
Georgia Institute of Technology
Amount: $20,000 (Fall 1996)
Principal Investigator

50. Development of the Transportation Research, Education, and Development World Wide Web Server
Georgia Institute of Technology
American Society of Civil Engineers
Amount: $2,000 (1996)
Principal Investigator

51. Assessment of Motor Vehicle Air Quality Impacts and Development of an Emission Modeling Protocol for Conformity Analysis
Institute of Transportation Studies, University of California, Davis
California DOT
Amount: $168,000 (1993-1994)
Principal Investigator

52. Environmental Aspects of IVHS: Air Quality Impacts of IVHS
Institute of Transportation Studies, University of California, Davis
Partners for Advanced Transit and Highways
Amount: $85,000 (1992-1994)
Co-Principal Investigator with Simon Washington

53. Evaluating the Air Quality Impacts of Heavy-Duty Trucks
Institute of Transportation Studies, University of California, Davis
Amount: $40,000 (1990-1991)
Principal Investigator

Submitted

1. License Plate Reader Technology: Privacy Risk Analysis
National Cooperative Highway Research Program
Amount: $125,000 (2015), $95,000 in CEE

2. Transportation Network Performance Monitoring and Distributed Simulation for Transportation Energy Efficiency
Concept Paper submitted 12/20/14 (first step toward receiving an invitation to submit a full proposal)
U.S. Department of Energy, ARPA-E
Amount: $2,800,000 (2015-2017)

3. City of Atlanta Sidewalk Data Collection, Sidewalk Sentry Upgrades, and Sidewalk Asset Management System
City of Atlanta and Georgia Department of Transportation
Amount: $335,000 (2014-2015)

4. I-85 HOT Corridor Crash Impact Assessment for Weaving Activity
Georgia Department of Transportation (Submitted to the RAC)
Amount: $180,000 (2014-2015)
Co-Principal Investigator: Michael Hunter, Angshuman Guin

5. Measurement of Sidewalk Quality Data for Cobb County Transit Routes
Cobb County Transportation Department and AECOM
Amount: $42,000 (2014)

6. Connecting Opportunities: An Interactive Tool to Visualize Express Lane Impacts on Employment Access
Georgia Department of Transportation (Submitted to the RAC)
Amount: $300,000 (2014-2015)
Co-Principal Investigator: Yanzhi Xu

B. AS INVESTIGATOR

Funded

1. EPA Clean Air Research Center
US Environmental Protection Agency
Amount: $8,000,000, with $3,400,00 at Georgia Tech, and $1,800,000 in CEE (2011-2016)

2. Blood Marker Analysis of In-Vehicle Driver Exposure to PM
Centers for Disease Control
Amount: $150,000 (2008-2009), $50,000 in CEE
Investigator (with Dr. Jeremy Sarnat, Emory University, and Michael Bergin, Georgia Tech)

3. Atlanta Heavy-Duty Vehicle and Equipment Inventory and Emissions Study
Georgia Regional Transportation Administration
Amount: $300,000 (2002-2003)
Principal Investigator: Dr. Michael O. Rodgers

4. Predictive Diagnostics for Bus Maintenance
National Research Council
Amount: $15,000 in CEE (2002)
Principal Investigator: Ronald Wagner, GTRI

5. Implementation of MOBILE/MEASURE
US Environmental Protection Agency
Amount: $238,000 (2001-2002)
Principal Investigator: Dr. Michael O. Rodgers

6. Electronic Travel Diary Applications in the Atlanta Year 2000 Travel Survey Update
(A Component of the $1.6M SMARTRAQ Initiative)
Atlanta Regional Commission, Georgia DOT, FHWA, CDC
Amount: $300,000 (1998-2000)
Co-Principal Investigators: Dr. Larry Frank and Dr. Simon Washington

7. Development of Vehicle Activity Components for the Georgia Tech GIS-Based Modal Emissions Model
Georgia Institute of Technology
Federal Highway Administration and USEPA
Amount: $380,000 (1995-1996)
Co-Principal Investigators: Dr. Michael Meyer and Dr. Mike Rodgers

8. Development of the GIS-Based Modal Emissions Model
Georgia Institute of Technology
Federal Highway Administration and USEPA
Amount: $380,000 (1995-1996)
Co-Principal Investigator: Dr. Michael Meyer and Dr. Mike Rodgers

9. A Protocol for Developing Representative Facility-Type Driving Cycles
California Department of Transportation
Amount: $239,000 (1994-1996)
Principal Investigator Simon Washington

10. Analysis of TCMs Designed to Reduce Freeway Congestion
Institute of Transportation Studies, University of California, Davis
South Coast Air Quality Management District
Amount: $148,000 (1992-1994)
Principal Investigator Brett Koenig

Submitted

1. None

VII. HONORS AND AWARDS

Professional

Golden Shoe Award, Pedestrian-friendly Research Project, Georgia Tech's Comprehensive Sidewalk Inventory and Research, Pedestrians Educating Drivers on Safety (PEDS), Atlanta (2013)
Association of Pedestrian and Bicycle Professionals, Annual Meeting, Best Poster Award (2013)
Pyke Johnson Award for Best Transportation Research Board Paper in Planning and Environment, Yoon, et al., A Methodology for Developing Transit Bus Speed-Acceleration Matrices to be used in Load-Based Mobile Source Emissions Models, National Research Council (2005)
Certificate of Appreciation for Outstanding Service, National Academy of Sciences (2003)
Testimonial of Appreciation for Distinguished Service, National Research Council (2002)
Certificate of Appreciation, Clean Air Act Advisory Committee (1998)
Eno Foundation Transportation Leadership Fellow (1993)
Chevron Corporation Research Fellow (1992)
Air & Waste Management Association Scholar (1990)
Tribute of Appreciation, Rule Effectiveness Study, USEPA Region IX (1990)
Air & Waste Management Association, Third Prize, Student Poster Competition (1990)
University of California, Davis, Graduate Student Travel Grant Recipient (1990)
US Environmental Protection Agency Fellow (1989)
Sustained Superior Accomplishment Award, California Air Resources Board (1988)
Registered Engineer in Training: CA XE065494

Institute

Research Innovation Award, School of CEE (2013)
Outstanding Faculty Leadership for Development of Graduate Research Assistants, School of CEE (2000)
Outstanding Teaching Award, School of CEE (1999)
Outstanding Faculty Leadership for Development of Graduate Research Assistants, School of CEE (1998)
Faculty Development Grant Recipient, Georgia Tech (1997)
C-SPAN in the Classroom Fellow (1996)
Georgia Institute of Technology, Class of 1969 Teaching Fellow (1996)
Grant Recipient, UC Transportation Center (1992)
Institute of Transportation Studies Fellow (1991)

ORGANIZATIONAL CONFLICT OF INTEREST CERTIFICATE

Customer: U.S. Environmental Protection Agency

Contractor: ICF Incorporated, LLC, 9300 Lee Highway, Fairfax, VA 22031

Prime Contract: EP-C-12-011

Subcontract/Peer Reviewer: Randall Guensler

In accordance with EPAAR 1552.209-70 through 1552.209-73, Subcontractor/Consultant certifies to the best of its knowledge and belief, that:

___X___ No actual or potential conflict of interest exists.

_______ An actual or potential conflict of interest exists. See attached full disclosure.

Subcontractor/Consultant certifies that its personnel, who perform work on this contract, have been informed of their obligations to report personal and organizational conflict of interest to Contractor and Subcontractor/Consultant recognizes its continuing obligation to identify and report any actual or potential organizational conflicts of interest arising during performance under referenced contract.

____
Subcontractor/Consultant

8/10/2015
____
Date

100 Cambridgepark Drive, Suite 500 — Cambridge MA 02140 — 617.250.4200 — 617.250.4261 fax — www.icfi.com

Appendix B. Charge Letter

June 23rd, 2015

Dr. Kanok Boriboonsomsin
Center for Environmental Research and Technology
University of California at Riverside
1084 Columbia Ave
Riverside, CA 92507

Subject: Peer Review of EPA Vehicle Population and Activity Update Report

Dear Dr. Boriboonsomsin,

ICF International has been contracted by EPA to facilitate a peer review. In late April we corresponded by email and you indicated your availability to participate as a paid reviewer to review of the EPA Office of Transportation and Air Quality's report "Vehicle Population and Activity Update Report", also known as the "Fleets Report". You have been selected to participate on this panel. ICF will compensate you $3,000 for your services. This charge letter provides you with a list of directed questions for your review, the review schedule, and the materials we would like you to send to us at the conclusion of the review. In addition, attached to this letter is a copy of the report that we would like you to review.

Charge Questions

We are submitting this material for you to review the selected methods and their underlying assumptions, their consistency with the current science as you understand it and the clarity and completeness of the presentation. For this review, no independent data analysis is required. Rather, we ask that you assess whether the information provided is representative of the state of current understanding, and whether incorporating this information in MOVES will result in appropriate predictions and conclusions.

We request that you provide us with your comments on the content sequentially. Grammatical/formatting and other minor comments can be provided separately.

Below are questions to define the scope of the review; we are not expecting individual responses to the questions, but would like them to help guide your response.

General Questions to Consider

1. Does the presentation describe the selected data sources sufficiently to allow the reader to form a general view of the quantity, quality and representativeness of data to be used in the development of emission rates? Are you able to recommend alternate data sources that might better allow the model to estimate national or regional default values?

2. Is the description of analytic methods and procedures clear and detailed enough to allow the reader to develop an adequate understanding of the steps taken and the assumptions made by EPA

in developing the model inputs? Are examples selected for tables and figures well chosen and do they assist the reader in understanding the intended approaches and methods?

3. Are the methods and procedures employed technically appropriate and reasonable with respect to the relevant disciplines, including physics, chemistry, engineering, mathematics and statistics? Are you able to suggest or recommend alternate approaches that might better achieve the goal of developing accurate and representative model inputs? In making recommendations please distinguish between cases involving reasonable disagreement in adoption of methods as opposed to cases where you conclude that current methods involve specific technical errors.

4. In areas where EPA has concluded that applicable data is meager or unavailable, and consequently has made assumptions to frame approaches and arrive at solutions, do you agree that the assumptions are appropriate and reasonable? If not, and you are so able, please suggest an alternative set(s) of assumptions that might lead to more reasonable or accurate model inputs while allowing a reasonable margin of environmental protection.

5. Are the resulting model inputs appropriate, and to the best of your knowledge and experience, reasonably consistent with physical and chemical processes involved in mobile source emissions formation and control? Are the resulting model inputs empirically consistent with the body of data and literature that has come to your attention?

Schedule
The schedule for this peer review is as follows:

- June 23rd 2015: Charge letter distributed to reviewers
- August 7, 2015: Comment/review due via email to Laurence.O'Rourke@icfi.com

Materials

Upon completion of your review, you should submit your report under a cover letter that states 1) your name, 2) the name and address of your organization, and 3) a statement of any real or perceived conflict(s) of interest.

Should you have any questions or concerns, feel free to contact me via phone at 617-250-4226 or by email. In addition, the EPA project manager for this effort is Kent Helmer and he may be reached at 734-214-4825.

Thanks for your participation!

Sincerely,

Larry O’Rourke
Manager, ICF International

Attachment: EPA Fleet and Activity Report 20150619_peer_review

June 23rd, 2015

Dr. Randall Guensler
Georgia Institute of Technology
790 Atlantic Dr.
Atlanta, GA 30332

Subject: Peer Review of EPA Vehicle Population and Activity Update Report

Dear Dr. Guensler,

ICF International has been contracted by EPA to facilitate a peer review. In late April we corresponded by email and you indicated your availability to participate as a paid reviewer to review of the EPA Office of Transportation and Air Quality's report "Vehicle Population and Activity Update Report", also known as the "Fleets Report". You have been selected to participate on this panel. ICF will compensate you $3,000 for your services. This charge letter provides you with a list of directed questions for your review, the review schedule, and the materials we would like you to send to us at the conclusion of the review. In addition, attached to this letter is a copy of the report that we would like you to review.

Charge Questions

We are submitting this material for you to review the selected methods and their underlying assumptions, their consistency with the current science as you understand it and the clarity and completeness of the presentation. For this review, no independent data analysis is required. Rather, we ask that you assess whether the information provided is representative of the state of current understanding, and whether incorporating this information in MOVES will result in appropriate predictions and conclusions.

We request that you provide us with your comments on the content sequentially. Grammatical/formatting and other minor comments can be provided separately.

Below are questions to define the scope of the review; we are not expecting individual responses to the questions, but would like them to help guide your response.

General Questions to Consider

1. Does the presentation describe the selected data sources sufficiently to allow the reader to form a general view of the quantity, quality and representativeness of data to be used in the development of emission rates? Are you able to recommend alternate data sources that might better allow the model to estimate national or regional default values?

2. Is the description of analytic methods and procedures clear and detailed enough to allow the reader to develop an adequate understanding of the steps taken and the assumptions made by EPA in developing the model inputs? Are examples selected for tables and figures well chosen and do they assist the reader in understanding the intended approaches and methods?

3. Are the methods and procedures employed technically appropriate and reasonable with respect to the relevant disciplines, including physics, chemistry, engineering, mathematics and statistics? Are you able to suggest or recommend alternate approaches that might better achieve the goal of developing accurate and representative model inputs? In making recommendations please distinguish between cases involving reasonable disagreement in adoption of methods as opposed to cases where you conclude that current methods involve specific technical errors.

4. In areas where EPA has concluded that applicable data is meager or unavailable, and consequently has made assumptions to frame approaches and arrive at solutions, do you agree that the assumptions are appropriate and reasonable? If not, and you are so able, please suggest an alternative set(s) of assumptions that might lead to more reasonable or accurate model inputs while allowing a reasonable margin of environmental protection.

5. Are the resulting model inputs appropriate, and to the best of your knowledge and experience, reasonably consistent with physical and chemical processes involved in mobile source emissions formation and control? Are the resulting model inputs empirically consistent with the body of data and literature that has come to your attention?

Schedule
The schedule for this peer review is as follows:

- June 23nd 2015: Charge letter distributed to reviewers
- July 31th 2015: Comment/review due via email to Laurence.O'Rourke@icfi.com

Materials

Upon completion of your review, you should submit your report under a cover letter that states 1) your name, 2) the name and address of your organization, and 3) a statement of any real or perceived conflict(s) of interest.

Should you have any questions or concerns, feel free to contact me via phone at 617-250-4226 or by email. In addition, the EPA project manager for this effort is Kent Helmer and he may be reached at 734-214-4825.

Thanks for your participation!

Sincerely,

Larry O'Rourke
Manager, ICF International

Attachment: EPA Fleet and Activity Report 20150619_peer_review

Appendix C. Kanok Boriboonsomsin Review Comments

UNIVERSITY OF CALIFORNIA, RIVERSIDE

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COLLEGE OF ENGINEERING - 022
CENTER FOR ENVIRONMENTAL RESEARCH & TECHNOLOGY
(909) 781-5791   FAX (909) 781-5790

RIVERSIDE, CALIFORNIA 92521-0434

August 7, 2015

Larry O'Rourke
Manager, ICF International

RE: Peer Review of *Draft Report on Population and Activity of On-road Vehicles in MOVES2014*

Dear Mr. O'Rourke:

Thank you for inviting me to conduct a peer review of the *Draft Report on Population and Activity of On-road Vehicles in MOVES2014*. I have completed the review.

Enclosed with this letter is a summary of my review comments and recommendations. These comments are made on the basis of the current state of science as I understand it. To the best of my knowledge, I have no real or perceived conflicts of interest in conducting this peer review.

Please feel free to contact me should you have any questions or need additional information regarding this review.

Sincerely,

Kanok Boriboonsomsin, Ph.D., P.E.
College of Engineering - Center for Environmental Research and Technology
University of California at Riverside
1084 Columbia Avenue, Riverside, CA 92507
Tel: 951-781-5792, Fax: 951-781-5744
Email: kanok@cert.ucr.edu

Enclosure: A summary of review comments and recommendations

Peer Review of *Draft Report on Population and Activity of On-road Vehicles in MOVES2014*

By: Kanok Boriboonsomsin, Ph.D., P.E.
College of Engineering - Center for Environmental Research and Technology
University of California at Riverside

This is a review of the *Draft Report on Population and Activity of On-road Vehicles in MOVES2014*, referred to as the "Fleets Report", prepared by the EPA Office of Transportation and Air Quality. I was also a peer reviewer of the *Draft MOVES2009 Highway Vehicle Population and Activity Data*, which helped me identify and understand changes made to the national default values for vehicle population and activity inputs in MOVES2014 during the time of this review.

Overall, the Fleets Report is well written and organized, with sensible use of examples, tables, and figures. I appreciate the addition of Section 2 (MOVES Vehicle and Activity Classifications), which will help readers understand early on the various ways in which vehicles and their activities are classified in the context of MOVES. I find the description of analytical methods and procedures to be sufficiently clear with appropriate use of mathematical equations to help explain complex calculations, such as in Section 9.2 (Heavy-Duty Average Speed Distributions). I also appreciate the list of areas for future research in Section 16 (Conclusion and Areas for Future Research), which informs research directions for improving the vehicle population and activity data inputs in future updates of MOVES.

In terms of the vehicle population and activity inputs, I find that the national default values in MOVES2014 have been appropriately updated based on more recent data from Polk2011, AEO2014, and TEDB2013. Perhaps, the most important development in this update is the use of nationwide GPS dataset to develop average speed distributions for light-duty vehicles. This is an exciting time for vehicle activity research due to the increasing availability of large-scale, high-resolution instrumented vehicle data from a variety of sources. As indicated in the Fleets Report, many of the limitations in the current MOVES vehicle activity inputs can be addressed through analysis of such instrumented vehicle data.

Detailed comments and suggestions are provided below. These are made with the understanding of the challenges of developing nationally representative default values for MOVES vehicle population and activity inputs under the limited resources that the EPA has.

Section 1 – Introduction

- An early explanation of the analysis years considered in this report (e.g., 2011 being the base year) would be helpful to readers.

Section 2.3 – Regulatory Classes

- The mapping between multiple vehicle classification schemes has always been a challenging topic. The introduction of a new regulatory class 40 is well thought out, and the rationale for it is well explained.

Section 2.4 – Fuel Types

- The population of CNG-fueled refuse trucks is growing and emissions test data of these trucks are increasingly available. This source type-fuel type combination may be considered for modeling in future versions of MOVES.

Section 2.8 – Allowable Vehicle Modeling Combinations

- Tables 2-6 and 2-7 provide a very good summary of allowable vehicle modeling combinations in MOVES2014.
- Where would shuttle buses (e.g., those used to pick up and drop off passengers at airports) fit in Table 2-7?

Section 4.1 – Historic Vehicle Miles Traveled (1990 and 1999-2011)

- Does FHWA publish the methodology used to adjust VMT data for 2000-2006? If not, the average ratio method used appears reasonable.

Section 4.2 – Projected Vehicle Miles Traveled (2012-2050)

- The methods used to project VMT for future years are appropriate.

Section 5.1 – Historic Source Type Populations (1990 and 1999-2011)

- It is described that "the 2000-2010 distributions among source types within the general truck categories were linearly interpolated between 1999 and 2011". However, the 2000-2010 truck population distributions in Figures 5-2, 5-3, and 5-4 do not show linear trends. Please clarify the linear interpolation that was performed.

Section 5.2 – Projected Vehicle Populations (2012-2050)

- The use of VMT growth as a surrogate for vehicle population growth is reasonable according to the analysis of VMT per vehicle trends shown in Table 5-2.

Section 6.2.1 – Fuel Type and Regulatory Class Distributions

- Data on actual fuel type used by E85-capable vehicles are available for 100 vehicles in California (http://www.dot.ca.gov/research/researchreports/reports/2015/final_report_task_1919.pdf), which may be used in future updates.
- According to AEO2014, hybrid electric and plug-in hybrid electric vehicles are projected to grow from 2.2% of total cars and light truck sales in 2011 to 6.1% in 2040. Would they warrant their own category with respect to fuel type in future versions of MOVES?

Section 8 – VMT Distribution of Source Type by Road Type

- In Table 8-2, it is my personal opinion that some numbers are not intuitive. For example, I would think that refuse trucks are operated mostly in urban areas, but the table shows that these trucks have about the same VMT fraction in rural and urban areas. In another example, combination long-haul trucks have a very similar VMT distribution to that of combination short-haul trucks although I would expect long-haul trucks to have a higher VMT fraction on rural restricted access roads. The numbers in Table 8-2 are developed from the 2011 NEI V1, which is probably the most appropriate source of this type of data at this time. These numbers may be compared with numbers developed from large-scale GPS datasets for each source type in the future.

Section 9.1 – Light-Duty Average Speed Distributions

- It may be of interest to compare some of the average speed distributions estimated from TomTom dataset with those estimated from traffic monitoring systems. For example, California has the Freeway Performance Measurement System or PeMS (http://pems.dot.ca.gov/). Average speed distributions can be estimated using a subset of TomTom data on California freeways and compare to those estimated from PeMS. This would help understand potential biases, if any, in TomTom data. It is understood that to do so will require additional analyses by TomTom as the raw data are not provided to ERG and EPA.
- In Figure 9-1, it is observed that the highest average speed fraction for urban unrestricted access road is not in the lowest average speed bin (< 2.5 mph) although one would expect a significant

amount of idle time at signalized intersections. This may be due to the length of intersection segments being much longer than a typical length of traffic queue, which causes the zero speed while idling in the queue to be canceled out by relatively higher speeds before joining the queue. I am not sure how much this shift in the average speed distribution would impact emission inventories at the national scale. If the impact would be significant enough, these intersection segments may be divided into shorter segments in future analyses.

Section 9.2 – Heavy-Duty Average Speed Distributions

- The adjustment made in this section is well done.

Section 10.2 – Ramp Activity

- What data were used to estimate operating mode distributions for ramp activity?
- The ramp fraction may be determined using either PeMS or TomTom data. It is understood that the latter will require additional analyses by TomTom as the raw data are not provided to ERG and EPA.

Section 11.1 – National Default Hoteling Rate

- The assumptions made in this section can be validated using large-scale GPS datasets of commercial trucks, for example, the truck GPS dataset maintained by the American Transportation Research Institute (ATRI) (http://atri-online.org/2014/10/28/truck-gps-data-for-tracking-freight-flows/).

Section 11.2 – Hoteling Activity Distribution

- There are studies that provide data on APU and truck electrification usage that may be considered in future updates. For example:
    - Frey, H. C., P.-Y. Kuo, and C. Villa. (2008). Methodology for characterization of long-haul truck idling activity under real-world conditions. *Transportation Research Part D*, 13, 516-523.
    - National Renewable Energy Laboratory (NREL)'s Truck Stop Electrification Testing (http://www.nrel.gov/transportation/fleettest_truck_stop_electrification.html).

Section 12 – Temporal Distributions

- Temporal distributions of VMT rely heavily on the 1996 OHIM report. Traffic monitoring systems, such as PeMS, may be considered as a source of more recent data, especially for restricted access roads. Note that in the case of PeMS, VMT are estimated separately for cars and trucks, which can be used to represent light-duty source types and heavy-duty source types, respectively.

Section 12.1 – VMT Distribution by Month of the Year

- Container volumes at ports around the US may be considered for use as a surrogate of VMT distribution by month of the year for short-haul and long-haul combination trucks. For example, https://www.portoflosangeles.org/maritime/stats.asp.

Section 12.2 – VMT Distribution by Type of Day

- Data from traffic monitoring systems may be used to estimate DayVMTFraction for each month.

Section 12.4 – Engine Starts and Parking

- More recent instrumented vehicle data are available on NREL's Transportation Secure Data Center website (http://www.nrel.gov/transportation/secure_transportation_data.html) for passenger vehicles and on NREL's Fleet DNA website (http://www.nrel.gov/transportation/fleettest_fleet_dna.html) for commercial vehicles.

Section 12.5 – Hourly Hoteling Activity

- In future updates, the hourly hoteling activity may be estimated from large-scale GPS datasets of long-haul trucks such as ATRI's.

Section 14.2 – Road Load Coefficients

- The road load coefficients for light-duty vehicles were set to remain constant over time despite the Light-Duty Greenhouse Gas Rule (because the improvements in these coefficients have already been incorporated into the energy and emission rates). However, the road load coefficients for 2014 and later model year heavy-duty vehicles were updated in light of the 2014 Medium and Heavy-Duty Greenhouse Gas Rule. Shouldn't the impact of the 2014 Rule be expected to reflect in the energy and emission data to be collected in the future?

Section 16 – Conclusion and Areas for Future Research

- The national default values for vehicle population and activity inputs in MOVES2014 were developed for the base year of 2011. It may be of interest to validate the 2012-2014 projections for some of these inputs with actual data that are available for those years. This will allow the assumptions made in the projections to be adjusted if necessary.

Appendix D. Randall Guensler Review Comments

MEMORANDUM

To: Larry O'Rourke, ICF
From: Randall Guensler, PhD.
Date: September 15, 2015
Re: Population and Activity of On-road Vehicles in MOVES2014 Documentation Review

Thank you for the opportunity to participate in the peer review of the USEPA's Population and Activity of On-road Vehicles in MOVES2014 Documentation. I have provided suggested edits using revision marks and comments in the margins of the Word document. At various points in the paper, I have suggested edits to move text explaining tables so that the text appears before the table is presented. There are a number of sections in the document that I suggest be summarized in a single paragraph, shipping the detailed text off to an Appendix, to improve readability. The most important issues that I believe could be addressed in the document are summarized below:

1. **The MOVES Vehicle and Activity Classification section really needs an overview designed to introduce the reader to the content of the Chapter. This overview can help the reader understand that the emission rates need to be properly linked to the concepts of vehicle classes, vehicle source types, regulatory classes, etc..**
2. **Somewhere up front in this paper a very brief overview of emissions sources and modeling goals should be added. How MOVES works, in a nutshell, and what data are needed to run MOVES. This can also differentiate between baseline emissions by source type and correction factors. VSP can be addressed here as well as internal diving cycles. Then, the document can refer back to the general discussion when needed.**
3. **A big picture issue throughout the entire document is to set the stage for the reader as to why they should be using local-specific or regional-specific data. This is a common theme throughout my comments.**
4. **The paper could probably use a paragraph or two associated with the difficulty in mapping FHWA vehicle classes and EPA vehicle classes. Papers by Yoon and Liu offer some insight into these issues. Yoon discusses these in the context of visual classes for observational data, although that paper would need to be updated. Providing this in an Appendix might prove helpful to users. This applies in Chapter 3 as well.**
5. **There is a problem with MOVES implementation at a higher level that, if resolved, would significantly improve modeling efforts. As outlined on Page 10 and elsewhere, it is important to structure MOVES for users to enter mutually exclusive technology groups that can be derived from license plate observational data. Anything that can be added to the documentation to help users better classify their vehicle input based upon field observations will be appreciated by users. Comment 8 also suggests the development of a table to instruct users.**
6. **I suggest adding a new section (2.6) to introduce the use of model year distributions.**
7. **There are a number of detailed explanations that probably belong in Appendices rather than in the text to improve readability (and initial clarity).**

8. **The SCC classes are another big picture issue with MOVES, in that these contribute to the mutually exclusive technology groups. The concept is complex and needs to be explained better in the text on Page 11. I suggest the addition of a table for clarity.**
9. **The audience needs a connection between SCC and regulatory class in Section 2.7. At the same time, Table 2-5 loses the audience due to complexity. An overview paragraph would help here. This is one of the most complicated sections and general improvements would help the audience. Specific comments are provided in the document markup.**
10. **Table 2-8 appears to be the key table for the entire chapter. If the text is rewritten, I would suggest pointing all of the explanations and discussions so that they result in the reader reaching the table tih full understanding of the content of that table. A paragraph is needed after Table 2-8 to let the reader know that everything they do from her on out is to generate the data that will be used by the 80 groups represented in this table.**
11. **Table 2-9 is excellent and can be used to organize the presentation of materials before and after. Listing in order of use in the document, rather than alpha order, will help the structure.**
12. **Data sources introduction should be expanded significantly to inform the reader about what they need for modeling. Given the sensitivity and capabilities of MOVES, A goal here should be to shift users to locally-sourced data rather than national defaults.**
13. **As indicated in Comment 34, buses and HD Trucks experience different growth rates. A separate data source should be found for the next set of updates. At the very least, local data should be recommended for buses of all types (these data can be obtained from transit agencies).**
14. **Changes in vehicle ownership and mileage accrual rates are generally different. These sources can be obtained from registration databases coupled with I/M programs. This would be a worthwhile small study to sponsor.**
15. **The materials presented on Page 38 (Comment 41) are very confusing for the reader and serve to reinforce the need for users to obtain their own regional/local input data. The discussion can be simplified for clarity or expanded with detail for clarity.**
16. **Comment 48 identifies an internal problem in MOVES that causes problems for users in matching local fleet composition.**
17. **The Single-unit long haul truck distribution in Figure 7-1 is so different than the other curves that it warrants a detailed explanation….**
18. **The discussion on survival modeling could be significantly improved (see comments) and caveats should be added. A number of comments are also provided on model year distribution values, especially for the oldest vehicle groups. Plus, the detailed text in this section would fit better as an appendix. A focused peer review of this section is probably warranted (see comments). Mileage accrual for the older vehicles (page 65) is also a potential issue (see comments).**
19. **The Cubic Regression approach on Page 63 is not clearly defined.**
20. **Table 7-3 is good. Similar tables should be provided for other classes.**
21. **I could not replicate the data in Table 7-4. Please see comments.**
22. **I have some expertise in the availability and resolution of TomTom data. The use of these data as outlined in the document appears problematic. Comments are**

provided throughout Section 9.1 and 9.2. I cannot recommend the use of these data in this fashion. I recommend that additional research in this area be undertaken.

23. **The use of the driving cycle weighting is an issue in MOVES. (see comment 92 and 93). Use of local driving cycles is preferable when such data are available**
24. **It is not clear to users how they should handle activity on weaving and exit lanes. Comments 100-102 address this issue.**
25. **Section 12.3provides defaults for temporal distributions. Again, local data are preferred given the variability noted across urban areas.**

Population and Activity of On-road Vehicles in MOVES2014

June 2015

DRAFT REPORT

United States Environmental Protection Agency
Office of Transportation and Air Quality
Assessment and Standards Division

Table of Contents

1. Introduction

The United States Environmental Protection Agency's Motor Vehicle Emission Simulator, commonly referred to as MOVES, is a set of modeling tools for estimating emissions produced by on-road (cars, trucks, motorcycles, etc.) and nonroad (backhoes, lawnmowers, etc.) mobile sources. MOVES estimates the emissions of greenhouse gases (GHG), criteria pollutants and selected air toxics. The MOVES model is currently the official model for use for state implementation plan (SIP) submissions to EPA and for transportation conformity analyses outside of California. The model is also the primary modeling tool to estimate the impact of mobile source regulations on emission inventories.

The MOVES model calculates emission inventories by multiplying emission rates by the appropriate emission-related activity, applying correction (adjustment) factors as needed to simulate specific situations, and then adding up the emissions from all sources (populations) and regions. A useful analogy is that an inventory can be pictured as a stool; the three legs of the stool are the emission rates, activity, and populations, while the seat is the inventory. The emission rates are inputs to the model specified for various "processes" including running exhaust, start exhaust, and a number of evaporative processes, among others. The processes are largely chosen to be causal such that the physical or engineering principles involved in generating those emissions are isolated, which in turn allows research test programs to measure them scientifically.[a] These processes also define the activity, populations, and technology inputs required.

Comment [Rev1]: Vehicle activity by population is assigned MOVES activity-specific emission rates . These are separate legs.

Comment [Rev2]: The emission-producing vehicle activity and conditions that affect the magnitude of the applicable emission rates define the activity we have to quantify for model input.

This report describes the sources and derivation for on-road vehicle population and activity information and associated adjustments as stored in the MOVES2014 default databases. This data has been extensively updated from previous versions of MOVES. Emission rates, correction factor values, and information for nonroad equipment in the default database are described in other MOVES technical reports.[1]

The MOVES2014 default database has a domain that encompasses all on-road (highway) vehicle and nonroad equipment activity and emissions for the entire United States, Puerto Rico, and the Virgin Islands. Properly characterizing emissions from the on-road vehicle subset requires a detailed understanding of the cars and trucks that make up the vehicle fleet and their patterns of operation. The national default activity information in MOVES2014 provides a reasonable basis for estimating national emissions. The most important of these inputs, such as VMT and population estimates, come from long-term systematic national measurements.

~~However, the u~~Uncertainties and variability in ~~the~~ internal model default data and model input data contribute to ~~the~~ uncertainty in ~~the~~ resulting emission estimates. In particular, when modellers estimate emissions for specific geographic locations, EPA guidance recommends replacing many of the MOVES fleet and activity defaults with local data. This is especially true

[a] More detail on emission measurement is provided in the respective emission rate reports.

for inputs that vary geographically and for inputs where local data is more detailed or up-to-date than that provided in the MOVES defaults. MOVES has been specifically designed to accommodate the input of alternate, user supplied activity data for the most important parameters. EPA's Technical Guidance[2] provides more information on customizing MOVES with local inputs.

Population and activity data ~~is~~ are ever changing. As part of EPA's MOVES development process, the model undergoes major updates and review every few years. As we progress with MOVES, development of fleet and activity inputs (including projections) will continue to be an important area of focus and improvement.

[A transition paragraph is needed here]

2. MOVES Vehicle and Activity Classifications

EPA has developed some terminology that is specific to MOVES, particularly related to vehicle classification, such as "source use types" and "regulatory classes." The MOVES terms introduced in this section will be used throughout the report and will be discussed in later sections.

[Per comment rg14, I propose that an overview paragraph be added here to help the reader get through the subsections that follow. Something along the lines of:]

One of the major goals of MOVES modeling is to make sure that correct emission rates are assigned to vehicles in the onroad fleet. The onroad fleet is composed of a wide variety of vehicles, and fleet composition can vary significantly from location to location. For example, the morning fleet on freeways during the week (commuters) is composed of newer automobiles and trucks than are observed on local roads on weekends. Linking the onroad fleet composition to MOVES depends on a variety of fleet characteristics that affect emission rates. The onroad can first be broken down into *vehicle classes* (for example, light-duty automobile emission rates are very different from for heavy-duty truck emission rates). Within the vehicle classes, some subsets of vehicles are driven very differently than others. For example school buses vs. transit buses have different onroad driving patters, whereas light-duty passenger automobiles and passenger trucks are driven about the same. Hence, *vehicle classes* and *source use types* are employed in MOVES modeling. Within these *vehicle classes* and *source use types*, some subsets of vehicles are certified to different emissions standards using different laboratory test methods, depending upon intended end use, duty cycle, and vehicle weight, leading to different onroad emission rates. Hence, *vehicle classes* and *source use types* can be further broken into different *regulatory classes*. Within the *vehicle classes*, *source use types*, and *regulatory class* groupings, vehicles can be further subcategorized by *fuel type* and *vehicle model year* (because different regulatory standards have applied to vehicles over time and deterioration of emisisons control systems can affect emission rates). Finally, the onroad operations that lead to vehicle emissions from these vehicles vary significantly by *road facility type* and operating conditions. All of these factors are included in MOVES modeling. Hence, the model input data need to appropriately reflect the fleet that is being modeled, whether analyses are being conducted at a national, regional, or local scale.

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2.1. ~~HPMS~~ Vehicle Class (HPMS)

In this report, MOVES HPMS class refers to one of five high-level categories derived from the categories used in the US Department of Transportation (DOT) Highway Performance Monitoring System (HPMS) vehicle classes used by the Federal Highway Administration (FHWA) in the VM-1 Table of their annual Highway Statistics report. The five HPMS classes used in MOVES are: motorcycles (HPMSVTypeID 10), light-duty vehicles (25), buses (40), single unit trucks (50), and combination trucks (60).

Note that in MOVES2014, what we call the HPMS class for light-duty vehicles (25) denotes the sum of the VM-1 values for long wheelbase and short wheelbase light-duty vehicles. HPMSVTypeID 25 is new for MOVES2014 and replaces HPMSVTypeID 20 (passenger cars) and 30 (other two-axle four-tire vehicles) in MOVES2010. As such, in MOVES2014 any VMT input by HPMS class for passenger cars and light-duty trucks must be entered as a combined value in the new HPMSVTypeID 25. This change in HPMS classes has come about as passenger vehicles have evolved over time with the physical characteristics of "cars" and "trucks" becoming less distinct. In response, DOT has changed the HPMS classification system and MOVES has evolved to reflect this change.

Comment [Rev3]: Perhaps it would be useful to say why this happened due to the standards changes.

Comment [Rev4]: Mention crossover vehicles

2.2. Source Use Types

The primary vehicle classification in MOVES is source use type, or, more simply, source type. Source types are intended to be groups of vehicles with similar activity and usage patterns. On-road source types were categorized from the HPMS classes, but the HPMS vehicle classes were further differentiated into MOVES source types using vehicle characteristics from the US Census Bureau's Vehicle Inventory and Use Survey (VIUS). The MOVES2014 source types are listed in Table 2-1 along with the associated HPMS classes. More detailed source type definitions are provided in Section 5.2.

Table 2-1 MOVES2014 On-road Source Types

SsourceTypeID	Source Type Name	HPMSVTypeID	Description
11	Motorcycles	10	Motorcycles
21	Passenger Cars	25	Light-Duty Vehicles
31	Passenger Trucks (primarily personal use)	25	Light-Duty Vehicles
32	Light Commercial Trucks (primarily non-personal use)	25	Light-Duty Vehicles
41	Intercity Buses (non-school, non-transit)	40	Buses
42	Transit Buses	40	Buses
43	School Buses	40	Buses
51	Refuse Trucks	50	Single Unit Trucks
52	Single Unit Short-haul Trucks	50	Single Unit Trucks
53	Single Unit Long-haul Trucks	50	Single Unit Trucks
54	Motor Homes	50	Single Unit Trucks
61	Combination Short-haul Trucks	60	Combination Trucks
62	Combination Long-haul Trucks	60	Combination Trucks

In MOVES, the distinction between light-duty (LD) and heavy-duty (HD) source types is essential because light- and heavy-duty operating modes and emission rates were developed differently based on vehicle power and speed. Light-duty vehicles (sourceTypeID 11, 21, 31, and 32) use vehicle specific power (VSP), which is dependent on the measured mass of the test vehicle. Heavy-duty vehicles (sourceTypeID 41, 42, 43, 51, 52, 53, 54, 61, and 62) use scaled tractive power (STP) which is scaled by a fixed mass factor since because heavy-duty vehicle their emission rates correlates better with absolute vehicle power than with vehicle specific power. For more discussion on VSP and STP definitions, please refer to Section 14. 14. of this report and the MOVES2014 reports on light-duty and heavy-duty vehicle emission rate development, respectively.[3,4]

2.3. Regulatory Classes

In contrast to source types, regulatory classes are used to group vehicles that are subject to similar emission standards. The EPA employs different new vehicle certification standards for certain vehicle technology classes and weights. ~~regulates vehicle emissions based on groupings of technologies and classifications~~ These regulatory groupings ~~that~~ do not ~~necessarily correspond to~~ correlate well with DOT vehicle classifications used for activity monitoring and assessing ~~activity and~~ onroad usage patterns. To properly estimate fleet emissions, it is critical ~~for~~ that MOVES to account for differences in ~~these~~ emission standards within a source type~~, despite the fact that the activity data often uses a different classification scheme~~. Thus, ~~we must map~~ the two schemas must be reconciled.

The regulatory classes used in MOVES are summarized in Table 2-2 below. The "doesn't matter" regulatory class is used internally in the model if the emission rates for a given pollutant and process are independent of regulatory class. The motorcycle (MC) and light-duty vehicle (LDV) regulatory classes have a one-to-one correspondence with source type. Other source types are allocated between regulatory classes based on gross vehicle weight rating (GVWR), which is a set of eight classes developed by FHWA according to the combined weight of the vehicle and its load. Urban buses have their own regulatory definition, and therefore have an independent regulatory class.

Comment [Rev5]: This term is not user friendly and will cause confusion.

Table 2-2 Regulatory Classes in MOVES2014

Comment [Rev6]: This section is not easy for users to follow and understand until they start working with model input data for an extended period. It will likely help to add a table that shows the combined source type and regulatory class in one table with mutually exclusive rows to clarify the issues.

regClassID	Regulatory Class Name	Description
0	Doesn't Matter	Doesn't Matter
10	MC	Motorcycles
20	LDV	Light-Duty Vehicles
30	LDT	Light-Duty Trucks
40	LHD<=10k	Class 2b Trucks with 2 Axles and 4 Tires (8,500 lbs < GVWR <= 10,000 lbs)
41	LHD<=14k	Class 2b Trucks with 2 Axles and at least 6 Tires or Class 3 Trucks (8,500 lbs < GVWR <= 14,000 lbs)
42	LHD45	Class 4 and 5 Trucks (14,00 lbs < GVWR <= 19,500 lbs)
46	MHD	Class 6 and 7 Trucks (19,500 lbs < GVWR < =33,000 lbs)
47	HHD	Class 8a and 8b Trucks (GVWR > 33,000 lbs)
48	Urban Bus	Urban Bus (see CFR Sec. 86.091_2)

The GVWR distinction between light-duty (LD) and heavy-duty (HD) trucks falls in the midst of FHWA GVWR Class 2. Trucks of 6,001-8,500 lbs GVWR are sorted into Class 2a, which are considered light-duty vehicles, while vehicles of 8,500-10,000 lbs GVWR are sorted into Class 2b, which are considered light heavy-duty vehicles (LHD).

In MOVES2014, we have introduced a new regulatory class 40 for vehicles that are in Class 2b, but are classified as passenger truck or light-commercial trucks. These vehicles are regulated as heavy-duty vehicles by EPA, but the VMT from Class 2b vehicles with two axles and four tires are included in the light-duty vehicles categories of FHWA's *Highway Statistics* report. MOVES assigns operating modes for source types 31 and 32 according to VSP. As such, we created regulatory class 40, so that regulatory class 40 models the emission rates of Class 2b trucks according to VSP-based operating modes, and regulatory class 41 models the emission rates of Class 2b trucks according to STP-based operating modes. Class 2b trucks with two axles and at least six tires (colloquially known as "dualies") and Class 3 trucks fall into regulatory class 41 and are only modeled in the heavy-duty source types.

In summary, the light-duty truck source types (31 and 32) map only to regulatory classes 30 and 40 in MOVES2014, while the heavy-duty vehicle source types (41 and above) map to regulatory classes 41 and above.

[To clarify this section for model users, images are needed to describe the source type categories. We can provide examples from previous reports if needed. The Liu paper referenced in the comment above should have examples].

2.4. Fuel Types

MOVES2014 models vehicles and equipment powered by following fuel types: gasoline, diesel, E-85 (a blend of 85 percent ethanol and 15 percent gasoline), compressed natural gas (CNG), electricity, and liquefied petroleum gas (LPG, only available for nonroad equipment). Note that in some cases, a single vehicle can use more than one fuel; for example, flexible fuel vehicles are capable of running on either gasoline or E-85. Thus, fuel type refers to the capability of the vehicle capability rather than the fuel in the tank. In MOVES, the fuel actually used depends on a number of factors including the location, year, and month in which the fuel was purchased, as fuels transition from summer to winter compositions. Mode details on fuel composition in MOVES ~~as~~ is provided ~~explained~~ in the MOVES2014 technical report on the fuel supply.[5] The table below summarizes the fuel types available in MOVES.

Table 2-3 A list of allowable fuel types to power vehicles/equipment in MOVES2014

fuelTypeID	defaultFormulationID	Description
1	10	Gasoline
2	20	Diesel Fuel
3	30	Compressed Natural Gas (CNG)
4	40	Liquefied Petroleum Gas (LPG)*
5	50	Ethanol (E-85) Capable
9	90	Electricity

* MOVES2014 only models LPG use in nonroad equipment.

It is important to note that not all fuel type/source type combinations can be modeled in MOVES. That is, MOVES2014 will not model gasoline fueled long-haul combination trucks, gasoline intercity buses, or diesel motorcycles. ~~Though~~ Although there are other source types in the real world that can fuel with CNG, ~~Transit~~ transit buses are the most common and ~~thus~~ are currently the only on-road source type that may be modeled using CNG. Similarly, flexible fuel (E85-compatible) and electric vehicles are only modeled for passenger cars, passenger trucks, and light commercial trucks. None of the on-road (highway) source types can be modeled as fueled by LPG. For more information on how MOVES models the impact of fuels on emissions, please see the MOVES documentation on fuel effects.[6]

Comment [Rev7]: The current categorization is confusing and we recommend that the MOVES model should be restructured to employ very clear mutually exclusive technology groups that can be derived from analysis of license plate data and changed directly by user input. I believe that the model input side is doing this now (but should be more clearly shown in the tables). However, right now, there are regulatory class apportionments that are being conducted inside the model that are problematic.

See Liu, et al., 2015. Presented as paper trid.trb.org/view.aspx?id=1338436

Forthcoming as:
Liu, H., Y. Xu, R. Guensler, and M.O. Rodgers (in Press). Developing Vehicle Classification Inputs for Project-Level MOVES Analysis. Transportation Research Record. Number xxxx. pp. xx-xx. National Academy of Sciences. Washington, DC. 2015.

Comment [Rev8]: Another table here showing the mutually exclusive lines for source type, regulatory class, and fuel type might be helpful.

2.5. Road Types

MOVES calculates emissions separately for each of four road types [list them here] and for "off-network" activity when the vehicle is not moving. The MOVES roadtypes are based on two important distinctions in how FWHA classifies roads: 1) urban versus rural roadways are distinguished based on land use and human population density, and 2) unrestricted versus restricted are distinguished based on roadway access—, where restricted roads require the use of ramps. The urban/rural distinction is used primarily for national level calculations. It allows different default speed distributions in urban and rural settings. Of course, finer distinctions are possible. Users with more detailed information on speeds and acceleration patterns may choose to create their own additional road types, or may run MOVES at project level where emissions can be calculated for individual links.

It also allows separate output for ramp and non-ramp, as described in Section 10.2 below. The road type codes used in MOVES are listed in Table 2-4. The four MOVES road types (rows 2-5) are aggregations of FHWA functional facility types. MOVES also allows users to output separate emissions for ramp and non-ramp activity (rows 6-9), and is described later in Section 10.2. 10.2.

Comment [Rev9]: This is true even at the regional level as I recall. If not, state the difference.

Table 2-4 Road Type Codes in MOVES2014

roadTypeID	Description	FHWA Functional Types
1	Off Network	Off Network
2	Rural Restricted Access	Rural Interstates
3	Rural Unrestricted Access	Rural Principal Arterials, Minor Arterials, Major Collectors, Minor Collectors, and & Local Roads
4	Urban Restricted Access	Urban Interstates & and Urban Freeway/Expressway
5	Urban Unrestricted Access	Urban Principal Arterials, Minor Arterials, Collectors, & and Local Roads
6	Rural Restricted Access, without Ramps Excluded	Rural Interstates, Ramps Excluded
7	Urban Restricted Access without , Ramps Excluded	Urban Interstates, Ramps Excluded
8	Rural Restricted Access, only Ramps Only	Rural Interstate Ramps
9	Urban Restricted Access, only Ramps Only	Urban Interstate Ramps
100	Nonroad	

The MOVES roadtypes are based on two important distinctions in how FWHA classifies roads: 1) urban versus rural roadways are distinguished based on land use and human population density, and 2) unrestricted versus restricted are distinguished based on roadway access—restricted roads require the use of ramps. The urban/rural distinction is used primarily for national level calculations. It allows different default speed distributions in urban and rural settings. Of course, finer distinctions are possible. Users with more detailed information on speeds and acceleration patterns may choose to create their own additional road types, or may run MOVES at project level where emissions can be calculated for individual links.

2.6. Model Year Groups

[I would suggest adding a paragraph on model years here]

~~2.6.~~ 2.7. Source Classification Codes (SCC) [Move to Appendix]

Source Classification Codes (SCC) are used in air quality models, such as the UNC SMOKE[7] model, to ~~unambiguously~~ identify the specific activity source ~~of the emissions~~ when generating emission inventories. In MOVES, SCCs are single numerical codes that identify the vehicle type, fuel type, road type, and emission process. The SCCs were redesigned for MOVES2014 to directly relate to the source use types and road types used by MOVES.

The new SCCs retain the previous 10-digit design, but use different numerical combinations to avoid conflicts with existing codes. The new codes use MOVES numerical identification (ID) codes in the following form:

AAAFVVRRPP, where

- AAA indicates mobile source (this has a value of 220 for both on-road and nonroad),
- F indicates the MOVES fuelTypeID value,
- VV indicates the MOVES sourceTypeID value,
- RR indicates the MOVES roadTypeID value, and
- PP indicates the MOVES emission processID value.

Building the new SCC values in this way will allow additional source types, fuel types, road types, and emission processes to be easily added to the list of SCC values as changes are made to future versions of MOVES. The explicit coding of fuel type, source type, road type, and emission process also allows the MOVES SCCs to indicate aggregations. For example, a zero code (00) for any of the sourceTypeID, fuelTypeID, roadTypeID, and processID strings that make up the SCC indicates that the reported emissions are an aggregation of all categories of that type. Using the mapping described above, modelers can also easily identify the sourceTypeID, fuelTypeID, roadTypeID, and processID of emissions reported by SCC ~~without needing a decoding table~~. Refer to tables in the MOVES User Guide for the descriptions of the sourceTypeID, fuelTypeID, roadTypeID, and processID values currently used by MOVES.

~~The explicit coding of fuel type, source type, road type, and emission process also allows the MOVES SCCs to indicate aggregations. For example, a zero code (00) for any of the sourceTypeID, fuelTypeID, roadTypeID, and processID strings that make up the SCC indicates that the reported emissions are an aggregation of all categories of that type.~~

The SCC values used in previous versions of MOVES do not have a one-to-one correspondence with the new SCC values. However, MOVES2014 has the capability to report results by regulatory class as well as by SCC, which will aid in comparing SCC results from earlier versions of MOVES. All feasible SCC values are listed in the SCC table within the default database.

Comment [Rev10]: This is a mapping process and seems out of place. It should probably mode down below all of the other fleet composition elements. It would even be better as an Appendix.

Comment [Rev11]: I would suggest adding a brief section above this one that describes the process options.

Comment [Rev12]: Because this change does not yet address the regulatory class issue inside MOVES, I recommend that these SCCs be expanded now to include regulatory class for mutually exclusive tracking. Even if it takes time to address the internal model algorithms used to assign regulatory classes to these categories, the SCC values will need to be updated again later. It is better to make this change once, rather than adjusting the SCCs twice. Once the change is made, the SCCs can link directly to source bins. Putting placeholders in would be a good interim solution to support the next update.

Comment [Rev13]: The values for all of these should all be listed in the report sections that precede this one (most already are).

Comment [Rev14]: This is too vague and requires a user to go back through previous materials to see the differences. It would be better to provide current users with the explicit differences right here in the form of a table and supporting text.

~~2.7.~~ 2.8. Source Bins

To estimate emissions, MOVES must know all of the relevant ~~the~~ emission-related characteristics of the vehicle, such as the type of fuel that it is designed to use and the emission standards under which the vehicle was certified~~it is subject to~~. Therefore, MOVES stores emission rates by source bin in an internal data structure. ~~we group vehicles into~~ The source bins ~~that~~ are tied to ~~classify a~~ vehicle by discriminators relevant for emissions and energy calculations, including fuel type, regulatory class, and model year group. Each sourceBinID is a unique 19-digit identifier in the following form:

$1FFEERRMM0000000000$, where

- 1 is a placeholder,
- FF is a MOVES fuelTypeID,
- EE is a MOVES engTechID,[b]
- RR is a MOVES regClassID,
- MM is a MOVES shortModYrGroupID, and
- 10 trailing zeros for future characteristics.

A mapping of model year to model year groups is stored in the PollutantProcessModelYear table. Distributions of fuel and engine technologies and regulatory class are stored by model year in the SampleVehiclePopulation table. The MOVES Source Bin Distribution Generator combines information from these two tables to create a detailed SourceBinDistribution, essentially telling MOVES where to get emission rates to apply to the composite vehicle fleet. These bins may vary by pollutant and process as indicated in the SourceTypePolProcess table. In general, fuel type and model year group are relevant for all emission calculations, but the relevance of regulatory class and model year group depend on the pollutant and process being modeled. ~~Since~~

MOVES2014 can produce results by various vehicle classifications~~—~~ (source type, SCC, or regulatory class~~—~~) the mapping between SourceBinDistribution and SampleVehiclePopulation differs depending on the output selected.

Comment [Rev15]: You lost the audience connection between source type and regulatory class. A combined table (2-1 and 2-2) with the two factors showing how they work together as suggested earlier would help. All sections discussed earlier need to be reflected again in this discussion, and any parameter no longer specifically present in the 19 digit coding needs to be explained along the way.

Comment [Rev16]: Discuss in new MY section proposed above

Comment [Rev17]: Expand this paragraph. It is a separate thought from above]

[b] In MOVES2014, engTechID 1 is used for all fuel types except electric vehicles, where engTechID 30 is used instead. Thus, in this version, engTechID is somewhat redundant with fuel type and adds no new information when determining source bin distributions or calculating emissions.

Table 2-5 Data Tables Used to Allocate Source Type to Source Bin

Generator Table Name	Key Fields*	Additional Fields	Notes
SourceTypePolProcess	sourceTypeID polProcessID	isRegClassReqd isMYGroupReqd	Indicates which pollutant-processes the source bin distributions may be applied to and indicates which discriminators are relevant for each sourceTypeID and polProcessID (pollutant/process combination)
PollutantProcessModelYear	polProcessID modelYearID	modelYearGroupID	Assigns model years to appropriate model year groups for each polProcessID.
SampleVehiclePopulation	sourceTypeID modelYearID fuelTypeID engTechID regClassID	stmyFuelEngFraction stmyFraction	Includes fuel type and regulatory class fractions for each source type and model year, even for some source type/fuel type combinations that do not currently have any appreciable market share (i.e. electric cars). This table provides defaults for the Alternative Vehicle Fuel & Technology (AFVT) importer, and is used to determine reg class fractions when users modify alternative fuel vehicle fleet fractions.

* In these tables, the sourceTypeID and modelYearID are combined into a single sourceTypeModelYearID.

Comment [Rev18]: This has become much more convoluted than it needs to be. I would suggest starting with an overview paragraph right before Section 2.1 that describes the big picture. If you refer back to that conceptual outline throughout subsequent sections, it should help the audience. You have lost the vast majority audience by the time they get to this table.

While details of the SourceTypePolProcess and PollutantProcessModelYear tables are discussed in the reports on the development of the light- and heavy-duty emission rates[3,4], the SampleVehiclePopulation (SVP) table is a topic for this report and is discussed in Section 5.2.

~~2.8.~~ 2.9. ~~Allowable~~ MOVES Vehicle Fleet Modeling Combinations

Comment [Rev19]: Move these into discussions relevant to each parameter in the sections above. It's too late to walk through them here.

MOVES2014 allows users to model most combinations of source type, regulatory class, and fuel type. However, each combination must have accompanying emission rates; combinations that lack emissions testing or have negligible market share cannot be directly modeled in MOVES2014. Table 2-6 is a matrix summarizing the allowable source type-fuel type combinations. Most of the gasoline and diesel combinations exist with a few notable exceptions, but options for alternative fuels are limited as discussed earlier in Section 2.4.

MOVES also stores regulatory class distributions by source type in the SampleVehiclePopulation table. Table 2-7 summarizes the allowable source type-regulatory class combinations in MOVES2014. Any vehicles in regulatory class 40 and ~~less~~ lower are considered light-duty vehicles while any vehicles in regulatory class 41 and higher ~~greater~~ are considered heavy-duty vehicles. Similarly, source types 32 and ~~less~~ lower are considered light-duty vehicles and source types 41 and ~~above~~ higher are considered heavy-duty vehicles.

Table 2-8 joins together the information in the two matrices about source type, fuel type, and regulatory class combinations in MOVES2014. Each source type-fuel type combination contains all regulatory classes listed, except for gasoline transit buses, which have been called out separately.

Table 2-6 Matrix of the allowable source type-fuel type combinations in MOVES2014 (allowable combinations are marked with an X)

		Source Use Types												
		Motorcycles	Passenger Cars	Passenger Trucks	Light Commercial Trucks	Intercity Buses	Transit Buses	School Buses	Refuse Trucks	Short-Haul Single Unit Trucks	Long-Haul Single Unit Trucks	Motor Homes	Short-Haul Combination Trucks	Long-Haul Combination Trucks
Fuel Types		11	21	31	32	41	42	43	51	52	53	54	61	62
Gasoline	1	X	X	X	X		X	X	X	X	X	X	X	
Diesel	2		X	X	X	X	X	X	X	X	X	X	X	X
CNG	3						X							
E85	5		X	X	X									
Electricity	9		X	X	X									

Table 2-7 Matrix of the allowable source type-regulatory class combinations in MOVES2014 (allowable combinations are marked with an X)

		Source Use Types												
		Motorcycles	Passenger Cars	Passenger Trucks	Light Commercial Trucks	Intercity Buses	Transit Buses	School Buses	Refuse Trucks	Short-Haul Single Unit Trucks	Long-Haul Single Unit Trucks	Motor Homes	Short-Haul Combination Trucks	Long-Haul Combination Trucks
Regulatory Classes		11	21	31	32	41	42	43	51	52	53	54	61	62
MC	10	X												
LDV	20		X											
LDT	30			X	X									
LHD<=10k	40			X	X									
LHD<=14k	41					X		X	X	X	X	X		
LHD45	42					X	X	X	X	X	X	X		
MHD67	46					X	X	X	X	X	X	X	X	X
HHD8	47					X	X	X	X	X	X	X	X	X
Urban Bus	48						X							

Table 2-8 A summary of source type, fuel type, and regulatory class combinations in MOVES2014

sourceTypeID	fuelTypeID	regClassID
11	1	10
21	1, 2, 5, 9	20
31	1, 2, 5, 9	30, 40
32	1, 2, 5, 9	30, 40
41	2	41, 42, 46, 47
42	1	42, 46, 47
	2, 3	48
43	1, 2	41, 42, 46, 47
51	1, 2	41, 42, 46, 47
52	1, 2	41, 42, 46, 47
53	1, 2	41, 42, 46, 47
54	1, 2	41, 42, 46, 47
61	1, 2	46, 47
62	2	46, 47

[Add a paragraph here about how the goal of the user is to provide the model input data needed to correctly apportion the vehicle fleet into these 80 mutually exclusive categories. This can be done by the user, by inputting specific MOVES input data files, or users can rely on default inputs and internal MOVES algorithms.]

2.10. Emission Rate Correction Factors

[Add a section here on general use that leads into next section]

~~2.9.~~ 2.11. Default Inputs and Fleet and Activity Generators

Population and activity data are critical inputs for ~~calculating~~ estimating emission inventories from emissions processes such as running exhaust, start exhaust, and evaporative emissions. In MOVES, most running emissions are distinguished by operating modes, depending on road type and vehicle speed. Start emissions are determined based on the time a vehicle has been parked prior to the engine starting ("soak"). Evaporative emissions modes are affected by vehicle operation and the time that vehicles are parked. Emission rates are further categorized by source bins with similar fuel type, regulatory classification, and other vehicle and activity characteristics.

Because of these distinctions, MOVES calculators require information on vehicle population and activity at a very fine scale. In project-level modeling, ~~this~~ accurate detailed information may be available and manageable, for example from a license plate observation study. However, in other cases the fleet and activity data used in the MOVES calculators must usually be generated from more aggregate and readily available inputs ~~in a condensed or more readily available format~~. MOVES uses a series of "generators" to create fine-scale ~~information~~ fleet composition and activity input data ~~from~~ using user inputs and MOVES defaults. For example,

~~The~~ the MOVES Total Activity Generator (TAG) estimates hours of vehicle activity using vehicle miles travelled (VMT) and speed information to transform VMT into source hours operating (SHO). Some ~~Other types of~~ vehicle activity types are generated by applying

Comment [Rev20]: This is the key table. Everything you say and do in the entire section should lead to a solid text description of this table in this section. Everything else in this sections should be integrated into earlier sections.

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Comment [Rev21]: Given the importance of the previous section, which summarizes everything presented in Chapter 2, this could be a separate chapter if desired.

Comment [Rev22]: A search and replace should be run for the word calculating, as these models are estimating the inventory.

Comment [Rev23]: Somewhere in the last chapter, the pollutant processes probably need be discussed.... Perhaps at the very beginning, setting the stage that all that follows applies to the different processes. That is, you need vehicle fleet compositions for each emissions process.

Comment [Rev24]: This section has moved out of baseline emission rates and is really starting to deal with correction factors associated with certain processes. These data are needed as well, as corrections differ for vehicle population and activity subgroups. I suggest a bigger picture discussion on correction factors that reinforces the need to properly estimate the fleet composition.

appropriate factors to vehicle populations. For example, ~~Vehicle~~ vehicle starts, extended idle hours, and source hours (including hours operating and not-operating) are also generated. The default database for MOVES2014 contains national estimates for VMT, vehicle population, and vehicle age distributions for every possible analysis year (1990 and 1999-2050). ~~For national inventory runs, annual national activity is distributed temporally and spatially using allocation factors.~~

The Source Bin Distribution Generator (SBDG) uses information on sourceType, ~~fuel type fractions,~~ regulatory class distributions, fuel type fractions, model year distributions, and similar information to estimate the number of vehicles belonging to each source bin ~~as a function of source type and model year~~. The SBDG maps the activity data ~~(by source types)~~ to sourcebins, which then map directly to ~~the~~ internal MOVES sourcebin emission rates.

There are a number of MOVES modules that generate operating mode distributions based on vehicle activity inputs. The Rates Operating Mode Distribution Generator and the Link Operating Mode Distribution Generator use information on speed distributions and driving patterns (driving schedules) to develop operating mode fractions for each source type, road type, and time of day. Similarly, the Evaporative Emissions Operating Mode Generator and the Start Operating Mode Distribution Generator use MOVES inputs to develop operating mode distributions for starts and vapor venting. The details of each these generators and other MOVES2014 algorithms are described in the MOVES2014 Module Reference.[8]

This report documents the sources and calculations used to produce the default population and activity data in the MOVES2014 database used to compute national level emissions based on defaults for individual counties, months, day types, and hours of the day. In particular, this report will describe the data used to fill the tables listed in Table 2-9~~Table 2-9~~.
2.9

Comment [Rev25]: Now you have introduced the operating mode distribution (VSP bin element), but did not describe op mode bin as part of the overall 2.1 to 2.9 process description. You really shouldn't just wave your hands and call out to the MOVES documentation here. If you want to use the concept here, it should be introduced earlier at the sourcebin discussion. Makes the reader feel like they must have missed a step earlier.

Comment [Rev26]: This paragraph should tell the reader why they need all of the elements that are presented in table 2-9, linking the logic back to all of the discussions leading up to this section. Doing so will summarize everything for the reader and provide a good transition to the next chapter.

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Table 2-9 MOVES Database Elements Covered in this Report

Database Table Name	Content Summary	Report Sections
AvgSpeedDistribution	Distribution of time among average speed bins	Section 09
DayVMTFraction	Distribution of VMT between weekdays and weekend days	Section 12. 12
DriveSchedule	Average speed of each drive schedule	Section 010
DriveScheduleAssoc	Mapping of which drive schedules are used for each combination of source type and road type	Section 010
DriveScheduleSecond	Speed for each second of each drive schedule	Section 010
FuelType	Broad fuel categories that indicate the fuel vehicles are capable of using.	Section 2. 2
HotellingActivityDistribution	Distribution of hotelling activity to the various operating modes	Section 011
HotellingCalendarYear	Rate of hotelling hours per rural restricted access VMT	Section 011
HourVMTFraction	Distribution of VMT among hours of the day	Section 12. 12
HPMSVtypeYear	Annual VMT by HPMS vehicle types	Section 4. 4
MonthGroupHour	Coefficients to calculate air conditioning demand as a function of heat index	Section 15. 15
MonthVMTFraction	Distribution of annual VMT among months	Section 12. 12
PollutantProcessModelYear	Assigns model years to appropriate groupings, which vary by pollutant and process	Section 4. 4
RegulatoryClass	Sorts vehicles into weight-rating based groups in which emission regulations are applied	Section 2. 2
RoadOpModeDistribution	Operating mode distributions by source type, road type, and speed bin	Section 010
RoadType	Distinguishes roadways by population density of geographic area and by type of access, particularly the use of ramps for entrance and exit.	Section 2
RoadTypeDistribution	Distribution of VMT among road types	Section 8. 8
SampleVehicleDay	Identifies vehicles in the SampleVehicleTrip table	Section 12. 12
SampleVehiclePopulation	Fuel type and regulatory class distributions by source type and model year.	Section 4. 4
SampleVehicleTrip	Trip start and end times used to determine vehicle start and soak times	Section 12. 12
SCC	Source Classification Codes that identify the vehicle type, fuel type, road type and emission process in MOVES output.	Section 2. 2
SourceBinDistribution	Distribution of population among different vehicle sub-types (source bins)	Section 4. 4

Comment [Rev27]: I think that listing the variables in chapter order, rather than alpha order, will probably work better for the reader. In fact a table for each "Section" might work best, because you can provide a very brief three sentence explanation for each table as to how the inputs will be used and why they are important. For folks who need to look up an input by alpha order, an index at the end of the document could be used.

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Table 2-9 MOVES Database Elements Covered in this Report

Database Table Name	Content Summary	Report Sections
SourceTypeAge	Rate of survival to subsequent age, relative mileage accumulation rates, and fraction of functional air conditioning equipment	Section 7. 7 Section 15. 15
SourceTypeAgeDistribution	Distribution of vehicle population among ages	Section 7. 7
SourceTypeHour	The distribution of total daily hotelling among hours of the day	Section 12. 12
SourceTypeModelYear	Prevalence of air conditioning equipment	Section 15. 15
SourceTypePolProcess	Indicates which sourcebin discriminators are relevant for each source type and pollutant/process	Section 4. 4
SourceTypeYear	Vehicle counts by year	Section 05
SourceUseType	Mapping from HPMS class to source type, including source type names	Section 2. 2
SourceUseTypePhysics	Road load coefficients and vehicle masses for each source type used to calculate Vehicle Specific Power and Scaled Tractive Power	Section 14. 14
Zone	Allocation of activity to zone (county)	Section 013
ZoneRoadType	Allocation of driving time to zone (county) and road type	Section 013

Comment [Rev27]: I think that listing the variables in chapter order, rather than alpha order, will probably work better for the reader. In fact a table for each "Section" might work best, because you can provide a very brief three sentence explanation for each table as to how the inputs will be used and why they are important. For folks who need to look up an input by alpha order, an index at the end of the document could be used.

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3. Data Sources

A number of organizations collect data relevant to this report. The most important sources used to populate the vehicle population and activity portions of the MOVES database are described here. These sources are referred to throughout this document by the abbreviated name given in this description, but the reference citation is only given here.

Comment [Rev28]: Expand this paragraph. Looking for most recent and accurate data sources that can be updated on a regular basis and externally verified through observation.

3.1. VIUS

Until 2002, the US Census Bureau conducted the Vehicle Inventory and Use Survey (VIUS)[9] to collect data on the physical characteristics and activity of US trucks every five years. The survey is a sample of private and commercial trucks that were registered in the United States as of July of the survey year. The survey excludes automobiles, motorcycles, government-owned vehicles, ambulances, buses, motor homes, and nonroad equipment.

For MOVES, VIUS provides information to characterize trucks by source type and to estimate age, fuel type, and regulatory class distributions as well as relative mileage accumulation rates. MOVES2014 uses data from both the 1997 and 2002[10] surveys. While the survey includes a large number of vehicles and was designed to be representative of the US fleet, information on model year is not available for many of the older trucks. Thus, the distribution data for many older model years is sparse and sometimes erratic. Note that the Census Bureau discontinued VIUS in 2002, although there has been discussion recently about reinitiating the survey.

Comment [Rev29]: This leaves the audience hanging about how you do things now....

3.2. Polk NVPP® and TIP®

Acquired by IHS Inc. (http://www.ihs.com) in July 2013, R.L. Polk & Co. was a private company providing automotive information services. The company maintained two databases relevant for MOVES: the National Vehicle Population Profile (NVPP®)[11] and the Trucking Industry Profile (TIP®Net) Vehicles in Operation[12] database. The first focused on light-duty cars and trucks, the second focused on medium and heavy-duty trucks. Both provides were based upon data compiled ~~data~~ from state vehicle registration databases and title transfer records~~lists~~. For MOVES2014, EPA used NVPP® and TIP® datasets purchased for 1999 and 2011. Polk/IHS data ~~was~~ were used ~~in determining~~ to assess vehicles populations by age, fuel type, and regulatory class. At the time of these EPA data purchases, Polk was independently operated, so ~~we will continue to refer to~~ these datasets are referred to ~~under~~ using the Polk name in this report.

3.3. EPA Sample Vehicle Counts

Neither VIUS nor the Polk dataset contained enough information separately to develop distributions by regulatory class, fuel type, and age for ~~each~~ all vehicle source type in MOVES. ~~, so~~ EPA combined ~~these~~ the Polk datasets~~, and incorporated~~ with additional data sources to cover vehicles types, such as motorcycles, buses, and motor homes that were excluded from either the VIUS or Polk datasets. The resulting sample vehicle counts dataset is the basis for the MOVES2014 SampleVehiclePopulation table and the 2011 age distributions. More details on ~~how we constructed~~ the Sample Vehicle Counts dataset can be found in Section 5.2.

3.4. FHWA *Highway Statistics*

Each year the US DOT Federal Highway Administration's (FHWA) Office of Highway Policy Information publishes *Highway Statistics*. This volume summarizes a vast amount of roadway and vehicle data assembled by local and state agencies and reported through ~~from~~ the Highway Performance Monitoring System, a national information system that collects data from states and other sources on many facets of the US roadway system.

Comment [Rev30]: Need to grab and insert the official description of HPMS and indicate how the data are assembled.

In MOVES2014, vehicle miles traveled (VMT) and vehicle population data for the historic years 1990 and 1999-2011 come from four tables in *Highway Statistics*: MV-1[13], MV-10[14], VM-1[15], and VM-2[16], which we will reference by table name. For some years, the VMT values were revised by FHWA in subsequent publications. Table 3-1 summarizes the data source and revision date we used for each historical year.

Table 3-1 Corresponding *Highway Statistics* Data Source for Historical Years

Year	FHWA Publication Source (Publication/Revision Date)
1990	*Highway Statistics 1991* (October 1992)
1999	*Highway Statistics 1999* (October 2000)
2000	*Highway Statistics 2000* (April 2011)
2001	*Highway Statistics 2001* (April 2011)
2002	*Highway Statistics 2002* (April 2011)
2003	*Highway Statistics 2003* (April 2011)
2004	*Highway Statistics 2004* (April 2011)
2005	*Highway Statistics 2005* (April 2011)
2006	*Highway Statistics 2006* (April 2011)
2007	*Highway Statistics 2007* (April 2011)
2008	*Highway Statistics 2008* (April 2011)
2009	*Highway Statistics 2010* (December 2012)
2010	*Highway Statistics 2010* (December 2012)
2011	*Highway Statistics 2011* (March 2013)

3.5. FTA National Transit Database

The US DOT, Federal Transit Administration (FTA) summarizes financial and operating data from mass transit agencies across the country in the National Transit Database (NTD).[17] For MOVES2014, we used 1999-2011 vehicle counts from the NTD Revenue Vehicle Inventory for ~~motor~~ transit buses ~~(MB)~~ to ~~determine~~ assess fuel type distributions and populations.

3.6. School Bus Fleet Fact Book

The *School Bus Fleet Fact Book* includes estimates, by state, of the number of school buses and total miles traveled.[18] The Fact Book is published by Bobit Publications. School bus mileage accumulation rates came from the 1997 Fact Book, originally used in MOBILE6. We have used 1999-2011 sales data from the 2009 and 2012 Fact Book to ~~calculate~~ estimate fleet age distributions.

3.7. MOBILE6

MOBILE6 was a precursor to MOVES used to estimate highway vehicle emissions. In some cases, we have used estimates from MOBILE6 model with only minor adaptation. In particular, we used MOBILE6 data for some relative mileage accumulation rates, air conditioning usage rates, and driving schedules.

The MOBILE6 data ~~is~~ are documented in technical reports, particularly M6.FLT.002, *Update of Fleet Characterization Data for Use in MOBILE6 - Final Report*.[19] Additional MOBILE6 documentation is available online.[20]

3.8. *Annual Energy Outlook* & National Energy Modeling System

The *Annual Energy Outlook* (AEO)[21] describes Department of Energy forecasts for future energy consumption. The National Energy Modeling System (NEMS) is used to generate these projections based on economic and demographic forecasts. Vehicle sales and miles travelled are included in the projections because they strongly influence fuel consumption. Therefore, the AEO is an important source of future projections in MOVES. For MOVES2014, we used AEO2014 to forecast VMT and vehicle populations in years 2012-2050.

Comment [Rev31]: If you compared AEO and HPMS values for historic data, you should indicate whether there is good agreement since you are using the two data sources for VMT old and new, rather than just the AEO or Oak Ridge data (I believe that the historic energy data relies on Oak Ridge analyses).

3.9. Transportation Energy Data Book

Each year, Oak Ridge National Laboratory produces the annual Transportation Energy Data Book (TEDB) for the Department of Energy. This book summarizes transportation and energy data from a variety of sources, including EPA, FHWA, Polk, and Ward's Automotive, Inc. For MOVES we used information for estimating vehicle sales and survival fractions for historic years 1990 and 1999-2011 from TEDB Edition 32, published in 2013.[22]

3.10. FHWA Weigh-in-Motion

FHWA compiles truck weight data by axle configuration and roadway type from individual states' Weigh-in-Motion (WIM) programs.[23] The average weight for single unit trucks and combination trucks was determined from FHWA's Vehicle Travel Information System (VTRIS) W-3 Tables using data collected in 2011.

3.11. Motorcycle Industry Council *Statistical Annual*

The Motorcycle Industry Council (MIC) collects data on sales, ownership, and activity trends each year. MIC's *Statistical Annual* summarizes this data,[24] which we used in MOVES2014, particularly the 1999-2011 sales of highway motorcycles.

4. VMT by Calendar Year and Vehicle Type

For national level calculations, MOVES calculates source operating hours from national VMT by vehicle type. The default database contains national VMT estimates for all analysis years, which include 1990 and 1999-2050. Years 1991-1998 are excluded because there is no regulatory requirement to analyze them and including them would increase model complexity. Calendar year 1990 continues to be a base year ~~because of~~ given the adoption of the Clean Air Act Amendments of 1990.

The national VMT estimates are stored in the HPMSVTypeYear table, which includes three data fields: HPMSBaseYearVMT (discussed below), baseYearOffNetVMT, and VMTGrowthFactor. Off Network VMT refers to the portion of activity that is not included in travel demand model networks or any VMT that is not otherwise reflected in the other four road types. ~~The field baseYearOffNetVMT is provided in case it is useful for modeling local areas. However, the r~~Reported HPMS VMT values are assumed to ~~, used to calculate the national averages discussed here, are intended to~~ include all VMT for all national analyses. Thus, for MOVES2014 national defaults, the baseYearOffNetVMT is zero for all vehicle types. The field baseYearOffNetVMT is provided in case it proves useful for modeling local areas. ~~Additionally, the~~ The VMTGrowthFactor field is not used in MOVES2014 and is set to zero for all vehicle types.

4.1. Historic Vehicle Miles Traveled (1990 and 1999-2011)

The HPMSBaseYearVMT field stores the total national VMT for each HPMS vehicle ~~type~~ class for all analysis years. For ~~historical years~~ 1990 and 1999-2011, the VMT is derived from the FHWA VM-1 tables. In reporting years 2007 and later, the VM-1 data use an updated methodology with different HPMS vehicle type categories. The current HPMS categories are Light-Duty (Short Wheelbase), Light-Duty (Long Wheelbase), Motorcycles, Buses, Single Unit Trucks, and Combination Trucks. Because MOVES categorizes light-duty source types based on vehicle type and not wheelbase length, the short and long wheelbase categories are combined into a single category of Light-Duty Vehicles (HPMSVTypeID 25). Internally, the MOVES Total Activity Generator[c] allocates this VMT to MOVES source types and ages using vehicle populations, age distributions and relative mileage accumulation rates.

For years prior to 2007, the VM-1 data with historical vehicle type groupings ~~needed to be~~ wasadjusted for consistency. In early 2011, the FHWA released such adjusted VMT data for years 2000-2006 to match the new category definitions. Shortly afterward, the agency replaced these adjusted numbers with the unadjusted VMT data stating, "[FHWA] determined that it is more reliable to retain the original 2000-2006 estimates because the information available for those years does not fully meet the requirements of the new methodology."[d] However, lacking a

[c] For more information on the MOVES Total Activity Generator, please see the MOVES2014 Module Reference, available on the MOVES website: http://www.epa.gov/otaq/models/moves/#user

[d] This text appears in a footnote to FHWA's *Highway Statistics* Table VM-1 for publication years 2000-2009.

better adjustment methodology, we used the retracted FHWA-adjusted values as the VMT for 2000-2006.

This left two years, 1990 and 1999, that needed to be adjusted to be consistent with the new HPMS vehicle categories. These adjustments were made using the average ratio of the methodology change for each vehicle category. This was found by dividing the FHWA-adjusted VMT for each vehicle category by the original VMT for each year 2000-2006 and then calculating the average ratio for each category. This ratio was then applied to the corresponding VMT values reported in VM-1 for 1990 and 1999. ~~Since~~ Because FHWA's adjustments conserved the original total VMT estimates, we normalized our adjusted values such that the original total VMT for the years ~~were~~ remained unchanged.

The resulting values for historic years by HPMS Vehicle Class are listed in Table 4-1. The VMT for 1990 and 1999 were EPA-adjusted from VM-1, 2000-2006 were FHWA-adjusted, and 2007-2011 were unadjusted, other than the simple combination of the short and long wheelbase classes into light-duty vehicles.

Table 4-1 Historic Year VMT by HPMS Vehicle Class in Millions of Miles

Year	Motorcycles	Light-Duty Vehicles	Buses	Single Unit Trucks	Combination Trucks
1990	11,404	1,943,197	10,279	70,848	108,624
…					
1999	13,619	2,401,408	14,853	100,534	160,921
2000	12,175	2,458,221	14,805	100,486	161,238
2001	11,120	2,499,069	12,982	103,470	168,969
2002	11,171	2,555,467	13,336	107,317	168,217
2003	11,384	2,579,194	13,381	112,723	173,539
2004	14,975	2,652,092	13,523	111,238	172,960
2005	13,773	2,677,641	13,153	109,735	175,128
2006	19,157	2,680,535	14,038	123,318	177,321
2007	21,396	2,691,034	14,516	119,979	184,199
2008	20,811	2,630,213	14,823	126,855	183,826
2009	20,822	2,633,248	14,387	120,207	168,100
2010	18,513	2,648,457	13,770	110,738	175,789
2011	18,500	2,646,641	13,783	103,515	163,692

4.2. Projected Vehicle Miles Traveled (2012-2050)

The previous section describes historic fleet VMT. This section presents how EPA projected those values into the future. The VMT growth in years beyond 2011 is based on the VMT projections as described in AEO2014 [cite]. Due to differences in methodology, the absolute VMT values presented in AEO differ slightly from the HPMS values in VM-1 where the analysis years overlap. Therefore, the projections in AEO were not used directly. Instead, percent changes from year to year in the projected values were calculated and applied to the HPMS data. Since AEO2014 only projects out to 2040, VMT for years 2041-2050 were assumed to continue to grow at the average growth rate over 2031-2040.

Comment [Rev32]: Write out first uses of acronyms in each chapter.

Comment [Rev33]: FHWA asserts that HPMS is the gold standard. Hence, applying AEO growth factors to HPMS seems reasonable given the "ground truth" assumption.

A mapping between the two data sources was necessary because the vehicle categories differed between AEO and HPMS. AEO's light-duty category was mapped to both the combined HPMS light-duty and the motorcycle categories. Motorcycles were included here because they were not explicitly accounted for elsewhere in AEO. Since buses span a large range of heavy-duty vehicles and activity, the combination of AEO's light medium, medium, and heavy heavy-duty categories was mapped to the HPMS bus category. AEO's light medium and medium heavy-duty categories were combined for mapping to the HPMS single unit truck category, and AEO's heavy heavy-duty category was mapped to the HPMS combination truck category.

Comment [Rev34]: This seems a bit shaky. Bus activity growth will not parallel HDV truck growth. There are completely different causal factors in play. Ingle unit and large trucks are also likely to grow at different rates. Not sure I have a reasonable alternative to propose though. Al least the uncertainty should be acknowledged here.

The percent growth changes over time from the groupings described above were calculated and applied by HPMS category to the 2011 base year VMT from VM-1. The resulting values are presented in Table 4-2 below.

Table 4-2 VMT projections for 2012-2050 by HPMS Vehicle Class in Millions of Miles

Year	Motorcycles	Light-Duty Vehicles	Buses	Single Unit Trucks	Combination Trucks
2012	18,776	2,686,152	13,384	103,284	157,396
2013	19,030	2,722,469	13,954	108,811	163,467
2014	19,073	2,728,546	14,374	113,054	167,837
2015	19,162	2,741,392	14,991	118,343	174,804
2016	19,375	2,771,828	15,612	123,348	181,988
2017	19,590	2,802,578	16,036	126,693	186,928
2018	19,756	2,826,337	16,325	128,737	190,433
2019	19,931	2,851,349	16,609	130,692	193,905
2020	20,107	2,876,481	16,906	132,833	197,484
2021	20,284	2,901,914	17,222	135,237	201,214
2022	20,454	2,926,116	17,550	137,759	205,076
2023	20,627	2,950,908	17,877	140,171	208,983
2024	20,807	2,976,667	18,173	142,243	212,579
2025	20,997	3,003,914	18,495	144,418	216,551
2026	21,205	3,033,572	18,799	146,389	220,329
2027	21,426	3,065,195	19,052	147,999	223,510
2028	21,662	3,099,033	19,277	149,382	226,348
2029	21,897	3,132,690	19,509	150,824	229,268
2030	22,133	3,166,361	19,765	152,391	232,509
2031	22,378	3,201,376	20,005	153,916	235,518
2032	22,625	3,236,805	20,198	155,034	237,990
2033	22,867	3,271,436	20,429	156,435	240,929
2034	23,086	3,302,691	20,725	158,246	244,678
2035	23,293	3,332,329	21,017	159,910	248,437
2036	23,493	3,360,885	21,308	161,452	252,265
2037	23,687	3,388,760	21,600	162,945	256,123
2038	23,880	3,416,287	21,887	164,353	259,948
2039	24,060	3,442,035	22,146	165,603	263,426
2040	24,217	3,464,551	22,417	166,905	267,050
2041	24,436	3,495,877	22,701	168,431	270,775
2042	24,657	3,527,485	22,989	169,970	274,552
2043	24,880	3,559,380	23,280	171,524	278,381
2044	25,105	3,591,563	23,575	173,091	282,264
2045	25,332	3,624,036	23,874	174,673	286,201
2046	25,561	3,656,804	24,176	176,270	290,193
2047	25,792	3,689,868	24,483	177,881	294,241
2048	26,025	3,723,230	24,793	179,507	298,345
2049	26,261	3,756,894	25,107	181,147	302,507
2050	26,498	3,790,863	25,425	182,803	306,726

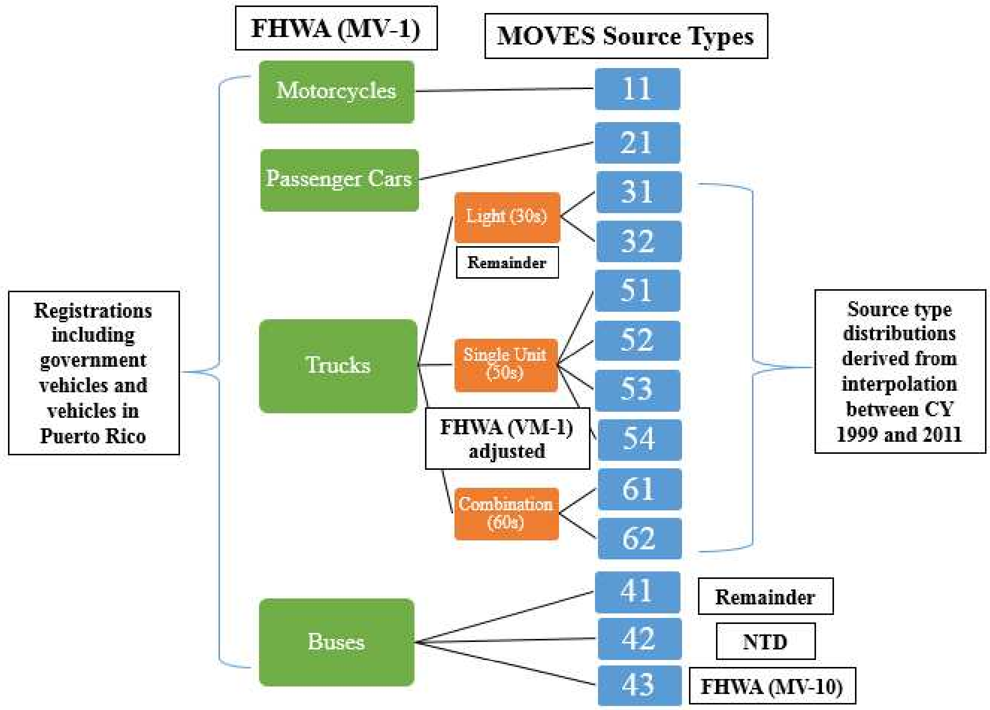
5. Vehicle Populations by Calendar Year

MOVES uses vehicle populations to characterize emissions activity that is not directly dependent on VMT, such as daily diurnal evaporative emissions . These Vehicle population data are also used to allocate VMT from HPMS class to source type and age (for more details, see Section 7. 7.). The default database stores historic estimates and future projections of total US vehicle populations in 1990 and 1999-2050 by source type. All of these values have been updated in MOVES2014 with using improved data sources. The MOVES database stores this information in the SourceTypeYear table, which has three data fields: sourceTypePopulation, salesGrowthFactor, and migrationRate. However, the salesGrowthFactor and migrationRate fields are not currently used in MOVES2014.

5.1. Historic Source Type Populations (1990 and 1999-2011)

MOVES populations for calendar years 1990 and 1999-2011 are derived top-down from registration data in Table MV-1 of the Federal Highway Administration's annual *Highway Statistics* report. In this the FHWA table, vehicles are separated into four general vehicle categories: motorcycles, passenger cars, trucks, and buses. These categories include government vehicles and vehicles in Puerto Rico but do not account for vehicles in the Virgin Islands, due to their relatively small effects on national population estimates. Motorcycle and car data were used without adjustment, but since because MOVES populations are input by source type, allocations within the general categories of trucks and buses were necessary, as shown in Figure 5-1.

Figure 5-1 Conceptual map of allocating FHWA MV-1 vehicle registration estimates to MOVES source types



Trucks were separated into single unit and combination trucks using registration data in the *Highway Statistics* VM-1 Table. The remaining MV-1 truck registrations were allocated to ~~the~~ light-duty trucks. Single unit and combination trucks were ~~further~~ then sub-allocated among their respective source types using the EPA sample vehicle counts data [citation here]. ~~Since we only had sample~~ Because vehicle sample counts were only available for calendar years 1999 and 2011, the 2000-2010 distributions among source types within the general truck categories were linearly interpolated between 1999 and 2011, rather than using ~~the~~ predictions for these years as was done for ~~in~~ MOVES2010b. ~~This~~ The linear interpolation ensured that every source type population would more or less track its general MV-1 population, as shown for example in for allocating between short-haul and long-haul combination trucks below (see Figure 5-2). This linear interpolation method was also used for single unit truck (see Figure 5-3) and light-duty truck source types (see Figure 5-4). Car and motorcycle populations ~~are~~ were reported directly in the MV-1 Table and thus were not subject to linear interpolation adjustments.

Figure 5-2 Combination truck source type populations interpolated 1999-2011

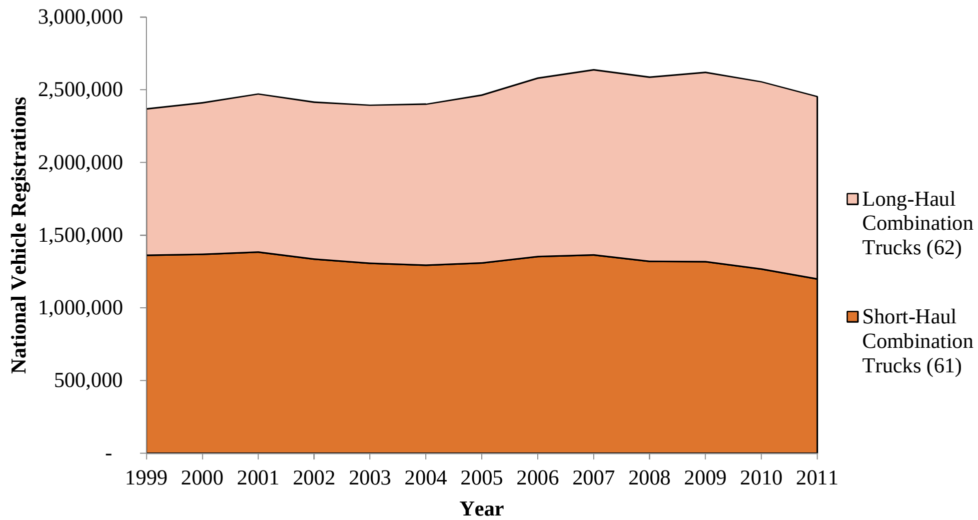


Figure 5-3 Single unit truck source type populations interpolated 1999-2011

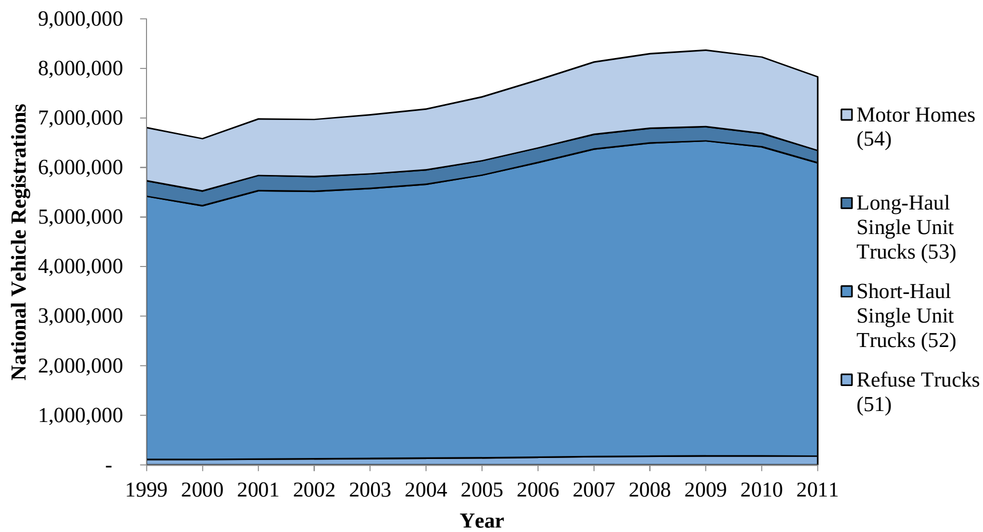


Figure 5-4 Light-duty vehicle source type populations; light trucks interpolated 1999--2011

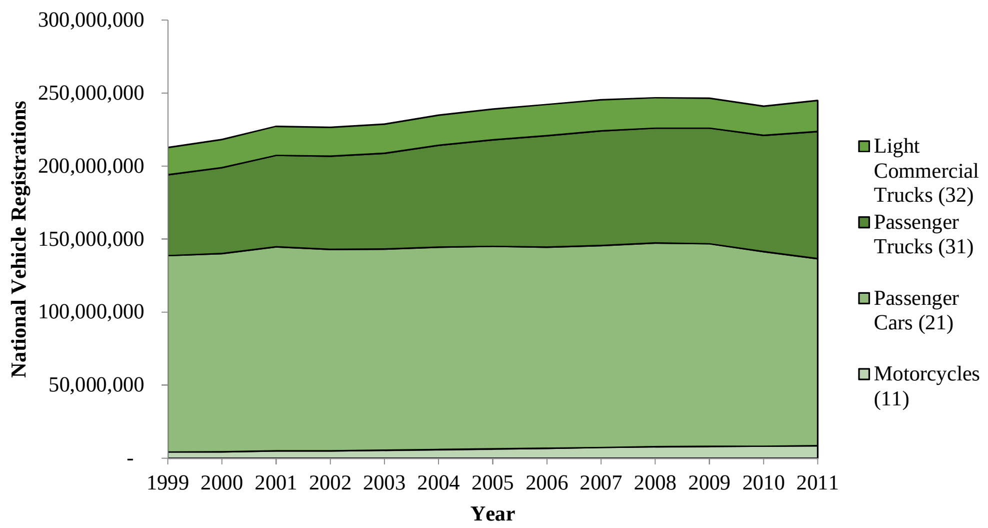
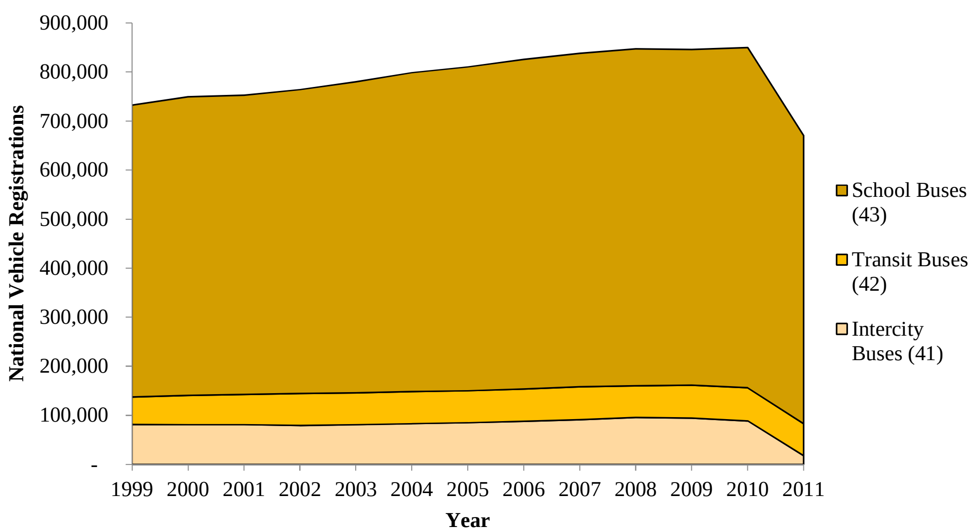


Figure 5-5 Bus source type populations in MOVES2014



Buses were allocated in a similar fashion as trucks, but using different data sources. School bus estimates for all years 1999-2011 were taken from the *Highway Statistics* Table MV-10 and transit bus estimates for these years were taken from the National Transit Database (NTD), compiled by the Federal Transit Administration. The remainder of MV-1 bus registrations were allocated to the intercity bus source type. Since school and transit bus registrations in Puerto Rico were not readily available, we estimated them by multiplying the US transit or school bus

Comment [Rev35]: What about tour buses and express buses? Perhaps can be ignored at national scale, but user should be cautioned to obtain local/county data as needed.

registrations by the ratio of bus registrations in Puerto Rico to the total MV-1 bus registrations. MOVES2014 bus populations are shown in Figure 5-5. Note that the precipitous drop in bus populations from 2010 to 2011 is reflected in the MV-1 bus registration data published by FHWA, which has been used in MOVES2014 without adjustment.

Table 5-1 Historic Source Type Populations for Calendar Years 1990 and 1999-2011 (in thousands)

Year	Motorcycle	Passenger Car	Passenger Truck	Light Commercial Truck	Intercity Bus	Transit Bus	School Bus	Refuse Truck	Single Unit Short-haul Truck	Single Unit Long-haul Truck	Motor Home	Combination Short-haul Truck	Combination Long-haul Truck
1990	4,281	145,112	27,700	9,903	60	59	511	67	3,870	145	927	1,177	705
…													
1999	4,174	134,480	55,472	18,532	81	56	595	105	5,312	314	1,073	1,361	1,008
2000	4,368	135,670	58,930	19,217	81	60	609	106	5,123	296	1,055	1,368	1,043
2001	4,925	139,709	62,685	19,947	81	61	611	116	5,416	305	1,137	1,384	1,087
2002	5,026	137,996	63,789	19,801	79	65	620	120	5,396	297	1,155	1,335	1,080
2003	5,392	137,745	65,651	19,873	81	65	634	126	5,452	292	1,189	1,307	1,088
2004	5,813	138,642	69,860	20,616	83	65	650	132	5,528	288	1,228	1,293	1,108
2005	6,259	138,779	72,980	20,987	85	65	660	141	5,703	289	1,290	1,309	1,155
2006	6,770	137,742	76,321	21,380	88	66	672	152	5,948	293	1,370	1,353	1,228
2007	7,254	138,354	78,443	21,398	91	67	680	164	6,208	297	1,456	1,364	1,274
2008	7,869	139,501	78,596	20,868	96	65	687	172	6,322	293	1,509	1,319	1,268
2009	8,046	138,743	79,219	20,464	94	67	684	178	6,356	286	1,544	1,317	1,303
2010	8,125	133,313	79,641	20,007	89	68	694	180	6,234	271	1,540	1,266	1,289
2011	8,553	128,078	87,030	21,252	18	66	587	176	5,915	248	1,487	1,198	1,255

Note that the decline in sales seen in the 2008 recession results in a flattening of total population growth rates, and eventually a decline for Passenger Cars and Combination Long-haul trucks as shown in Table 5-1. This suggests that the decline in sales was accompanied by a delay in the scrappage of older vehicles. The dynamic vehicle survival rates in MOVES and their impact on age distributions are discussed in Section 7.1.2.

5.2. Projected Vehicle Populations (2012-2050)

The previous section described the historic national fleet as it appeared in the data sources. This section presents how EPA projected those vehicle populations into the future. Future fleet composition ~~This work~~ is inherently dependent on projections of both vehicle sales and scrappage rates. While future vehicle sales are commonly included in economic forecasts, there are no reliable sources for projected national vehicle scrappage. Therefore, ~~we decided to use~~ projected VMT growth was selected as a surrogate for vehicle population growth. In examining VMT per vehicle by HPMS class over the historic years presented above, this surrogate appears reasonable for use at the national level. Table 5-2 shows the VMT values of Table 4-1 divided by the vehicle populations of Table 5-1 grouped by HPMS classification. At this level of aggregation, VMT per vehicle ~~is~~ remains relatively constant at the national level~~with no clear trends over time~~.

Comment [Rev36]: Historically, this has not been true for urban areas. We have owned more vehicles and driven more miles, but vehicles have been serving as low-mileage backup vehicles. It is probably close enough for now, but should be investigated further.

Comment [Rev37]: Need to keep reminding reader throughout that they need to get their own data for County and local analyses.

Table 5-2 VMT per Vehicle by HPMS Classification

Year	Motorcycles	Light-Duty Vehicles	Buses	Single Unit Trucks	Combination Trucks
1999	3,263	11,518	20,291	14,776	67,928
2000	2,787	11,497	19,740	15,271	66,876
2001	2,258	11,240	17,240	14,837	68,381
2002	2,223	11,533	17,455	15,401	69,655
2003	2,111	11,552	17,155	15,969	72,459
2004	2,576	11,575	16,946	15,501	72,037
2005	2,201	11,505	16,238	14,783	71,075
2006	2,830	11,385	16,995	15,885	68,702
2007	2,950	11,298	17,322	14,767	69,825
2008	2,645	11,007	17,480	15,291	71,058
2009	2,588	11,044	17,026	14,372	64,160
2010	2,279	11,369	16,181	13,464	68,802
2011	2,163	11,197	20,541	13,227	66,731

~~Therefore, the~~ The AEO growth factors used to project future VMT as described in Section 4.2. were also used to project vehicle populations~~. (~~ (m~~M~~otorcycle growth was calculated using factors from light-duty vehicles~~.~~). Because ~~Since~~ these growth factors are by HPMS class, the 2011 source type populations were aggregated by HPMS class before the growth factors were applied to the base populations. The resulting HPMS class population projections are presented in Table 5-3. However, MOVES cannot use populations in this format as it requires ~~them to be disaggregated~~ disaggregation by source type. The distribution projected HPMS class populations to source type ~~was~~ were calculated with the same algorithm used to produce age distributions. Please see Section 7.1.2.2. for a detailed discussion on this topic. The resulting projected source type populations are tabulated in Section 17. (Appendix A).

Table 5-3 Projected HPMS Category Populations for 2012-2050 (in thousands)

Year	Motorcycles	Light-Duty Vehicles	Buses	Single Unit Trucks	Combination Trucks
2012	8,571	236,285	704	8,198	2,471
2013	8,687	239,479	734	8,637	2,566
2014	8,706	240,028	757	8,973	2,635
2015	8,747	241,178	789	9,393	2,745
2016	8,844	243,868	822	9,790	2,857
2017	8,943	246,584	844	10,056	2,935
2018	9,018	248,692	860	10,218	2,990
2019	9,098	250,904	875	10,373	3,045
2020	9,178	253,126	890	10,543	3,100
2021	9,260	255,371	906	10,733	3,159
2022	9,337	257,508	923	10,934	3,220
2023	9,416	259,695	941	11,126	3,281
2024	9,498	261,966	956	11,290	3,338
2025	9,585	264,368	974	11,463	3,400
2026	9,680	266,983	990	11,620	3,459
2027	9,781	269,767	1,004	11,747	3,510
2028	9,888	272,745	1,015	11,858	3,554
2029	9,996	275,707	1,027	11,978	3,600
2030	10,103	278,670	1,041	12,107	3,650
2031	10,215	281,752	1,053	12,234	3,698
2032	10,328	284,871	1,063	12,335	3,737
2033	10,439	287,918	1,075	12,454	3,783
2034	10,538	290,669	1,091	12,606	3,842
2035	10,633	293,277	1,106	12,745	3,901
2036	10,724	295,790	1,122	12,877	3,961
2037	10,813	298,244	1,137	13,007	4,021
2038	10,901	300,667	1,152	13,129	4,081
2039	10,983	302,932	1,166	13,238	4,136
2040	11,055	304,914	1,180	13,346	4,193
2041	11,155	307,671	1,196	13,472	4,251
2042	11,256	310,453	1,210	13,599	4,311
2043	11,357	313,260	1,226	13,731	4,371
2044	11,460	316,092	1,241	13,864	4,432
2045	11,564	318,951	1,257	13,998	4,494
2046	11,668	321,835	1,273	14,135	4,556
2047	11,774	324,745	1,289	14,273	4,620
2048	11,880	327,681	1,304	14,411	4,684
2049	11,988	330,642	1,322	14,550	4,750
2050	12,096	333,632	1,338	14,691	4,816

6. Fleet Characteristics

MOVES categorizes vehicles into thirteen source use types, as described -in Section 2.1. ~~2.1~~, ~~which are~~ defined using physical characteristics, such as number of axles and tires, and travel behavior characteristics, such as typical trip lengths and duty cycles. This section describes the defining characteristics of the source types in greater detail and explains how source type is related to fuel type and regulatory class, primarily through the SampleVehiclePopulation table.

6.1. Source Type Definitions

MOVES Source types are intended to further divide HPMS vehicle classifications into groups of vehicles with similar activity patterns For example, passenger trucks and light commercial trucks are expected to have different daily trip patterns. VIUS was ~~our~~ the main source of information for distinguishing these vehicles. Table 4-6 summarizes how the VIUS2002 parameters were used to delineate the light-duty, single unit, and combination truck source types for MOVES2014.

Axle arrangement (AXLE_CONFIG) was used to define four categories: straight trucks with two axles and four tires (codes 1, 6, 7, 8), straight trucks with two axles and six tires (codes 2, 9, 10, 11), all straight trucks (codes 1-21), and all tractor-trailer combinations (codes 21+). Primary distance of operation (PRIMARY_TRIP) was used to define short-haul (codes 1-4) for vehicles with primary operation distances less than 200 miles and long-haul (codes 5-6) for 200 miles and greater. The VIN-decoded gross vehicle weight (ADM_GVW) and survey weight (VIUS_GVW) were used to distinguish vehicles less than 10,000 lbs. as light-duty and vehicles greater than or equal to 10,000 lbs. as heavy-duty. Any vehicle with two axles and at least six tires was considered a single unit truck regardless of weight. We also note that refuse trucks have their own VIUS vocational category (BODYTYPE 21) and that MOVES distinguishes between personal (OPCLASS 5) and non-personal use.

Comment [Rev38]: Put details on cut points in the table below

Table 6-1 VIUS2002 Parameters Used to Distinguish Truck Source Types in MOVES2014

Source Type	Axle Arrangement	Primary Distance of Operation	Weight	Body Type	Operator Classification
Passenger Trucks	AXLE_CONFIG in (1,6,7,8)†	Any	ADM_GVW in (1,2) & VIUS_GVW in (1,2,3)	Any	OPCLASS =5
Light Commercial Trucks	AXLE_CONFIG in (1,6,7,8)†	Any	ADM_GVW in (1,2) & VIUS_GVW in (1,2,3)	Any	OPCLASS ≠5
Refuse Trucks*	AXLE_CONFIG in (2,9,10,11)	TRIP_PRIMARY in (1,2,3,4)	Any	BODYTYPE =21	Any
	AXLE_CONFIG <=21	TRIP_PRIMARY in (1,2,3,4)	ADM_GVW > 2 & VIUS_GVW > 3	BODYTYPE =21	Any
Single Unit Short-Haul Trucks*	AXLE_CONFIG in (2,9,10,11)	TRIP_PRIMARY in (1,2,3,4)	Any	BODYTYPE ≠21	Any
	AXLE_CONFIG <=21	TRIP_PRIMARY in (1,2,3,4)	ADM_GVW > 2 & VIUS_GVW > 3	BODYTYPE ≠21	Any
Single Unit Long-Haul Trucks*	AXLE_CONFIG in (2,9,10,11)	TRIP_PRIMARY in (5,6)	Any	Any	Any
	AXLE_CONFIG <=21	TRIP_PRIMARY in (5,6)	ADM_GVW > 2 & VIUS_GVW > 3	Any	Any
Combination Short-Haul Trucks	AXLE_CONFIG >=21	TRIP_PRIMARY in (1,2,3,4)	Any	Any	Any
Combination Long-Haul Trucks	AXLE_CONFIG >=21	TRIP_PRIMARY in (5,6)	Any	Any	Any

† In the MOVES2014 analysis, ~~we did not constrain~~ axle configuration of light-duty trucks was not constrained, so there are some, albeit very few, trucks that have three axles or more and/or six tires or more. These vehicles are classified as light-duty trucks based primarily on their weight. Only 0.27% of light-duty trucks have such tire and/or axle parameters and they have a negligible impact on vehicle populations and emissions.
* For a source type with multiple rows, the source type is applied to any vehicle with either set of parameters.

Comment [Rev39]: The table if very confusing for users. It would be better to replace codes in the table with intuitive values.

Motorcycles and passenger cars in MOVES borrow vehicle definitions from the FHWA Highway Performance Monitoring System (HPMS) classifications from the *Highway Statistics* MV-1 Table. Source type definitions for intercity, transit, and school buses are taken from various US Department of Transportation sources. While refuse trucks were identified and separated from other single unit trucks in VIUS, motor homes were not.

6.1.1. Motorcycles

According to the HPMS vehicle description, motorcycles (sourceTypeID 11) are, “all two- or three-wheeled motorized vehicles, typically with saddle seats and steered by handlebars rather than a wheel.”[25] This category usually includes any registered motorcycles, motor scooters, mopeds, and motor-powered bicycles. Neither the 2011 Polk dataset nor VIUS contain any information on motorcycles. As noted in Section 5.1. ~~5.1~~ information on motorcycle populations comes from HPMS MV-1 registrations.

6.1.2. Passenger Cars

Passenger cars are defined as any coupes, compacts, sedans, or station wagons with the primary purpose of carrying passengers.[25] All passenger cars (sourceTypeID 21) are categorized in the light-duty vehicle regulatory class (regClassID 20). Cars were not surveyed in VIUS, but Polk has a robust yet proprietary dataset of car registrations from all fifty states.

6.1.3. Light-Duty Trucks

Light-duty trucks include pickups, sport utility vehicles (SUVs), and vans. Depending on use and GVWR, we categorize them into two different MOVES source types: 1) passenger trucks (sourceTypeID 31), and 2) light commercial trucks (sourceTypeID 32). According to 2011 VM-1 vehicle classifications from FHWA, light-duty vehicles are those weighing less than 10,000 pounds (i.e. they are in weight class 1 and 2), except Class 2b trucks with two axles or more and at least six tires are assigned to the single unit truck category.

VIUS contains many survey questions on weight; we chose to use both a VIN-decoded gross vehicle weight rating (ADM_GVW) and a respondent self-reported GVWR (VIUS_GVW) to differentiate between light-duty and single unit trucks. For the passenger trucks, there is a final VIUS constraint that the most frequent operator classification (OPCLASS) must be personal transportation. Inversely, light commercial trucks (sourceTypeID 32) have a VIUS constraint that their most frequent operator classification must not be personal transportation.

6.1.4. Buses

MOVES has three bus source types: intercity (sourceTypeID 41), transit (sourceTypeID 42), and school buses (sourceTypeID 43). Buses were not included in either VIUS or the Polk dataset, so supplementary data sources were necessary. MOVES uses various US Department of Transportation definitions for buses.

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Transit buses are defined in the Federal Transit Administration's National Transit Database (NTD), which states that they are buses owned by a public transit organization for the primary purpose of transporting passengers on fixed routes and schedules. According to FHWA, school buses are defined as vehicles designed to carry more than 10 passengers, used to transport K-12 students between their home and school.[26] Intercity buses are, as defined by the Bureau of Transportation Statistics, "interstate motor carrier of passengers with an average annual gross revenue of at least one million dollars,"[27] but MOVES also considers any bus that cannot be categorized as either a transit or school bus to be an intercity bus.

6.1.5. Single Unit Trucks

The single unit HPMS class in MOVES consists of refuse trucks (sourceTypeID 51), short-haul single unit trucks (sourceTypeID 52), long-haul single unit trucks (sourceTypeID 53), and motor homes (sourceTypeID 54). With 2013 VM-1 updates to vehicle classifications, FHWA now defines a single unit truck as a single-frame truck with a gross vehicle weight rating of greater than 10,000 pounds or with two axles and at least six tires—colloquially known as a "dualie." As with light-duty truck source types, single unit trucks are sorted using VIUS parameters, in this case that includes axle configuration (AXLE_CONFIG) for straight trucks (codes 1-21), vehicle weight (both ADM_GVW and VIUS_GVW), most common trip distance (TRIP_PRIMARY), and body type (BODYTYPE). All short-haul single unit trucks must have a primary trip distance of 200 miles or less and must not be refuse trucks and all long-haul trucks must have a primary trip distance of greater than 200 miles. Refuse trucks are short-haul single unit trucks with a body type (code 21) for trash, garbage, or recyclable material hauling. Motor homes are not included in VIUS.

6.1.6. Combination Trucks

A combination truck is any truck-tractor towing at least one trailer according to VIUS. MOVES divides these tractor-trailers into two MOVES source types: short-haul (sourceTypeID 61) and long-haul combination trucks (sourceTypeID 62). Like single unit trucks, short-haul and long-haul combination trucks are distinguished by their primary trip length (TRIP_PRIMARY) in VIUS. If the tractor-trailer's primary trip length is equal to or less than 200 miles, then it is considered short-haul. If the tractor-trailer's primary trip length is greater than 200 miles, then it is considered long-haul. Short-haul combination trucks are typically older than long-haul combination trucks and ~~these short-haul trucks~~ are often purchased in secondary markets~~,~~ for use in ~~such as for~~ drayage applications, after being used primarily for long-haul trips.[28]

6.2. Sample Vehicle Population

To match source types to emission rates, MOVES must associate each source type with specific fueltypes and regulatory classes. Much of default the information on fleet characteristics is stored in the SampleVehiclePopulation table, which contains two fractions: 1) stmyFraction, and 2) stmyFuelEngFraction. The former fraction defines the default fuel type distribution, which can be modified by the user through the Alternative Fuel Vehicle and Technology (AVFT) table, and the latter fraction forms the default regulatory class distribution. Both SVP fractions are computed through the EPA sample vehicle counts dataset that joins 2011 national R.L. Polk vehicle registration data with Vehicle Inventory and Use Survey (VIUS) classifications.

Comment [Rev40]: Define each variables as it is presented. For example, add "(source type model year fraction)."

6.2.1. Fuel Type and Regulatory Class Distributions

The stmyFraction is the default national fuel type and regulatory class allocation for each source type and model year. Written out mathematically, we define the stmyFraction as,

$$f(stmy)_{i,j,k,l} = \frac{N_{i,j,k,l}}{\sum_{j\epsilon J,k\epsilon K} N_{i,j,k,l}}, \quad \text{Equation 1}$$

where the number of vehicles N in a given model year i, regulatory class j, fuel type k, and source type l is divided by the sum of vehicles across the set of all regulatory classes J and all fuel types K. That is, the denominator only differs by source type and model year. For example, model year 2010 passenger trucks have stmyFractions that indicate the distribution of these vehicles between gasoline, diesel, E85, and electricity and regulatory classes 30 and 40. These values must sum~~s~~ to one for each source type and model year. A value of zero indicates that the MOVES default population of vehicles of that source type, model year, fuel type and regulatory class is negligible or does not exist.

While stmyFraction indicates MOVES default values, the stmyFuelEngFraction allows the modeling of non-default fuel type distributions. For each allowable combination of source type, model year and fuel type, the stmyFuelEngFraction indicates the expected regulatory class distribution, whether or not these vehicles exist in the default. Similar to the stmyFraction above, we define stmyFuelEngFraction as,

$$f(stmyfueleng)_{i,j,k,l} = \frac{N_{i,j,k,l}}{\sum_{j\epsilon J} N_{i,j,k,l}}, \qquad \text{Equation 2}$$

for number of vehicles N, model year i, regulatory class j, fuel type k, source type l, and the set of all regulatory classes J. The denominator differs by source type, model year, and fuel type in this case. For example, for model year 2010 gasoline passenger trucks, the table will list a stmyFuelEngFraction for regulatory class 30 and another for regulatory class 40. These fractions sum to one for each combination of source type, model year and fuel type.

For example, while the stmyFraction indicates that the MOVES defaults assign zero fraction of model year 2010 passenger trucks to the electricity fuel type, the stmyFuelEngFraction indicates a default (hypothetical) regulatory class distribution if these vehicles existed. In this case, MOVES would model them all as belonging to regulatory class 30. The stmyFraction is particularly important because it allows users ~~can~~ to edit fuel type distributions using the Alternative Vehicle Fuel and Technology (AVFT) importer. For instance, a user can create a future scenario ~~in which there is~~ with a ~~high~~ large penetration of electric passenger trucks. The stmyFuelEngFraction allows MOVES to assign vehicles to their regulatory class without requiring this input from the user. This means an allowed stmyFuelEngFraction must never be zero.

~~As an example,~~ Figure 6-1~~Figure 6-1~~ shows the national default fuel type fractions for all light-duty vehicles among the different MOVES fuel types. As noted in Section 2.4. ~~2.4~~ these fuel type fractions indicate the fuel capability of the vehicle and not the fuel being used by the vehicle. In this report's nomenclature, E85-capable and flexible fuel vehicles are synomous~~—~~, meaning they can accept either gasoline or E85 fuel. Although these vehicle are capable of running on E85, the fuel type distributions do not have any information on how often they actually use E85. Discussion on fuel usage can be found in the MOVES2014 Fuel Supply Report.[5]

Comment [Rev41]: This whole paragraph is confusing (and reinforces the need to allow the user to provide direct inputs rather than relying on the internal algorithms for assignment, as noted earlier. If this paragraph remains, it should either be expanded to provide the exact details of the internal method, or reduced to avoid confusion.

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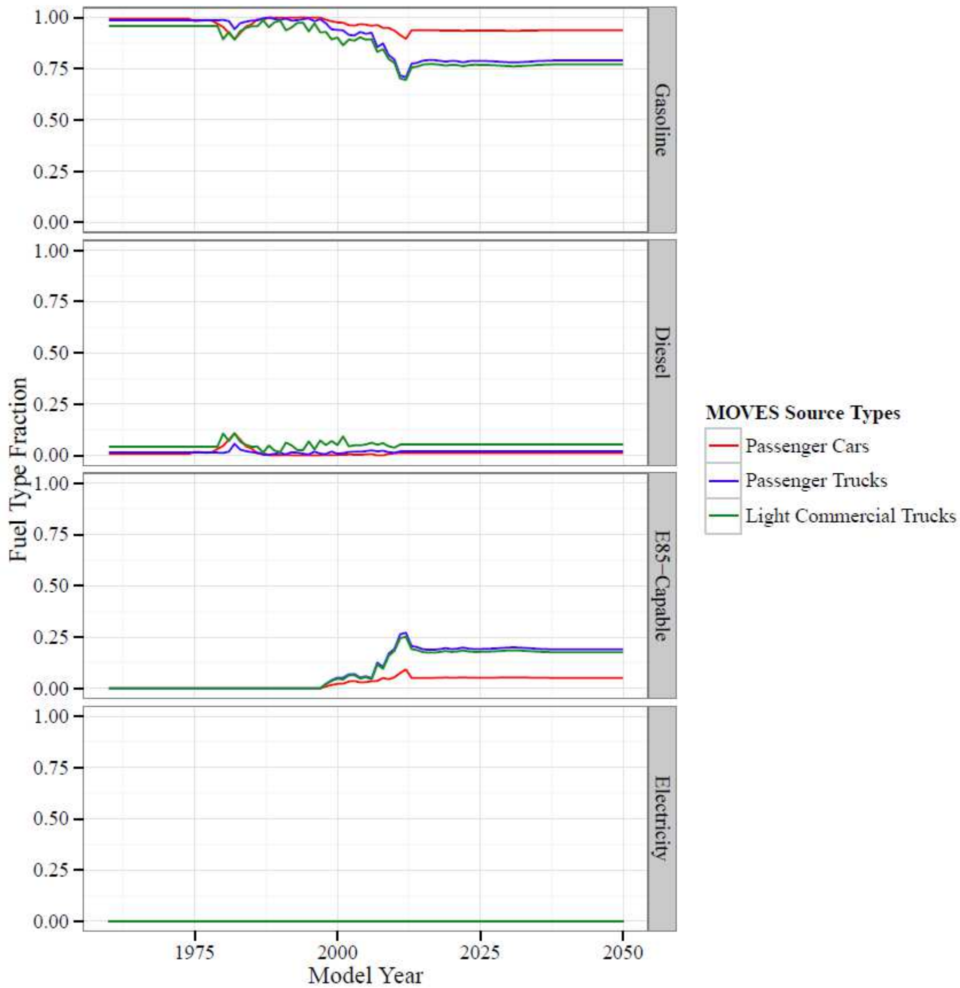
Comment [Rev42]: This would be a good user input for the next MOVES update.

Figure 6-1 Default fuel type fractions for light-duty source types in MOVES2014, where being E85-capable indicates flexible fuel vehicle populations and all default electric vehicle populations are zero



6.2.2. Sample Vehicle Counts

The SampleVehiclePopulation table fractions have been developed by EPA using the sample vehicle counts dataset referenced in Section 3. ~~3~~, which primarily joins calendar year 2011 registration data from R.L. Polk and the Vehicle Inventory and Use Survey (VIUS) results. The sample vehicle counts dataset was generated by multiplying the 2011 Polk vehicle populations by the source type allocations from VIUS.

While VIUS provides source type classifications, ~~we~~ the update relies ~~relied~~ primarily on the 2011 Polk vehicle registration dataset to form the basis of the fuel type and regulatory class distributions in the SampleVehiclePopulation table. ~~We purchased the~~ The Polk dataset was purchased in April 2012, so it did not ~~have~~ contain complete registration records for model year 2012 vehicles ~~and~~ . ~~t~~Therefore model year 2012 vehicles were omitted from the SVP analysis. The Polk data was provided with the following fields: vehicle type (cars or trucks), fuel type, gross vehicle weight rating (GVWR) for trucks, household vehicle counts, and work vehicle counts. We combined the household and work vehicle counts. The MOVES distinction between personal and commercial travel for light-duty trucks comes from VIUS.

Comment [Rev43]: Write out

The Polk records by FHWA truck weight class were grouped into MOVES GVWR-based regulatory classes, as shown in Table 6-2~~Table 6-2~~ below. As stated above, all passenger cars were assigned to regClassID 20. The mapping of weight class to regulatory class is straightforward with one notable exception for delineating trucks weighing more or less than 8,500 lbs.

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Table 6-2 Initial mapping from FHWA truck classes to MOVES regulatory classes.

Vehicle Category	FHWA Truck Weight Class	Weight Range (lbs)	regClassID
Trucks	1	< 6,000	30
Trucks	2a	6,001 – 8,500	30*
Trucks	2b	8,501 – 10,000	41*
Trucks	3	10,001 – 14,000	41
Trucks	4	14,001 – 16,000	42
Trucks	5	16,001 – 19,500	42*
Trucks	6	19,501 – 26,000	46
Trucks	7	26,001 – 33,000	46
Trucks	8a	33,001 – 60,000	47
Trucks	8b	> 60,001	47
Cars			20

*After the Polk data has been sorted into source types (described later in this section), some regulatory classes were merged or divided. Any regulatory class 41 vehicles in light-duty truck source types have been reclassified into the new regulatory class 40 (see explanation in Section 2.3. ~~2.3~~), any regulatory class 30 vehicles in single unit truck source types have been reclassified into regulatory class 41, and any regulatory class 42 vehicles in combination truck source types have been reclassified into regulatory class 46.

~~Since~~ Because the Polk dataset did not distinguish between Class 2a (6,001-8,500 lbs) and Class 2b (8,501-10,000 lbs) trucks, ~~but~~ and because MOVES regulatory classes 30, 40, and 41 all fall within Class 2, ~~we needed~~ a secondary data source was needed to allocate the Polk gasoline and diesel trucks between Class 2a and 2b. ~~We derived information~~ Data from an Oak Ridge National Laboratory (ORNL) paper[29] summarized in Table 6-3~~Table 6-2~~ was used to allocate the Polk Class 2 gasoline and diesel trucks into the regulatory classes. Class 2a trucks are in regulatory class 30 and Class 2b trucks are in either regulatory class 40 or 41.

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Comment [Rev44]: Need to let the reader know that they can essentially modify these values using reasonable regional or local input data.

Table 6-3 Fractions used to distribute Class 2a and 2b trucks

Fuel Type	Truck Class	
	2a	2b
Gasoline	0.975	0.760
Diesel	0.025	0.240
	1.000	1.000

Additionally, the Polk dataset includes a variety of fuels, some that are included in MOVES and others that are not. Only the Polk gasoline and diesel vehicles were included in ~~our~~ the analysis; all other alternative fuel vehicles were omitted. While MOVES2014 does model light-duty E-85 and electric vehicles, and compressed natural gas (CNG) transit buses, these relative penetrations of alternative fuel vehicles ~~have been~~ were developed from secondary data sources rather than Polk. Polk excludes some government fleets and retrofit vehicles that could potentially be large contributors to these alternative fuel vehicle populations. Instead we used flexible fuel vehicle sales data reported for EPA certification, and dedicated CNG bus populations from the National Transit Database. The Table 6-4~~Table 6-4~~ illustrates how Polk fuels were mapped to MOVES fuel types, and which Polk fuels were not used in MOVES.

This mapping in Table 6-4~~Table 6-4~~ led ~~us to discard~~ discarded 0.22 percent, roughly 530,000 vehicles (mostly dedicated or aftermarket alternative fuel vehicles), of Polk's 2011 national fleet in developing the default fuel type fractions. However, because the MOVES national population is derived top-down from FHWA registration data, as outlined in Section 5.1. ~~5.1~~ the total population is not affected. We considered the Polk vehicle estimates to be a sufficient sample for the fuel type and regulatory class distributions in the SampleVehiclePopulation table.

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Comment [Rev45]: Table 6-4 is not needed and may confuse readers. Just indicate the ones that were used and state that 0.22 percent were discarded and list some examples.

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Table 6-4 A list of fuels from the Polk dataset used to develop MOVES fuel type distributions.

Polk Fuel Type	MOVES fuelTypeID	MOVES fuelType
Unknown	N/A	
Undefined	N/A	
Both Gas and Electric	1	Gasoline
Gas	1	Gasoline
Gas/Elec	1	Gasoline
Gasoline	1	Gasoline
Diesel	2	Diesel
Natural Gas	N/A	
Compressed Natural Gas	N/A	
Natr.Gas	N/A	
Propane	N/A	
Flexible (Gasoline/Ethanol)	N/A	
Flexible	N/A	
Electric	N/A	
Cnvrtble	N/A	
Conversion	N/A	
Methanol	N/A	
Ethanol	N/A	
Convertible	N/A	

Next we transformed the VIUS dataset into MOVES format. The VIUS vehicle data was first assigned to MOVES source types using the constraints in Table 6-1~~Table 6-1~~ and then to MOVES regulatory classes using the mapping described in Table 6-2~~Table 6-2~~, including the allocation between Class 2a and 2b trucks from the ORNL study in Table 6-3~~Table 6-3~~. Similar to our fuel type mapping of the Polk dataset, we chose to omit alternative fuel vehicles, as summarized below in Table 6-5~~Table 6-5~~.Table 6-1 VIUS2002 Parameters Used to Distinguish Truck Source Types in MOVES2014

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Source Type	**Axle Arrangement**	**Primary Distance of Operation**	**Weight**	**Body Type**	**Operator Classification**
Passenger Trucks	AXLE_CONFIG in (1,6,7,8)[†]	Any	ADM_GVW in (1,2) & VIUS_GVW in (1,2,3)	Any	OPCLASS =5
Light Commercial Trucks	AXLE_CONFIG in (1,6,7,8)[†]	Any	ADM_GVW in (1,2) & VIUS_GVW in (1,2,3)	Any	OPCLASS ≠5
Refuse Trucks*	AXLE_CONFIG in (2,9,10,11)	TRIP_PRIMARY in (1,2,3,4)	Any	BODYTYPE =21	Any
	AXLE_CONFIG <=21	TRIP_PRIMARY in (1,2,3,4)	ADM_GVW > 2 & VIUS_GVW > 3	BODYTYPE =21	Any
Single Unit Short-Haul Trucks*	AXLE_CONFIG in (2,9,10,11)	TRIP_PRIMARY in (1,2,3,4)	Any	BODYTYPE ≠21	Any
	AXLE_CONFIG <=21	TRIP_PRIMARY in (1,2,3,4)	ADM_GVW > 2 & VIUS_GVW > 3	BODYTYPE ≠21	Any
Single Unit Long-Haul Trucks*	AXLE_CONFIG in (2,9,10,11)	TRIP_PRIMARY in (5,6)	Any	Any	Any
	AXLE_CONFIG <=21	TRIP_PRIMARY in (5,6)	ADM_GVW > 2 & VIUS_GVW > 3	Any	Any
Combination Short-Haul Trucks	AXLE_CONFIG >=21	TRIP_PRIMARY in (1,2,3,4)	Any	Any	Any
Combination Long-Haul Trucks	AXLE_CONFIG >=21	TRIP_PRIMARY in (5,6)	Any	Any	Any

[†] In the MOVES2014 analysis, axle configuration of light-duty trucks was not constrained, so there are some, albeit very few, trucks that have three axles or more and/or six tires or more. These vehicles are classified as light-duty trucks based primarily on their weight. Only 0.27% of light-duty trucks have such tire and/or axle parameters and they have a negligible impact on vehicle populations and emissions.

* For a source type with multiple rows, the source type is applied to any vehicle with either set of parameters.

Table 6-5 Mapping of VIUS2002 fuel types to MOVES2014 fuel types

VIUS Fuel Type	VIUS Fuel Code	MOVES fuelTypeID	MOVES fuelType
Gasoline	1	1	Gasoline
Diesel	2	2	Diesel
Natural gas	3	N/A	
Propane	4	N/A	
Alcohol fuels	5	N/A	
Electricity	6	N/A	
Gasoline and natural gas	7	1	Gasoline
Gasoline and propane	8	1	Gasoline
Gasoline and alcohol fuels	9	1	Gasoline
Gasoline and electricity	10	1	Gasoline
Diesel and natural gas	11	2	Diesel
Diesel and propane	12	2	Diesel
Diesel and alcohol fuels	13	2	Diesel
Diesel and electricity	14	2	Diesel
Not reported	15	N/A	
Not applicable	16	N/A	

This process yielded VIUS data by MOVES source type, model year, regulatory class, and fuel type. The VIUS source type distributions were calculated in a similar fashion to the SampleVehiclePopulation fractions discussed above for each regulatory class-fuel type-model year combination. Stated formally, for any given model year i, regulatory class j, and fuel type k, the source type population fraction f for a specified source type l will be the number of VIUS trucks N in that source type divided by the sum of VIUS trucks across the set of all source types L. The source type population fraction is summarized in the following formula:

$$f(VIUS)_{i,j,k,l} = \frac{N_{i,j,k,l}}{\sum_{l \in L} N_{i,j,k,l}} \qquad \text{Equation 3}$$

The VIUS data in our analysis spanned model year 1986 to 2002. The 2002 source type distribution has been used for all distributions after MY 2002 and the 1986 distribution for all prior to MY 1986.

From there the source type distributions from VIUS were multiplied by the Polk vehicle populations to generate the sample vehicle counts by source type, as shown schematically in Figure 6-2Figure 6-2. Expressed in equation form, the sample vehicle counts are,

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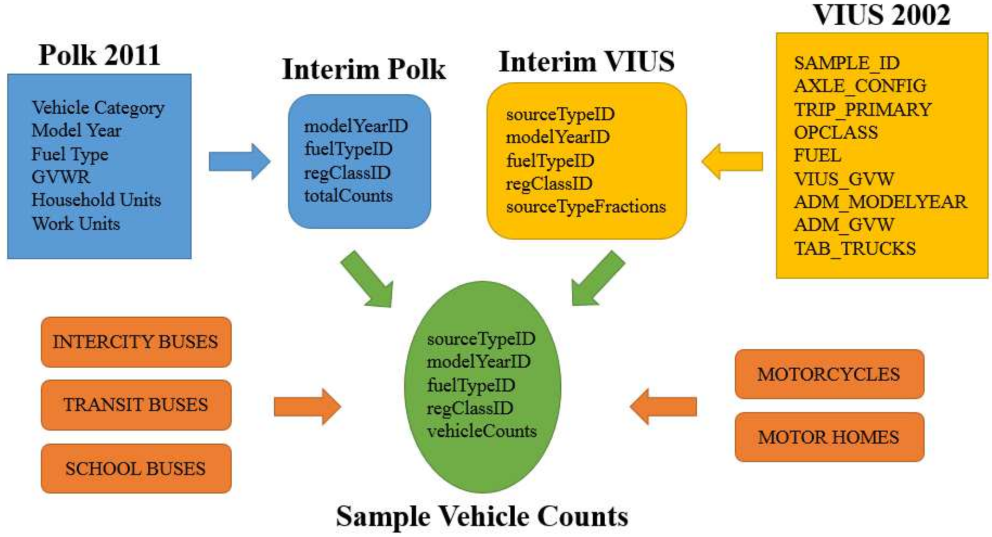
$$N(SVP)_{i,j,k,l} = P(Polk)_{i,j,k,l} \cdot f(VIUS)_{i,j,k,l}, \qquad \text{Equation 4}$$

where N is the number of vehicles used to generated the SampleVehiclePopulation table, P is the 2011 Polk vehicle populations, and f is the source type distributions from VIUS.

Figure 6-2 A schematic overview of how the 2011 Polk dataset and VIUS 2002 were joined to create EPA's sample vehicle counts for MOVES2014. Note that data on buses, motorcycles, and motor homes was pulled from other sources.

Comment [Rev46]: Move the text from the caption into the paragraph at figure citation. Create new shorter figure title.



These sample vehicle counts by source type were then utilized to calculate the SVP fractions, stmyFraction and stmyFuelEngFraction, as defined above. Due to a small sample size of vehicles 30 years old and older in both the Polk and VIUS datasets, MOVES2010b SVP fractions were used for MY 1981 and earlier, which roughly follows the same procedure outlined above but instead uses a 1999 Polk vehicle registration dataset joined with VIUS. These MOVES2010b SVP fractions for MY 1960-1981 are described in Section 18. ~~18~~ (Appendix B). MOVES2014 assumes no changes to fuel type distributions after model year 2011 except for flexible-fuel (E85-capable) vehicles, which are assumed to displace gasoline vehicles based on sales estimates as described below. MOVES2014 estimates any other population growth by source type, as described earlier in Section 5.2. ~~5.2~~ rather than growth for specific fuel types within a source type.

Comment [Rev47]: Write out

All Class 2b and 3 trucks were initially assigned to regulatory class 41 until vehicles were sorted into source types. Once the sample vehicle counts were available by source type, any light-duty trucks (sourceTypeID 31 or 32) in the original LHD regulatory class less than 14,000 lbs (regClassID 41) were reclassified in the new LHD regulatory class less than 10,000 lbs (regClassID 40), whereas any heavy-duty vehicles (sourceTypeID 41 and above) remained in regClassID 41. Similarly, any single unit trucks (sourceTypeID 52 and 53) in the LDT regulatory class (regClassID 30) were reclassified in regClassID 41 as heavy-duty vehicles. We also moved any regClassID 42 vehicles in combination truck source types to regClassID 46 because tractor-trailers must be either Class 7 or 8 trucks. This ensures a clean break between light- and heavy-duty emission results and that the emission calculations use the appropriate fixedMassFactor when calculating vehicle-specific power (VSP) for light-duty vehicles and scaled tractive power (STP) for heavy-duty vehicles.

As noted above, the initial sample vehicle counts dataset did not contain motorcycles, buses, or motor homes, so information on these source types was appended. Motor homes~~—~~, even though they are considered single unit vocational vehicles~~—~~, cannot be identified in VIUS. In the subsections below, we have provided more detailed descriptions by source type.

Comment [Rev48]: This is the problem identified earlier associated with sing fixed assignments inside MOVES. The user cannot control these allocations later in the process. See the discussion in Liu, et al., 2015.

Comment [Rev49]: Vague

6.2.2.1. Motorcycles

The representation of motorcycles in the SampleVehiclePopulation table is straightforward. All motorcycles fall into the motorcycle regulatory class (regClassID 10) and must be fueled by gasoline. We acknowledge that some alternative fuel motorcycles have been prototyped and may even be in small production, but they account for a negligible fraction of total US motorcycle sales and cannot be modeled in MOVES2014.

6.2.2.2. Passenger Cars

Any passenger car is considered to be in the light-duty vehicle regulatory class (regClassID 20). Cars were included in the Polk dataset purchased in 2012, and EPA's subsequent sample vehicle counts dataset, which provided the split between gasoline and diesel cars in the SampleVehiclePopulation table. Flexible fuel (E85-capable) cars were also included in the SVP fuel type distributions but added after the sample vehicle counts analysis. We assume that a flexible fuel vehicle would directly displace its gasoline counterpart. For model years 2011 and earlier, we used manufacturer reported sales to EPA ~~in order~~ to ~~calculate~~ estimate the fraction of sales of flexible fuel cars among sales of all gasoline and flexible fuel cars and added those penetrations as the fraction of E85 (fuelTypeID 5) vehicles and deducted them from the gasoline cars in the Polk dataset.

Comment [Rev50]: Either write them all out or use the acronym every time. The user has to pause each time they encounter this.

Similarly, for model years 2012 and later, we used Annual Energy Outlook (AEO) car sales projections from AEO2014's table labeled "Light-Duty Vehicle Sales by Technology Type" to derive flexible fuel vehicle penetrations and applied them to the Sample Vehicle Population, exclusively for regulatory class 20.[30] All other alternative fueled cars were determined to have insignificant market shares now and into the future.

While MOVES can model electric vehicles (fuelTypeID 9), the current market share of electric cars is sufficiently small that we have set the default electric car population to zero. Users can model an electric vehicle population by using the AVFT tool to redistribute market share. Electric vehicles do not have any tailpipe emissions, but MOVES2014 has electric vehicle rates for energy consumption, brakewear, and tirewear (electric vehicle brake and tirewear emission rates are copied from gasoline vehicles). Please consult the MOVES2014 documentation on greenhouse gases[31] and brake and tirewear[32], respectively, for more information on the development of the energy and emission rates themselves.

6.2.2.3. Light-Duty Trucks

~~Since~~ Because passenger and light commercial trucks are defined as light-duty vehicles, they are constrained to regulatory class 30 and 40. Within the sample vehicle counts, GVWR Class 1 and

2a trucks were classified as regulatory class 30 and Class 2b trucks with two axles and four tires were classified as regulatory class 40. Both light-duty truck source types are divided between gasoline and diesel using the underlying splits in the sample vehicle counts data. Passenger trucks and light commercial trucks have similar but distinct distributions. Similar to cars, a penetration of flexible fuel (E-85-capable) light-duty trucks was calculated using EPA certification sales for historic years (MY 2011 and earlier) and AEO light truck projections for future years (MY 2012 and later) from AEO2014's Table 64. The flexible fuel vehicle penetration was applied to regClassID 30 for both E-85 (fuelTypeID 5) passenger and light commercial trucks and then deducted from their gasoline counterparts in the same regulatory class.

6.2.2.4. Buses

In line with the US Energy Information Administration (EIA) assumptions, all intercity buses in MOVES are powered by diesel fuel.[33] The following non-school bus regulatory class distribution for intercity buses was applied to all model years based on 2011 FHWA data, as shown in Table 6-6~~Table 6-5~~.[34]

Table 6-6 Regulatory class fractions of school and non-school buses using 2011 FHWA data

Vehicle Type	MOVES regClassID				
	41	42	46	47	Total
Non-School Buses	0.1856	0.0200	0.1214	0.6730	1
School Buses	0.0106	0.0070	0.9371	0.0453	1

The National Transit Database (NTD) Revenue Vehicle Inventory (Form 408) closely tracks the number of motor buses ~~(MB)~~ by fuel type each year and those statistics are used to develop the MOVES fuel type distributions for transit buses. The mapping from the NTD fuel types to MOVES fuel types is summarized in Table 6-7~~Table 6-6~~.

Table 6-7 Mapping National Transit Database Fuel Types to MOVES Fuel Types

NTD code	NTD description	fuelTypeID	MOVES Fuel Description
BD	Bio-diesel	2	diesel
BF	Bunker fuel	N/A	
CN	Compressed natural gas	3	CNG
DF	Diesel fuel	2	diesel
DU	Dual fuel	2	diesel
EB	Electric battery	N/A	
EP	Electric propulsion	N/A	
ET	Ethanol	N/A	
GA	Gasoline	1	gasoline
GR	Grain additive	N/A	
HD	Hybrid diesel	2	diesel
HG	Hybrid gasoline	1	gasoline
KE	Kerosene	N/A	
LN	Liquefied natural gas	3	CNG
LP	Liquefied petroleum gas	N/A	
MT	Methanol	N/A	
OR	Other	N/A	

While some other MOVES fuel types are included in the NTD, the transit bus fuel type distributions were allocated between diesel, CNG, and gasoline only. Together, these three fuel types account for more than 99 percent of all transit buses in 2011, so no other alternative fuels are ~~allowed~~ employed within the transit bus source type due to negligible market shares.

Biodiesel does not appear in the SampleVehiclePopulation table—in MOVES it is considered a fuel subtype rather than a fuel type—so biodiesel buses were added to the diesel buses from the NTD. Liquefied natural gas (LNG) comprises less than ten percent of all natural gas transit buses and only about 1.5 percent of the whole transit bus fleet in 2011. Without any readily available emission rate data on LNG buses, ~~we grouped~~ all LNG ~~natural gas fueled~~ transit buses were grouped ~~together~~with CNG transit buses, ~~. This means we effectively model LNG buses~~ as if they were powered by CNG. Due to limited data, ~~we assume that~~ gasoline is assumed to have ~~has~~ a one-percent market share prior to model year 2000 and ~~that~~ diesel has a 99 percent market share prior to MY 1990. All other market shares of transit bus fuel types are derived using the NTD, as shown in Table 6-8~~Table 6-7~~. MOVES modelers can adjust these distributions between the fuel types using the AVFT tool.

Table 6-8 Fuel type market shares by model year for transit buses in MOVES2014

Model Year	MOVES Fuel Type		
	Gasoline	Diesel	CNG
1982-1989	1.00%	99.00%	0.00%
1990	1.00%	98.30%	0.70%
1991	1.00%	97.20%	1.80%
1992	1.00%	94.40%	4.60%
1993	1.00%	91.40%	7.60%
1994	1.00%	90.50%	8.50%
1995	1.00%	83.70%	15.30%
1996	1.00%	89.20%	9.80%
1997	1.00%	81.60%	17.40%
1998	1.00%	84.10%	14.90%
1999	1.00%	87.70%	11.30%
2000	0.85%	91.57%	7.58%
2001	0.88%	90.51%	8.60%
2002	0.91%	89.09%	10.00%
2003	0.94%	88.06%	10.99%
2004	0.89%	86.85%	12.27%
2005	1.05%	85.61%	13.34%
2006	1.18%	84.73%	14.09%
2007	1.29%	83.99%	14.72%
2008	1.61%	82.91%	15.49%
2009	1.89%	82.55%	15.56%
2010	2.14%	81.96%	15.90%
2011+	2.46%	81.75%	15.79%

Urban transit buses are regulated separately from other heavy-duty vehicles, under 40 CFR 86.091-2.[35] For this reason, CNG and diesel transit buses are each categorized in regulatory class 48. Lacking better data for gasoline transit buses, ~~we used~~ a single regulatory class distribution is derived from a study of diesel and CNG transit buses, highlighted in the MOVES2014 HD Emissions Rates Report[4], ~~for gasoline transit buses~~ as shown in Table 6-9~~Table 6-8~~ below.

Table 6-9 Regulatory class fractions of gasoline transit buses in MOVES2014

MOVES Source Type & Fuel Type	MOVES regClassID			
	42	46	47	Total
Gasoline Transit Buses	0.2683	0.0976	0.6341	1

The MOVES2014 school bus fuel type distribution is based on MOBILE6 estimates, originally calculated from 1996 and 1997 Polk bus registration data, for model years 1982-1996 are summarized in Table 6-10~~Table 6-9~~. The Union of Concerned Scientists estimates that roughly one percent of school buses run on non-diesel fuels, so we have assumed that one percent of school buses are gasoline fueled in MY 1997 and later.[36] The school bus regulatory class distribution was also derived from the 2011 FHWA data in Table 6-6Table 6-5.

Table 6-10 Fuel type market shares by model year for school buses in MOVES2014

Model Year	MOVES Fuel Type	
	Gasoline	Diesel
1982	67.40%	32.60%
1983	67.62%	32.38%
1984	61.55%	38.45%
1985	48.45%	51.55%
1986	32.67%	67.33%
1987	26.55%	73.45%
1988	24.98%	75.02%
1989	22.90%	77.10%
1990	12.40%	87.60%
1991	8.95%	91.05%
1992	1.00%	99.00%
1993	12.05%	87.95%
1994	14.75%	85.25%
1995	11.43%	88.57%
1996	4.15%	95.85%
1997+	1.00%	99.00%

6.2.2.5. Single Unit Trucks

The fuel type and regulatory class distributions for the single unit trucks are calculated directly from the EPA's sample vehicle counts datasets, except motor homes. The single unit source types are split between gasoline and diesel only. Single unit vehicle are distributed among the heavy-duty regulatory classes (regClassIDs 41, 42, 46, and 47) based on the underlying sample vehicle data. Motor home was not included as a VIUS body type response, so their fuel type and regulatory class distributions have been were developed through supplementary data sources. The fuel type distribution for motor homes is unchanged from MOVES2010b, originally based on interpolating information from the Recreation Vehicle Industry Association (RVIA) on fuel type market shares.[37]

Comment [Rev51]: This contrasts with the statement in Section 21.6. Can't tell how the split was made.

Table 6-11 Fuel type market shares for motor homes in MOVES2014

Model Year	Percent ~~of~~ Diesel	Percent ~~of~~ Gasoline
1982-1993	15%	85%
1994	18%	82%
1995	21%	79%
1996	23%	77%
1997	26%	74%
1998	29%	71%
1999	32%	68%
2000	34%	66%
2001	37%	63%
2002	40%	60%
2003	41%	59%
2004	43%	57%
2005	44%	56%
2006	46%	54%
2007	47%	53%
2008	49%	51%
2009	50%	50%
2010+	50%	50%

The motor home regulatory class distribution, shown below in Table 6-12~~Table 6-11~~, is used across all model years based on the same 2011 FHWA dataset referenced above for school and non-school buses.

Table 6-12 Regulatory class fractions of motor homes using 2011 FHWA data

MOVES Source Type	MOVES regClassID				
	41	42	46	47	Total
Motor Homes	0.2697	0.3940	0.2976	0.0387	1

6.2.2.6. Combination Trucks

Combination trucks consist mostly of Class 8 trucks in the MOVES HHD regulatory class (regClassID 47) but also contain some Class 7 trucks in the MHD regulatory class (regClassID 46), predominantly in short-haul. Similarly, almost all combination trucks are diesel fueled. MOVES does not model gasoline long-haul combination trucks. Even for the short-haul source type, gasoline combination trucks are being phased out rapidly. After model year 2005, MOVES2014 assumes no gasoline combination trucks sales. These fuel type and regulatory class trends come out of the sample vehicle counts dataset. There has been growing interest in natural gas for freight transportation but currently this remains largely in the planning stages. There has not been sufficient testing of these trucks to develop MOVES emission rates. ~~We will consider adding n~~Natural gas combination trucks will likely be added to MOVES as they become more prevalent and their emissions are more thoroughly tested.

7. Vehicle Characteristics that Vary by Age

Age is an important factor in calculating vehicle emission inventories, identifying high emitters, and characterizing travel behavior. MOVES employs a number of different age dependent factors, including deterioration of engine and emission after-treatment technology due to tampering and malmaintenance, vehicle scrappage and fleet turnover, and mileage accumulation over the lifetime of the vehicle. Deterioration effects are detailed in the MOVES2014 reports on the development of light-duty and heavy-duty emission rates.[3,4] In this section, there is discussion of vehicle age distributions, survival rates, and relative mileage accumulation rates by source type.

7.1. Age Distributions

A vehicle's age is simply the difference between its model year and the calendar year of analysis. Age distributions in MOVES vary by source type and range from zero to 30+ years (~~, so that~~ all vehicles 30 years and older are modeled ~~together~~as a single group). As such, an age distribution is comprised of 31 fractions, where each fraction represents the number of vehicles present at a certain age divided by the vehicle population for all ages, as summarized later in this section in Equation 9. ~~Since~~ Because sales and scrappage rates are not constant, varying wih economic conditions over time, these distributions vary by calendar year. The age distribution for each source type is stored in the SourceTypeAgeDistribution table, and fractions from each source type's age distribution sum to one across a calendar year. MOVES default age distributions were compiled from a variety of data sources, which are discussed below. Age distributions for the 2011 base year are summarized in Table 7-1; all other years are available in the MOVES2014 default database SourceTypeAgeDistribution table.

7.1.1. Age Distributions from Registration Data

Ideally, ~~all~~ historic age distributions ~~could~~ would be derived from registration data sources for each MOVES analysis year ~~available in MOVES~~. However, acquiring such data ~~is~~ was prohibitively costly~~, so~~ . So, MOVES2014 ~~only~~ contains registration-based age distributions for only two analysis years: 1990 and 2011. The following sections detail how these data were analyzed and used in MOVES2014.

7.1.1.1. 1990 Age Distributions

MOVES2014 age distributions for calendar year 1990 ~~have~~ were not ~~been~~ updated since the last model release. Please refer to Section 19. ~~19~~ (Appendix C) for more information on the 1990 distributions.

7.1.1.2. 2011 Age Distributions

The 2011 age distributions for cars and trucks were derived from the ~~sample vehicle counts~~ Polk dataset, as discussed earlier in Section 6.2.2. This sample vehicle data includes eight of the thirteen source types: passenger cars (21), passenger trucks (31), light commercial trucks (32), refuse trucks (51), short-haul single unit trucks (52), long-haul single unit trucks (53), short-haul combination trucks (61), and long-haul combination trucks (62). We were able to develop zero to 30+ year age distributions in 2011 for the eight source types mentioned.

For the source types that were not included in the sample vehicle data—, specifically motorcycles, motor homes, and buses—,we calculated the 2011 age distributions were created using by running MOVES2010b, updated with with the latest sales data available for these source types. That is, MOVES2010b was run used with 1999 populations, sales, and scrappage forecasts to project future populations by model year, which we then used to compute age distributions. This approach kept the MOVES2010b base populations and scrappage rates but substituted in MY 1999-2011 sales. We pulled sales for motorcycles (11) from the Motorcycle Industry Council's *Statistical Annual* report[24], transit buses (42) from internal EPA estimates based on manufacturer reporting, and school buses (43) from the *School Bus Fleet Fact Book*[18]. Since 2011 age distributions were calculated independently, intercity bus (41) and motor home (54) sales data were based on slightly different assumptions. Both of these source types used an average of Ward's Class 3-8 truck sales in Oak Ridge's *Transportation Energy Data Book*[22], transformed into MOVES source types using the allocation of sample vehicle counts described in Section 6. 6. For more information on these data sources, revisit Section 3. 3.

Table 7-1Table 7-1 shows the fraction of vehicles by age (0-30+ years) and source type for calendar year 2011. These 2011 age distributions became the basis for all the forecast age distributions in Section 7.1.2.2. 7.1.2.2 and all backcast age distributions in Section 7.1.2.3.

Comment [Rev52]: You can get to the same result without running MOVES to generate the distributions, instead using the internal default distributions. Running the model to generate an input for a model update will sound like an issue o reviewers.

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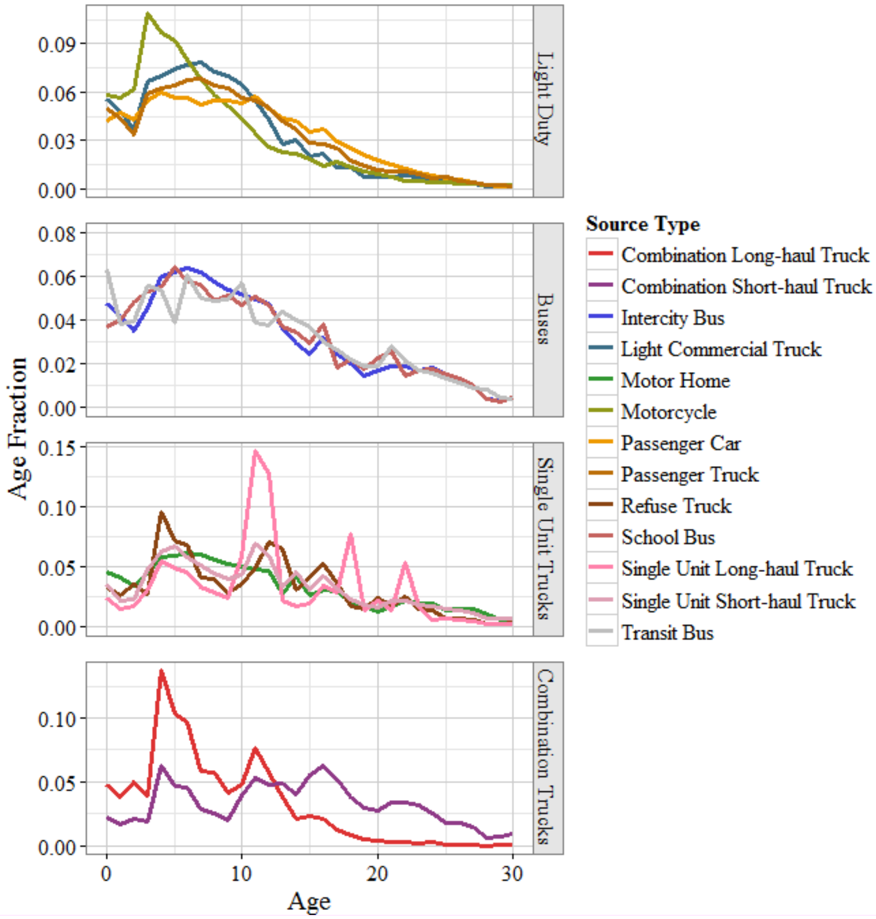
Figure 7-1 2011 Age Distributions for MOVES Source Types



Comment [Rev53]: Is there an explanation for the single unit long haul truck distribution (pink)?

Table 7-1 2011 Age Fractions for MOVES Source Types

Age	11	21	31	32	41	42	43	51	52	53	54	61	62
0	0.0585	0.042	0.0496	0.0557	0.0477	0.0628	0.0368	0.0334	0.035	0.0237	0.046	0.0219	0.0478
1	0.0565	0.0472	0.044	0.0482	0.0421	0.0385	0.0403	0.0265	0.0216	0.015	0.0406	0.0164	0.0378
2	0.0614	0.043	0.0335	0.0372	0.0353	0.0393	0.048	0.0351	0.0231	0.0176	0.034	0.0213	0.0501
3	0.1088	0.0545	0.0587	0.0668	0.0458	0.0555	0.0529	0.0273	0.0479	0.031	0.0442	0.0192	0.0392
4	0.0968	0.0597	0.0626	0.0703	0.0601	0.0539	0.0548	0.0956	0.0629	0.0544	0.0579	0.0629	0.1371
5	0.0917	0.0562	0.0644	0.0743	0.0617	0.0389	0.0644	0.0718	0.0666	0.0486	0.0594	0.0468	0.1028
6	0.0803	0.0562	0.0677	0.077	0.0638	0.0607	0.0574	0.0677	0.0577	0.045	0.0615	0.0455	0.0971
7	0.0682	0.0526	0.0686	0.0781	0.062	0.0498	0.0565	0.0407	0.0506	0.0333	0.0597	0.0288	0.0584
8	0.0583	0.0551	0.0638	0.0724	0.0574	0.0488	0.0487	0.04	0.0438	0.0284	0.0553	0.0256	0.057
9	0.0514	0.055	0.0624	0.0702	0.0538	0.0495	0.0511	0.029	0.0393	0.0238	0.0518	0.0199	0.0415
10	0.0436	0.0534	0.0562	0.0647	0.0517	0.057	0.0467	0.0357	0.0427	0.059	0.0498	0.0391	0.0482
11	0.0348	0.0575	0.0545	0.055	0.0492	0.0385	0.0508	0.0488	0.0697	0.1457	0.0474	0.0535	0.0766
12	0.0263	0.05	0.0504	0.0433	0.0478	0.0374	0.047	0.0702	0.0591	0.1267	0.0461	0.0482	0.0572
13	0.0224	0.0441	0.0424	0.0273	0.0362	0.0439	0.0371	0.0645	0.0334	0.0213	0.0271	0.049	0.0381
14	0.0215	0.042	0.0372	0.0305	0.0295	0.0401	0.0345	0.0312	0.0459	0.0175	0.0417	0.0398	0.0215
15	0.0188	0.0354	0.0284	0.0203	0.0244	0.0369	0.0298	0.0406	0.0308	0.0198	0.0258	0.0556	0.0234
16	0.0142	0.0367	0.0274	0.0219	0.0317	0.0303	0.038	0.0521	0.0423	0.0338	0.0305	0.0628	0.0209
17	0.0163	0.029	0.025	0.0137	0.0244	0.0264	0.0184	0.0367	0.0323	0.0279	0.0291	0.0524	0.0127
18	0.0133	0.0249	0.0175	0.0136	0.0201	0.0219	0.0219	0.0167	0.0225	0.0777	0.02	0.038	0.0086
19	0.0111	0.0209	0.0142	0.0073	0.0148	0.019	0.0177	0.0149	0.0179	0.0137	0.0175	0.0292	0.0052
20	0.0088	0.0178	0.012	0.007	0.0168	0.0192	0.0226	0.0233	0.0162	0.0213	0.013	0.0272	0.004
21	0.0071	0.015	0.0106	0.0075	0.0188	0.0281	0.0255	0.0166	0.022	0.0132	0.0171	0.0337	0.0031
22	0.0053	0.0124	0.0108	0.008	0.0187	0.0214	0.0145	0.0256	0.0211	0.0535	0.0221	0.0343	0.0031
23	0.0045	0.0097	0.0092	0.0073	0.0174	0.0168	0.0173	0.0147	0.0188	0.017	0.0196	0.0317	0.0019
24	0.0044	0.008	0.007	0.0057	0.018	0.0156	0.0175	0.0132	0.0171	0.0061	0.0191	0.025	0.0032
25	0.0037	0.0065	0.0071	0.0053	0.0151	0.0131	0.0153	0.0068	0.0154	0.0064	0.0141	0.0174	0.0009
26	0.0031	0.0053	0.0049	0.0037	0.0132	0.0113	0.0131	0.0068	0.0132	0.0055	0.015	0.0177	0.0009
27	0.0028	0.0042	0.004	0.0031	0.0104	0.0088	0.0101	0.0056	0.0113	0.0048	0.0152	0.0145	0.0007
28	0.002	0.0025	0.0024	0.0019	0.0041	0.0083	0.0037	0.0025	0.0067	0.0028	0.0098	0.0062	0.0003
29	0.0016	0.0017	0.0019	0.0015	0.0035	0.0045	0.0027	0.0029	0.0067	0.0028	0.0057	0.0073	0.0004
30+	0.0025	0.0016	0.0016	0.0012	0.0047	0.0039	0.0047	0.0035	0.0066	0.0027	0.0039	0.0089	0.0004

7.1.2. Forecasting and Backcasting Age Distributions

~~Since~~ Because purchasing registration data for all historic years ~~is~~ was prohibitively costly ~~and impossible for future years~~, an algorithm was developed to forecast and backcast age distributions from the 2011 age distribution described above for all other calendar years in the model. In prior versions of MOVES, these age distributions were calculated during the model run, using sales estimates and assuming a constant survival rate. In MOVES2014, age distributions for national level runs were pre-calculated using updated sales estimates and assuming a dynamic survival rate. However, while sales data for historic years are well known and projections for future years are common in economic modeling, historic and projected vehicle survival are not ~~well studied~~. For MOVES2014, a generic survival rate was scaled up or down for each calendar year based on our assumptions of sales and changes in total populations. The following three sections detail the derivation of the generic survival rate and the algorithms used to forecast and backcast age distributions using an adjusted survival rate in each year.

Comment [Rev54]: There is quite a bit of literature on retirement

Comment [Rev55]: This is a fairly weak justification.... If a method is applied later, stipulate the method and basis here.

7.1.2.1. Generic Survival Rates

The survival rate describes the fraction of vehicles of a given source type and age that remain on the road from one year to the next. Although this rate changes from year to year, in part as a function of vehicle purchases and availability of vehicles on the secondary market, a single generic rate was calculated from available data. While the use of this generic rate is described in the next couple of sections, its derivation is specified here.

Survival rates for motorcycles were calculated based on a smoothed curve of retail sales and 2008 national registration data as described in a study conducted for the EPA.[38] Survival rates for passenger cars, passenger trucks and light commercial trucks came from NHTSA's survivability Table 3 and Table 4.[39] These survival rates are based on a detailed analysis of Polk vehicle registration data from 1977 to 2002. We modified these rates to consistent with the MOVES format using the following guidelines:

- NHTSA rates for light trucks were used for both the MOVES passenger truck and light commercial truck source types.
- MOVES calculates emissions for vehicles up to age 30 (with all older vehicles lumped into the age 30 category), but NHSTA car survival rates were available only to age 25. Therefore, we extrapolated car rates to age 30 using the estimated survival rate equation in Section 3.1 of the NHTSA report. When converted to MOVES format, this caused a striking discontinuity at age 26 which we removed by interpolating between ages 25 and 27.
- According to the NHTSA methodology, NHTSA age 1 corresponds to MOVES ageID 2, so the survival fractions were shifted accordingly.
- Because MOVES requires survival rates for ageIDs < 2, these values were linearly interpolated with the assumption that the survival rate prior to ageID 0 is 1. Effectively, this results in a near constant survival rate until ageID 3 for light-duty vehicles and until ageID 4 for heavy-duty vehicles.
- NHTSA defines survival rate as the ratio of the number of vehicles remaining in the fleet at a given year as compared to a base year. However, MOVES defines the survival rate as

Comment [Rev56]: As noted below, a reader needs to see plots over time here to assess impact of assumptions. This can be done by overlaying future fleets by calendar year. The 30+ group should be growing slightly, or remaining stable, rather than shrinking over time, as folks hold onto vehicles longer. These are 1985 and older vehicles today. Vehicles in today's fleet are more durable. Need to reassure users that the failure rate assumption is reasonable with an independent confirmation.

the ratio of vehicles remaining from one year to the next, so we transformed the NHTSA rates accordingly.

Because MOVES ageID 30 is intended to represent all vehicles 30 years old and greater, this age category can grow quite large as our age distribution algorithm eventually transfers all vehicles to this age group. To assure that the population of very old vehicles does not grow excessively, the generic survival rate for ageID 30 was set to 0.3. The actual survival rate of these age 30+ vehicles is unknown.

Comment [Rev57]: See note below. Need to demonstrate that the rate is not so high as to distort future fleets in the other direction as well.

Quantitatively, the following piecewise formulas were used to derive the MOVES survival rates. In them, s_a represents the MOVES survival rate at age a, and σ_a represents the NHTSA survival rate at age a. When this generic survival rate is discussed below, the shorthand notation $\overrightarrow{S_0}$ will represent a one-dimensional array of s_a values at each permissible age a as described below.

Age 0: $$s_0 = 1 - \frac{1-\sigma_2}{3}$$ Equation 5

Age 1: $$s_1 = 1 - \frac{2(1-\sigma_2)}{3}$$ Equation 6

Age 2-29: $$s_a = s_{2\ldots 29} = \frac{\sigma_{a-1}}{\sigma_{a-2}}$$ Equation 7

Age 30: $$s_{30} = 0.3$$ Equation 8

With limited data available on heavy-duty vehicle scrappage, survivability for all other source types came from the *Transportation Energy Data Book*. We used the heavy-duty vehicle survival rates for model year 1980 (TEDB32, Table 3.14). The 1990 model year rates were not used because they were significantly higher than rates for the other model years in the analysis (i.e. 45 percent survival rate for 30 year-old trucks), and seemed unrealistically high. While limited data exists to confirm this judgment, a snapshot of 5-year survival rates can be derived from VIUS 1992 and 1997 results for comparison. According to VIUS, the average survival rate for model years 1988-1991 between the 1992 and 1997 surveys was 88 percent. The comparable survival rate for 1990 model year heavy-duty vehicles from TEDB was 96 percent, while the rate for 1980 model year trucks was 91 percent. This comparison lends credence to the decision that the 1980 model year survival rates are more in line with available data. TEDB does not have separate survival rates for medium-duty vehicles, so ~~it was necessary to apply~~ the heavy-duty rates were applied uniformly across the bus, single unit truck, and combination truck categories. The TEDB survival rates were transformed into MOVES format in the same way as the NHTSA rates, including setting age 30+ survival rates to 0.3 for all source types.

Comment [Rev58]: Need to be careful here. Differential retirements in model year groups could represent technology durability/ acceptability issues. Need to double-check prior to discounting sources. Caveat whole paragraph by reassuring the audience that you did the best you could and that users can specify their own future fleets and ignore the retirement rates.

The resulting survival rates are listed in the default database's SourceTypeAge table. Please note that since MOVES2014 does not calculate age distributions during a run, these values are not actively used by MOVES. However, they were used in the development of the national age distributions stored in the SourceTypeAgeDistribution table, and remain in the default database for reference.

Table 7-2 Survival Rate by Age and HPMS Class

Age	Motorcycles	Light-Duty Vehicles		Buses	Single Unit Trucks	Combination Trucks
		Passenger Cars	Passenger Trucks Light Comm. Trucks			
0	1.000	0.997	0.991	1.000	1.000	1.000
1	0.979	0.997	0.991	1.000	1.000	1.000
2	0.940	0.997	0.991	1.000	1.000	1.000
3	0.940	0.993	0.986	1.000	1.000	1.000
4	0.940	0.990	0.981	0.990	0.990	0.990
5	0.940	0.986	0.976	0.980	0.980	0.980
6	0.940	0.981	0.970	0.980	0.980	0.980
7	0.940	0.976	0.964	0.970	0.970	0.970
8	0.940	0.971	0.958	0.970	0.970	0.970
9	0.940	0.965	0.952	0.970	0.970	0.970
10	0.940	0.959	0.946	0.960	0.960	0.960
11	0.940	0.953	0.940	0.960	0.960	0.960
12	0.940	0.912	0.935	0.950	0.950	0.950
13	0.940	0.854	0.929	0.950	0.950	0.950
14	0.940	0.832	0.913	0.950	0.950	0.950
15	0.940	0.813	0.908	0.940	0.940	0.940
16	0.940	0.799	0.903	0.940	0.940	0.940
17	0.940	0.787	0.898	0.930	0.930	0.930
18	0.940	0.779	0.894	0.930	0.930	0.930
19	0.940	0.772	0.891	0.920	0.920	0.920
20	0.940	0.767	0.888	0.920	0.920	0.920
21	0.940	0.763	0.885	0.920	0.920	0.920
22	0.940	0.760	0.883	0.910	0.910	0.910
23	0.940	0.757	0.880	0.910	0.910	0.910
24	0.940	0.757	0.879	0.910	0.910	0.910
25	0.940	0.754	0.877	0.900	0.900	0.900
26	0.940	0.754	0.875	0.900	0.900	0.900
27	0.940	0.567	0.875	0.900	0.900	0.900
28	0.940	0.752	0.873	0.890	0.890	0.890
29	0.940	0.752	0.872	0.890	0.890	0.890
30	0.300	0.300	0.300	0.300	0.300	0.300

Comment [Rev59]: This is a potential concern. The depletion rate of the 30+ category is much faster than the entering fleet from year 29. Over a relatively short period of time, the 30+ category would disappear. A plot of MY distributions should be prepared and presented over time ti make sure this is not an issue.

7.1.2.2. 2012-2050 Age Distributions

The 2012-2050 age distributions were derived from the 2011 age distribution described above using population, survival, and sales projections. Age distributions are ~~easily~~ calculated from population counts, if the populations are known by age:

$$f_{a,y} = \frac{p_a}{P_y} \qquad \text{Equation 9}$$

Here, $f_{a,y}$ is the age fraction to be calculated, p_a is the population of vehicles at age a, and P_y is the total population in calendar year y. In this section, arrow notation will be used if the operations are to be performed at the individual age level. For example, $\overrightarrow{f_y}$ would be used to represent all age fractions in calendar year y. Another example is $\overrightarrow{P_y}$; it represents an array of p_a values at each permissible age in calendar year y. In contrast, P_y represents the total population in year y.

Intuitively, projecting an age distribution forward one year involves removing the vehicles scrapped in the base year and adding the new vehicles sold in the next year, as shown in Equation 10:

$$\overrightarrow{P_{y+1}} = \overrightarrow{P_y} - \overrightarrow{R_y} + \overrightarrow{N_{y+1}} \qquad \text{Equation 10}$$

where $\overrightarrow{P_{y+1}}$ is the population (known at each age) of the next year, $\overrightarrow{P_y}$ is the population in the base year, $\overrightarrow{R_y}$ is the population of vehicles removed in the in the base year, and $\overrightarrow{N_{y+1}}$ is new vehicles sold in the next year. Please note that the final term only includes new vehicles at age 0; if the equation is evaluated for any $a > 0$, the sales term is zero. Equation 10~~Equation 10~~ can be used algorithmically to forecast a known population distribution as follows:

1. Starting with the base population distribution ($\overrightarrow{P_y}$), remove the number of vehicles that did not survive ($\overrightarrow{R_y}$) at each age level.
2. Increase the population age index by one (for example, 3 year old vehicles are reclassified as 4 year old vehicles).
3. Add new vehicle sales ($\overrightarrow{N_{y+1}}$) as the age 0 cohort.
4. Combine the new age 30 and 31 vehicles into a single age 30 group.
5. This results in the next year population distribution ($\overrightarrow{P_{y+1}}$). If this algorithm is to be repeated, $\overrightarrow{P_{y+1}}$ becomes $\overrightarrow{P_y}$ for the next iteration.

Unfortunately, as described in the section above, the only survival information we have is a single snapshot. Because vehicle populations and new sales change differentially (for example, the historic populations shown in Section 5.1. ~~5.1~~ level off during the recent recession; at the same time, sales of most vehicle types plummeted), it is important to adjust the survival curve in response to changes in population and sales. We did so by defining a scalar adjustment factor k_y that can be algebraically calculated from population and sales estimates. Its use in determining the population of vehicles removed and its relationship to the generic survival rate $\overrightarrow{S_0}$ is given by Equation 11~~Equation 11~~. Note that the open circle operator ($\circ$) represents entrywise product; that is, each element in an array is multiplied by the corresponding element in the other one, and it results in an array with the same number of elements.

$$\overrightarrow{R_y} = k_y \cdot \left(1 - \overrightarrow{S_0}\right) \circ \overrightarrow{P_y} \qquad \text{Equation 11}$$

Substituting Equation 11~~Equation 11~~ into Equation 10~~Equation 10~~ yields:

$$\overrightarrow{P_{y+1}} = \overrightarrow{P_y} - k_y \cdot (1 - \overrightarrow{S_0}) \circ \overrightarrow{P_y} + \overrightarrow{N_{y+1}} \qquad \text{Equation 12}$$

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Comment [Rev60]: Showing a survival curve is a good idea. Survival curves can be developed separately for various technology groups if desired.

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Comment [Rev61]: I suggest moving all of the text from this point down to the end of the section into an Appendix. It is not needed here and adds to reader confusion for something that is rarely needed by a user. The bottom line is that you have made adjustments to the rates to try to help the predictions match the data without adjusting rate parameters. You can say that here and refer the user to an appendix.

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Since both the value of the scalar adjustment factor and the actual distribution of the next year's population are unknown, Equation 12Equation 12 can't be used yet. However, by using an estimate of next year's total population, it can be transformed into:

$$P_{y+1} = P_y - k_y \sum_a \left(\left(1-\overrightarrow{S_0}\right)\circ \overrightarrow{P_y}\right) + N_{y+1} \qquad \text{Equation 13}$$

This was algebraically solved for k_y and evaluated for each HPMS category[e] using the following information:

- Total populations P_y and P_{y+1} by HPMS category. For analysis year 2011, this information is described source type in Section 5.1. 5.1 and simply needs to be summed by HPMS category for use here. For years 2012+, this information is described in Section 5.2.
- Survival $\overrightarrow{S_0}$ by HPMS category, which is described in Section 7.1.2.1.
- Population distribution $\overrightarrow{P_y}$ by HPMS category. For analysis year 2011, this information came from combining the total populations described in Section 5.1. 5.1 with the age distributions described in Section 7.1.1.2. 7.1.1.2 and summing by HPMS category. For years 2012+, this comes from $\overrightarrow{P_{y+1}}$ of the previous year.
- New vehicle sales N_{y+1} by HPMS category, which are derived from AEO2014. The projection of sales was calculated as a percentage of the total population using the vehicle category mapping discussed in Section 4.2. 4.2; this is converted to the number of new vehicles by multiplying by the HPMS category population.

After determining k_y by HPMS category, Equation 12Equation 12 was used with the following information to compute the next year's population and then age distribution by source type:

- Population distribution $\overrightarrow{P_y}$ by source type. For analysis year 2011, this information came from combining the total populations described in Section 5.1. 5.1 with the age distributions described in Section 7.1.1.2. For years 2012+, this comes from $\overrightarrow{P_{y+1}}$ of the previous year.
- The scalar adjustment factor k_y and generic survival rate $\overrightarrow{S_0}$ applied by source type using the HPMS to source type mapping described by Table 2-1Table 2-1. Please note that limits were placed on the $k_y(1-\overrightarrow{S_0})$ term of Equation 12Equation 12: the value of this term for each age was restricted to being between 0 and 1.

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[e] Because vehicle survival rates use the categories of motorcycles, passenger cars, light-duty trucks, buses, single unit trucks, and combination trucks, these were the categories used for determining the scalar adjustment factor. Since these are essentially the HPMS categories used by MOVES with the additional subcategories of passenger car and light-duty trucks, the term "HPMS category" is used here for simplicity.

- New vehicle sales $\overrightarrow{N_{y+1}}$, determined as a percentage of the total population in AEO2014 as discussed above; this is converted to the number of new vehicles by multiplying by the total source type population.

With all of this information, the population distributions were algorithmically determined for years 2012-2050. The resulting total source type populations (P_y) are stored in the SourceTypeYear table of the default database. The resulting age distributions are stored in the SourceTypeAgeDistribution table.

[Text below was inserted EPA from July document update]

In addition to producing the 2012-2050 default age distributions, a version of this algorithm was implemented in the Age Distribution Projection Tool for MOVES2014.41 This tool can be used to project future local age distributions from user-supplied baseline distributions, provided that the baseline year is 2011 or later. This requirement ensures that the 2008-2009 recession is fully visible in the baseline. The differences between the default algorithm described above and the algorithm used in the tool are as follows:

- In the tool, the generic survival rate for all vehicle types at age 30 is set to one (1.0).
- Step 4 was modified so that in the tool, the new age 30 fraction is set equal to the new age 31 fraction. The new age 31 fraction is then discarded.
- In the tool, the age distribution for ages 1-29 is then normalized such that the full distribution (ages 0-30) sums to one (1.0).

Comment [Rev62]: Based on this text, it looks like the 0.3 value has been discarded, which is probably a good thing. This needs to be clarified and applicable text in this section corrected as needed.

The first two bullets were implemented to retain the fraction of 30+ year old vehicles in the user-inputted baseline distribution. This was done because local data frequently indicates a sizeable fraction in this age bin. Since the default scrappage curve was designed to prevent this bin from growing too large, the default algorithm would reduce this fraction in most cases. Therefore, the age 30+ fraction is not modified and the resulting age distribution in each iteration of the algorithm is normalized in the final step so that the full distribution sums to one. The sales rates and scrappage assumptions are the same in the tool as they are in the national case. In general, projections made with the tool tend to converge with the national age distributions the farther out the projection year becomes. This is because local projections of sales and scrappage are generally unavailable, and the national trends are the best available data.

7.1.2.3. 1999-2010 Age Distributions

The method used to backcast the 1999-2010 age distributions from the 2011 distribution is very similar to the forecasting method described above. For backcasting an age distribution one year, Equation 10 of the previous section can be rewritten as:

Comment [Rev63]: It is not clear why 1999-2010 this needs to be modeled with a survivor model at all, rather than simply interpolated between your 1990 and 2011 data sets, using sales figures for control given that there are no better data in between). Given that survival rates are so different across the country (e.g. New England vs. Arizona), and by technology as it entered the fleet, I'm not convinced that the detailed approach is warranted.

$$\overrightarrow{P_{y-1}} = \overrightarrow{P_y} - \overrightarrow{N_y} + \overrightarrow{R_{y-1}} \qquad \text{Equation 14}$$

Essentially, this can be thought of as taking the base year's population distribution, removing the vehicles sold (or added to the population) in that year, and then adding the vehicles that were removed in the year before. This can be represented algorithmically as follows:

1. Starting with the base population distribution ($\overrightarrow{P_y}$), remove the age 0 vehicles ($\overrightarrow{N_y}$).
2. Decrease the population age index by one (for example, 3 year old vehicles are reclassified as 2 year old vehicles).
3. Add the vehicles that were removed in the previous year ($\overrightarrow{R_{y-1}}$).
4. This results in the previous year population distribution ($\overrightarrow{P_{y-1}}$). If this algorithm is to be repeated, $\overrightarrow{P_{y-1}}$ becomes $\overrightarrow{P_y}$ for the next iteration.

The equation governing vehicle removal discussed the previous section is also applicable here. Taking careful note of the subscripts, Equation 11 and Equation 14 can be combined:

$$\overrightarrow{P_{y-1}} = \overrightarrow{P_y} - \overrightarrow{N_y} + k_{y-1} \cdot \left(1 - \overrightarrow{S_0}\right) \circ \overrightarrow{P_{y-1}} \qquad \text{Equation 15}$$

As in the forecasting situation, the value of the scalar adjustment factor and the actual distribution of the previous year's population are unknown. With a similar strategy of using the previous year's known total population, Equation 15~~Equation 15~~ can be transformed into:

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$$P_{y-1} = P_y - N_y + k_{y-1} \sum_a \left(\left(1 - \overrightarrow{S_0}\right) \circ \overrightarrow{P_{y-1}}\right) \qquad \text{Equation 16}$$

However, this still leaves a $\overrightarrow{P_{y-1}}$ term, which is unavoidable because the total number of vehicles removed is dependent on the age distribution of those vehicles. To properly solve Equation 16 for k_{y-1} and $\overrightarrow{P_{y-1}}$, a numerical method of approximation could be employed. However, due to lack of resources, $\overrightarrow{P_y}$ was used as a simple approximation of $\overrightarrow{P_{y-1}}$ on the left hand side of Equation 16. The following sources were used to determine k_{y-1} by HPMS category:

- Total populations P_y and P_{y-1} by HPMS category. For all historic analysis years, this information is described source type in Section 5.1. ~~5.1~~ and simply needs to be summed by HPMS category across all ages for use here.
- Survival $\overrightarrow{S_0}$ by HPMS category, which is described in Section 7.1.2.1.
- Population distribution $\overrightarrow{P_y}$ by HPMS category. For analysis year 2011, this information came from combining the total populations described in Section 5.1. ~~5.1~~ with the age distributions described in Section 7.1.1.2. ~~7.1.1.2~~ and summing by HPMS category. For other years, this comes from $\overrightarrow{P_{y-1}}$ of the previous iteration.
- New vehicle sales N_{y+1} data, which was collected by source type from a variety of sources. Each of these was summed by HPMS category. Motorcycles sales comes from the Motorcycle Industry Council; sales data for passenger cars, passenger trucks, light commercial trucks, refuse trucks, short-haul and long-haul single unit trucks, and short-haul and long-haul combination trucks comes from TEDB and VIUS; transit buses production estimates are based on EPA certification data; and school bus sales came from the *School Bus Fleet Fact Book*. No sales data were available for intercity buses, so the other bus categories were used as a surrogate. That is, the total transit bus production and school bus sales as a percentage of the transit and school bus populations in each year were applied to the intercity bus populations to estimate their sales. Similarly, no sales

data were available for motor homes, so a sales fraction was estimated by averaging the sales of refuse, short-haul, and long-haul single unit trucks as a fraction of their total population.

After determining k_{y-1} by HPMS category, Equation 15~~Equation 15~~ was used with the following information to compute the previous year's age distribution by source type:

- Population distribution $\overrightarrow{P_y}$ by source type. For analysis year 2011, this information came from combining the total populations described in Section 5.1. ~~5.1~~ with the age distributions described in Section 7.1.1.2. For other years, this comes from $\overrightarrow{P_{y-1}}$ of the previous iteration.
- The scalar adjustment factor k_{y-1} and generic survival rate $\overrightarrow{S_0}$ applied by source type using the HPMS to source type mapping described by Table 2-1~~Table 2-1~~. As with before, limits were placed on the $k_y(1-\overrightarrow{S_0})$ term, such that the value of this term for each age was restricted to being between 0 and 1. Also, the $\overrightarrow{P_{y-1}}$ term used when calculating the number of vehicles removed was approximated by $\overrightarrow{P_y}$.
- New vehicle sales $\overrightarrow{N_{y+1}}$, from the sources listed above and applied by source type.

With all of this information, the population distributions were algorithmically determined for years 1999-2010. The resulting age distributions are stored in the SourceTypeAgeDistribution table.

7.2. Relative Mileage Accumulation Rate

MOVES uses a relative mileage accumulation rate (RMAR) in combination with source type populations (see Section 5.1. ~~5.1~~) and age distributions described earlier in this section to distribute the total annual miles driven by each HPMS vehicle type (see Section 4. ~~4~~) to each source type and age group. Using this approach, the vehicle population and the total annual vehicle miles traveled (VMT) can vary from calendar year to calendar year, but the proportional travel by an individual vehicle of each age will not vary.

VMT is provided, either by default values or by user input, by the five Highway Performance Monitoring System (HPMS) vehicle classifications. These classifications are further broken down into the groupings of the MOVES source use types, as described in Section 2.1.

The RMAR is determined within each HPMS vehicle classification such that the annual mileage accumulation for a single vehicle of each age of a source type is relative to the mileage accumulation of all of the source types and ages within the HPMS vehicle classification. For

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Comment [Rev64]: Given the 140 pages to review, there is not enough time to perform a full technical analysis of Section 7.1. I would suggest that the equations be sent out for a separate and focused peer review.

Given the snapshot of data that are available for the development of the algorithms, my initial reaction is that too much time and effort has been spent generating equations and corrections that have limited basis in theory or the underlying data. There are lots of alternative approaches that could be taken for survival modeling. Separate models could be developed by technology group, and alternative functional forms could be explored.

You have lost your reader in this section. I would suggest that the entire detailed portion of this section after Equation 10 be moved to the appendix and a generic discussion be created to follow that equation. The discussion could talk about the general approach. Then, to support the explanation, a series of model year distribution or retirement charts can be shown to the user to provide some comfort that the future national fleet looks reasonable. Finally, the users need to be reassured that they can specify the composition of the future fleet off model using their own sales and survival functions.

Comment [Rev65]: This is important and should be highlighted a bit more.

example, passenger cars, passenger trucks and light commercial trucks are all within the same HPMS vehicle classification. By definition, new (age 0) passenger trucks and light commercial trucks have a RMAR of one (1.0).[f] Based on the data, new passenger cars have a RMAR of 0.885. This means that when the VMT assigned to the HPMS vehicle classification (25) is allocated to passenger cars, passenger trucks and light commercial trucks, a passenger car of age 0 will be assigned only 88.5% of the VMT assigned to a passenger truck or light commercial truck of age 0.

The RMAR values for MOVES2014 for the source types 11 (motorcycles), 41 (intercity buses), 42 (transit buses), 43 (school buses) and 54 (motor homes) were not changed from the values used in MOVES2010b. Passenger car and light-duty truck RMAR values were recalculated to reflect the change in the HPMS vehicle classifications used for VMT input and the remaining heavy-duty vehicle classifications were updated with data from the 2002 Vehicle Inventory and Use Survey (VIUS) and recalculated.

7.2.1. Motorcycles

The RMAR values for motorcycles in MOVES2014 were not changed from MOVES2010b estimates. The MOVES2010b RMAR values were calculated from MARs for motorcycles (category 11) based on the model years and odometer readings listed in motorcycle advertisements. A stratified sample of about 1,500 ads were examined. A modified Weibull curve was fit to the data to develop the relative mileage accumulation rates used in MOVES.[38]

Comment [Rev66]: I would not expect an upswing in the curve for the out-years, I guess I need to look at the functional form. The modified Weibull is most likely a different distribution.

7.2.2. Passenger Cars, Passenger Trucks and Light Commercial Trucks

In MOVES2010b, passenger cars were not included in the same HPMS vehicle classification as for passenger trucks and light commercial trucks. For MOVES2014, the MOVES2010b passenger car RMAR values were adjusted to reflect the relative difference in annual mile accumulation between passenger cars and the light trucks. Analysis of the data ~~determined~~ indicated that new passenger cars (age 0) accumulate only 88.5% of the annual miles accumulated by new light trucks. All of the RMAR values for passenger cars were adjusted to be 88.5% of their previous values.

The MOVES2010b RMAR values for passenger cars, passenger trucks and light commercial trucks (categories 21, 31 & 32) were taken from the NHTSA report on survivability and mileage schedules.[39] In the NHTSA analysis, annual mileage by age was determined for cars and for trucks using data from the 2001 National Household Travel Survey. In this NHTSA analysis, vehicles that were less than one year old at the time of the survey were classified as "age 1", etc. NHTSA used cubic regression to smooth the VMT by age estimates.

Comment [Rev67]: Terminology is unclear here. Was this a cubic spline fit, or a third order polynomial regression? A spline fit should be used.

[f] Within each HPMS vehicle class, an RMAR value of one is assigned to the source type and age with the highest annual VMT accumulation. Because we use the same mileage accumulation data for passenger trucks and light commercial trucks, they both have a value of one.

We used NHTSA's regression coefficients to extrapolate mileage to ages 26 through 30 not covered by the report. Since passenger trucks had the highest MAR in what was then the Light-Duty Truck HPMS category, each source type's mileage by age was divided by passenger truck mileage at "age 1" to determine a relative MAR. For consistency with MOVES age categories, ~~we then shifted~~ the relative MARs were shifted such that the NHTSA "age 1" ratio was used for MOVES age 0, etc. We used NHTSA's light truck VMT to ~~determine~~ develop ~~relative~~ MARs for both passenger trucks and light commercial trucks.

Comment [Rev68]: Passive voice is generally preferred to the use of the first person voice. There are too many to correct them. A search and replace is needed.

Comment [Rev69]: I would suggest a full-document search and replace for the word determine. Nothing that we do in emissions modeling can be described as "determining." We estimate, develop, test, assess, etc. We don't determine anything with such implied certainty..

Since a newer version of the National Household Travel Survey was available, we conducted a preliminary analysis of the impact of updating the MARs based on the 2009 National Household Travel Survey. This resulted in changes in MOVES' allocation of VMT by one percent or less for each of the vehicle categories covered by the survey. As such, we feel that the MARs developed from the 2001 survey are still reasonable for use in MOVES2014.

Comment [Rev70]: You have confounding effects from the recession here. The traffic volumes on freeways declined significantly during that period, but have been on the rise. MARs warrant a double check with post-2009 data. Given the vehicle purchase delays, the accumulation rates will likely vary even more by model year cluster. I don't have a better answer, but I question the stability assumption.

7.2.3. Buses

The RMAR values for all bus categories in MOVES2014 were not changed from MOVES2010b estimates. The Intercity Bus (category 41) annual mileage accumulation rate is taken from Motorcoach Census 2000.[40] The data did not distinguish vehicle age, so the same MAR (59,873 miles per year) was used for each age. The School Bus (category 43) annual mileage accumulation rate (9,939 miles per year) is taken from the 1997 School Bus Fleet Fact Book. The MOVES model assumes the same annual mileage accumulation rate for each age. The Transit Bus (category 42) annual mileage accumulation rate are taken from the MOBILE6 values for diesel transit buses (HDDBT). This mileage data was obtained from the 1994 Federal Transportation Administration survey of transit agencies.[41] The MOBILE6 equation was extended to calculate values for ages 26 through 30.

7.2.4. Other Heavy-Duty Vehicles

The RMAR values for source types 51 (refuse trucks), 52 (short haul single unit trucks), 53 (long haul single unit trucks), 61 (short haul combination trucks) and 62 (long haul combination trucks) were updated using the data from the 2002 Vehicle Inventory and Use Survey (VIUS). The total reported annual miles traveled by trucks in each source type was divided by the vehicle population to determine the average annual miles traveled per truck by source type.

Table 7-3 2002 VIUS Annual Mileage Accumulation Rates

Age	Model Year	Single Unit Trucks			Combination Trucks	
		Refuse (51)	Short-haul (52)	Long-haul (53)	Short-haul (61)	Long-haul (62)
0	2002	26,703	21,926	40,538	119,867	109,418
1	2001	32,391	22,755	28,168	114,983	128,287
2	2000	31,210	24,446	30,139	110,099	117,945
3	1999	31,444	23,874	49,428	105,215	110,713
4	1998	31,815	21,074	33,266	100,331	99,925
5	1997	28,450	21,444	23,784	95,447	94,326
6	1996	25,462	16,901	21,238	90,563	85,225
7	1995	30,182	15,453	27,562	85,679	85,406
8	1994	20,722	13,930	21,052	80,795	71,834
9	1993	25,199	13,303	11,273	75,911	71,160
10	1992	23,366	11,749	18,599	71,026	67,760
11	1991	18,818	13,675	15,140	66,142	80,207
12	1990	12,533	11,332	13,311	61,258	48,562
13	1989	15,891	9,795	9,796	56,374	64,473
14	1988	19,618	9,309	12,067	51,490	48,242
15	1987	12,480	9,379	16,606	46,606	58,951
16	1986	12,577	4,830	8,941	41,722	35,897
0-3	**1999-2002 Average**	**30,437**	**23,250**	**37,069**	**61,240**	**116,591**

For each source type, in the first few years, the data showed only small differences in the annual miles per vehicle and no trend. After that, the average annual miles per vehicle declined in a fairly linear manner, at least until the vehicles are at age 16 (the limit of the data). MOVES, however, requires mileage accumulation rates for all ages to age 30. For MOVES2014, we assumed that the mileage accumulation rate at age 30 would be the same as used for MOVES2010b.

Mileage accumulation rates for these vehicles were determined for each age from 0 to 30 using the following method:

1) Ages 0 through 3 use the same average annual mileage accumulation rate for age 0-3 vehicles of that source type.
2) Ages 4 through 16 use mileage accumulation rates calculated using a linear regression of the VIUS data for ages three through 16,
3) Ages 17 through 29 use values from interpolation between the values in age 16 and age 30.
4) Age 30 uses the MOVES2010b mileage accumulation rate for age 30. These rates were allocated to MOVES source types from MOBILE6 mileage accumulation rates, which were derived from the 1992 TIUS as documented in the Arcadis report.[42]

Comment [Rev71]: Similar tables should be presented for all vehicle classes above.

Comment [Rev72]: These are fairly significant assumptions that cannot be verified from the information provided. Older vehicles are relegated to different service activities, so these are important assumptions to verify, especially given the age of the 1992 TIUS data.

Table 7-4 Regression Statistics for Heavy-Duty Truck Annual Mileage Accumulation Rates Ages 4-16

Measurement	Refuse Truck (51)	Single Unit Short-haul (52)	Single Unit Long-haul (53)	Combination Short-haul (61)	Combination Long-haul (62)
Average*	30,437	23,250	37,069	61,240	116,591
Intercept	36,315	25,442	36,305	65,773	119,867
Slope	-1,510	-1,209	-1,794	-3,447	-4,884
Age 30	0.0320	0.0518	0.1025	0.0320	0.0571
* Average sample annual miles traveled for ages 0 through 3.					

Comment [Rev73]: I generated a quick spreadsheet to try to verify the use of the regression terms for refuse trucks, assuming intercept mileage for years 0-3, using regression parameters for years 4-16, and using a straight line decrease from year 16 to year 30 mileage (36315*0.0320), but I do not get the exact same values in table 7-5 when I create the ratios (they were close). This section needs to be re-drafted (reworded for method clarity) so that an external reviewer can easily confirm the approach. Try creating a spreadsheet to recreate Table 7-5 using this table information see where the language may need to be clarified.

Comment [Rev74]: It was unclear at first what this row meant and how it was used. The reader has to get to Table 7-5 to see that this is not a regression parameter, but an assumption that 30-year old vehicles accrue 3.2% percent of the mileage of a new vehicle. This should be removed from the table and changed to a text discussion.

The resulting relative mileage accumulation rates are shown in Table 7-5 below. Note that the first four values are identical and then decline linearly to age 16 and then linearly to age 30 with a different slope.

7.2.5. Motor Homes

Motor home relative mileage accumulation rates for MOVES2014 are unchanged from MOVES2010b. For motor homes (sourceTypeID 54), the initial MARs were taken from an independent research study[43] conducted in October 2000 among members of the Good Sam Club. The members are active recreation vehicle (RV) enthusiasts who own motor homes, trailers and trucks. The average annual mileage was estimated to be 4,566 miles. The data did not distinguish vehicle age, so the same MAR was used for each age.

Comment [Rev75]: The same approach used for motorcycles using mileage in ads might be applied here. Older motor homes do not likely accrue the same mileage rates.

Table 7-5 Relative Mileage Accumulation Rates for Heavy-Duty Trucks

ageID	Refuse (51)	Short Haul Single Unit (52)	Long Haul Single Unit (53)	Motor Home (54)	Short Haul Combination (61)	Long Haul Combination (62)
0	1.0000	0.6864	0.9729	0.0590	0.5269	1.0000
1	1.0000	0.6864	0.9729	0.0590	0.5269	1.0000
2	1.0000	0.6864	0.9729	0.0590	0.5269	1.0000
3	1.0000	0.6864	0.9729	0.0590	0.5269	1.0000
4	0.9525	0.6484	0.9165	0.0590	0.4941	0.9536
5	0.9050	0.6103	0.8601	0.0590	0.4613	0.9072
6	0.8575	0.5723	0.8036	0.0590	0.4286	0.8607
7	0.8099	0.5343	0.7472	0.0590	0.3958	0.8143
8	0.7624	0.4962	0.6908	0.0590	0.3631	0.7679
9	0.7149	0.4582	0.6343	0.0590	0.3303	0.7215
10	0.6674	0.4202	0.5779	0.0590	0.2975	0.6751
11	0.6199	0.3821	0.5215	0.0590	0.2648	0.6286
12	0.5724	0.3441	0.4650	0.0590	0.2320	0.5822
13	0.5249	0.3061	0.4086	0.0590	0.1993	0.5358
14	0.4773	0.2680	0.3522	0.0590	0.1665	0.4894
15	0.4298	0.2300	0.2957	0.0590	0.1338	0.4430
16	0.3823	0.1920	0.2393	0.0590	0.1010	0.3965
17	0.3573	0.1808	0.2293	0.0590	0.0950	0.3723
18	0.3323	0.1696	0.2194	0.0590	0.0890	0.3481
19	0.3073	0.1585	0.2094	0.0590	0.0830	0.3238
20	0.2822	0.1473	0.1994	0.0590	0.0770	0.2996
21	0.2572	0.1361	0.1894	0.0590	0.0710	0.2753
22	0.2322	0.1249	0.1795	0.0590	0.0649	0.2511
23	0.2072	0.1138	0.1695	0.0590	0.0589	0.2268
24	0.1821	0.1026	0.1595	0.0590	0.0529	0.2026
25	0.1571	0.0914	0.1496	0.0590	0.0469	0.1783
26	0.1321	0.0802	0.1396	0.0590	0.0409	0.1541
27	0.1071	0.0691	0.1296	0.0590	0.0349	0.1298
28	0.0820	0.0579	0.1197	0.0590	0.0289	0.1056
29	0.0570	0.0467	0.1097	0.0590	0.0229	0.0814
30	0.0320	0.0355	0.0997	0.0590	0.0169	0.0571

Comment [Rev76]: Insert a row above this, or use notations, to indicate what vehicle is the control for each column, i.e. highest accumulation value to which the RAR is applied. Refuse is its own, but combination is relative to long haul combination. Motor home is relative to... (don't remember offhand, so it would be good to add this feature).

8. VMT Distribution of Source Type by Road Type

For each source type, the RoadTypeVMTFraction field in the RoadTypeDistribution table stores the fraction of total VMT for each vehicle class that is traveled on each of the five roadway types. Users may supply the distribution VMT to vehicle classes for each road type for individual counties when using County Scale, however, for National Scale, the default distribution is applied to all locations.

The national default distribution of VMT to vehicle classes for each road type in MOVES2014 were derived to reflect the VMT data included in the 2011 National Emission Inventory (NEI) Version 1[44] (July 31, 2013). ~~This~~ These data ~~is~~ are provided by states every three years as part of the NEI project and is supplemented by EPA estimates, based on Federal Highway Administration (FHWA) reports[45], when state supplied estimates are not available.

The 2011 NEI v1 data[46] ~~is~~ were grouped by the Source Classification Code (SCC) used at that time, but ~~and~~ these older classifications do not map cleanly ~~map~~ to the source types used by MOVES. The VMT data were ~~was~~ mapped to ~~the~~ MOVES source types ~~used by MOVES~~ by calculating the fraction VMT for each source type found in each SCC classification result ~~in~~ for a national MOVES2010b run for calendar year 2011. The factors calculated from the MOVES201b run are shown in Section 20. ~~20~~ (Appendix D: SCC Mappings~~Appendix D~~). The first seven digits of the 10 digit SCC (SCC7) indicate the vehicle classification.

The SCC road types map cleanly to the MOVES road types. The eighth and ninth digits of the 10-digit SCC (SCC89) indicate the road type, as shown below in Table 8-1~~Table 8-1~~.

Table 8-1 Mapping of SCC Road Types to MOVES Road Types

SCC Road Type Code (SCC89)	SCC Road Type	MOVES Road Type ID	MOVES Road Type
11	Rural Interstate	2	Rural Restricted Access
13	Rural Other Principal Arterial	3	Rural Unrestricted Access
15	Rural Minor Arterial	3	Rural Unrestricted Access
17	Rural Major Collector	3	Rural Unrestricted Access
19	Rural Minor Collector	3	Rural Unrestricted Access
21	Rural Local	3	Rural Unrestricted Access
23	Urban Interstate	4	Urban Restricted Access
25	Urban Other Freeways & Expressways	4	Urban Restricted Access
27	Urban Other Principal Arterial	5	Urban Unrestricted Access
29	Urban Minor Arterial	5	Urban Unrestricted Access
31	Urban Collector	5	Urban Unrestricted Access
33	Urban Local	5	Urban Unrestricted Access

Once the SCC VMT values have been mapped to MOVES source types and road types, the national distribution of road type VMT by source type can be calculated from the NEI VMT estimates, summarized in Table 8-2~~Table 8-2~~. The off network road type (roadTypeID 1) is not used and is allocated none of the VMT.

Table 8-2 MOVES2014 Road Type Distribution by Source Type

Source Type	Description	Road Types					
		Off Network	Rural Restricted	Rural Unrestricted	Urban Restricted	Urban Unrestricted	
		1	**2**	**3**	**4**	**5**	**All**
11	-Motorcycle	0	0.0804768	0.3019230	0.1913280	0.4262730	1.000
21	-Passenger Car	0	0.0847394	0.2344520	0.2374280	0.4433810	1.000
31	-Passenger Truck	0	0.0859437	0.2753580	0.2178360	0.4208630	1.000
32	-Light Commercial Truck	0	0.0866643	0.2755600	0.2180390	0.4197360	1.000
41	-Intercity Bus	0	0.1409270	0.2811960	0.2195920	0.3582850	1.000
42	-Transit Bus	0	0.1384440	0.2813130	0.2196020	0.3606420	1.000
43	-School Bus	0	0.1383910	0.2813150	0.2196020	0.3606920	1.000
51	-Refuse Truck	0	0.2396390	0.2717580	0.2524620	0.2361420	1.000
52	-Single Unit Short-haul Truck	0	0.1635030	0.2869150	0.2345890	0.3149930	1.000
53	-Single Unit Long-haul Truck	0	0.1638220	0.2869700	0.2346570	0.3145510	1.000
54	-Motor Home	0	0.1233290	0.2876100	0.2255300	0.3635310	1.000
61	-Combination Short-haul Truck	0	0.2366730	0.2744240	0.2516600	0.2372430	1.000
62	-Combination Long-haul Truck	0	0.2476010	0.2705480	0.2543110	0.2275400	1.000

Comment [Rev77]: The allocations to the road types are not explained. Link this to the 2011 NEI. Placing that table in the text so the allocation can be seen will help.

9. Average Speed Distributions

Average speed is used in MOVES to convert VMT inputs into the Source Hours Operating (SHO) units that MOVES uses for internal calculations. It Average speed is also used to select appropriate applicable driving cycles, which are then used to calculate estimate exhaust running operating mode distributions at the national, county (and sometimes project) level (see Chapter 10). The MOVES average speed bins are defined in Table 9-1Table 9-1.

[Move table 9-1 here]

Instead of using a single average speed to convert VMT inputs into the Source Hours Operating (SHO) units and to apply driving cycles to the vehicle activity falling into each average speed bin in these tasks, MOVES2014 uses a distribution of average speeds by within each average speed bins. The AvgSpeedDistribution table lists the default fraction of driving time for each source type, road type, day, and hour employed in each average speed bin. The fractions sum to one for each combination of source type, road type, day, and hour. The MOVES average speed bins are defined in Table 9-1. [Tell the audience what you will present in the sections that follow.]

Field Code Changed

Table 9-1 MOVES Speed Bin Categories

Bin	Average Speed (mph)	Average Speed Range (mph)
1	2.5	speed < 2.5 mph
2	5	2.5 mph <= speed < 7.5 mph
3	10	7.5 mph <= speed < 12.5 mph
4	15	12.5 mph <= speed < 17.5 mph
5	20	17.5 mph <= speed < 22.5 mph
6	25	22.5 mph <= speed < 27.5 mph
7	30	27.5 mph <= speed < 32.5 mph
8	35	32.5 mph <= speed < 37.5 mph
9	40	37.5 mph <= speed < 42.5 mph
10	45	42.5 mph <= speed < 47.5 mph
11	50	47.5 mph <= speed < 52.5 mph
12	55	52.5 mph <= speed < 57.5 mph
13	60	57.5 mph <= speed < 62.5 mph
14	65	62.5 mph <= speed < 67.5 mph
15	70	67.5 mph <= speed < 72.5 mph
16	75	72.5 mph <= speed

9.1. Light-Duty Average Speed Distributions

For MOVES2014, the light-duty average speed distributions for light-duty vehicles are based on in-vehicle global position system (GPS) data. The data was obtained through a contract with

Eastern Research Group (ERG), who subcontracted with TomTom to provide summarized vehicle GPS data.[g] TomTom makes in-vehicle GPS navigation devices as well as supports cell-phone navigation applications. ERG provided the US EPA with updated values for the AvgSpeedDistribution calculated from the TomTom delivered data based on their consumers, which "virtually all" use them in light-duty cars, trucks and vans.

Comment [Rev78]: I have some concerns regarding the data that were used in this effort. The data resolution is dependent upon the TomTom device deployed in these vehicles and the service subscription. It is possible that data bias resulted from this effort, but the bias is impossible to evaluate given the information provided.

Some of the characteristics of the TomTom GPS data to consider are as follows:

Comment [Rev79]: You have nailed most of the potential biases in the bullets below. This was enough to keep us from using these data for our research efforts. There are significant vehicle class, lane choice, operating condition, and geographic biases that likely result. Given the tremendous sensitivity of MOVES to the selected duty-cycle, I am not inclined to recommend the use of the derived average speed for hours or selection of driving cycle weightings without much more information to evaluate this effort and comparative studies with other data sources.

- Data ~~is~~ are self-selective. Data is only recorded from users of TomTom GPS units and an iPhone application. Additionally, TomTom data is only collected when the units are on. This creates bias not only for users, but also for types of driving. Anecdotally, drivers that own GPS units are less likely to use them when they drive in familiar areas in comparison with unfamiliar areas. Compared to the default VMT by road type information in MOVES, TomTom over represents behavior on rural restricted access roads, which suggests the higher usage of GPS on vacations and business trips.
- No information on vehicle type is available. TomTom suggests that "virtually all" the vehicles are light-duty cars, trucks, and vans. MOVES allows for separate average speed distributions for each source type. However, due to a lack of information on other source types, the average speed distribution derived from the TomTom light-duty GPS data is applied to all source types, although the combination long-haul trucks distribution was adjusted as described at the end of this section. Other heavy-duty source types such as single unit long-haul trucks were not adjusted. We recognize this as a shortcoming of MOVES, and look to incorporate source-type specific average speed information in the future.
- The MOVES average speed distributions are based on the average speed in each roadway segment, not second-by-second speed measurements.
- Only data that is associated with the vehicle network is included in the average speed delivery. As part of the quality control methods, TomTom excludes data that does not "snap to the roadway grid" to remove points caused by loss of satellite signal and errors while the TomTom unit is trying to acquire the satellite signal. TomTom uses data quality control techniques to minimize data arising from non-light-duty-vehicle use, such as from pedestrians, bicycles, and airplanes

Comment [Rev80]: This is even more troubling, because it indicates that the most disaggregate TomTom data were not employed.

Under direction of ERG, TomTom queried its database of historic traffic probes to produce a table of total distance and total time as a function of road type, weekday/weekend, hour of the day, and average speed bin for the calendar year 2011 for the 50 states and the District of Columbia. TomTom delivered a table identifying the total distance and total time of vehicles travelling at an average speed interval for all combinations of:

[g] Much of the following text and tables are excerpted from the ERG Work Plan (EPA-121019), submitted to US EPA on January 11, 2012.

1. Identifier for Average Speed Bin (20 levels): Average speeds were binned in 5 mph increments, starting at 2.5mph: 0-2.5mph; 2.5mph-7.5mph; 7.5mph-12.5mph; … 92.5mph-97.5mph.

2. Identifier for Month of the Year (12 levels).

3. Identifier for Day of the Week (2 levels): The period for weekday is Monday, 00:00:00 to Friday, 23:59:59, and the period for weekend is Saturday, 00:00:00 to Sunday, 23:59:59.

4. Identifier for Time of Day (24 levels): Times are binned in one hour increments, starting at midnight: 00:00:00 to 00:59:59; 01:00:00 to 01:59:59, …, 23:00:00 to 23:59:59.

5. Identifier for Road Type (4 levels): TomTom used the information in Table 9-2 to classify between the TomTom Functional Classes and the MOVES road type description. TomTom also categorized the road types as rural or urban, according to the census definitions used in MOVES[h].

Table 9-2 Correspondence between TomTom Functional Class, Census Information, and MOVES Road Types.

MOVES Road Type Description	Census Information for the TomTom Roadway Segment	TomTom Functional Road Class
Rural Restricted Access	Rural	0 and 1
Rural Unrestricted Access	Rural	2 through 7
Urban Restricted Access	Urban	0 and 1
Urban Unrestricted Access	Urban	2 through 7

TomTom first “snapped” their data points onto road segments. Off-network driving data was not obtained from the TomTom data. Much of the TomTom data that does not “snap to the roadway grid” is caused by loss of satellite signal and errors while the TomTom unit is trying to acquire the satellite signal. Therefore, a difficult analysis would be required to separate real off-network data from GPS error data, and even if the analysis could be done, the reliability of the results would probably be unknown. As such, only data that was associated with the roadway grid was used in the analysis.

Table 9-3 shows the method for using the internal TomTom data (Columns E through I) to produce the desired output, which ERG used to produce the MOVES2014 tables. The example in the table uses 16 observations that might have been recorded on two urban unrestricted roadway segments (Column E) during TomTom personal navigation device use between 14:00:00 and 14:59:59 on a weekday in April, 2011. Column F is an internal ID (1-5 occur on Segment A, and 11-21 occur on Segment B). Column G gives the length of the segment. Column H gives the time that the device spent on the segment. Column I gives the average speed of the device on the

[h] http://www.census.gov/geo/www/ua/2010urbanruralclass.html

segment. The 16 observations are sorted by the average speed bin, which is given in Column J. The total distance traveled and the total time spent in each combination of road type, month, weekday/weekend, hour of the day, and average speed bin are given in Columns K and L. TomTom provided Columns A, B, C, D, J, K, and L to ERG. The data in those columns was purchased by ERG from TomTom and is provided under license terms that permit free distribution to EPA and the public. The raw data in Columns E, F, G, H, and I were not provided to ERG and the US EPA.

Comment [Rev81]: I cannot recommend this analysis or use of the results. Another independent data source is needed to verify these results. Naturalistic driving data or ATRI data.

Table 9-3 Example of Accumulating Total Distance and Total Time for the TomTom Deliverable Table

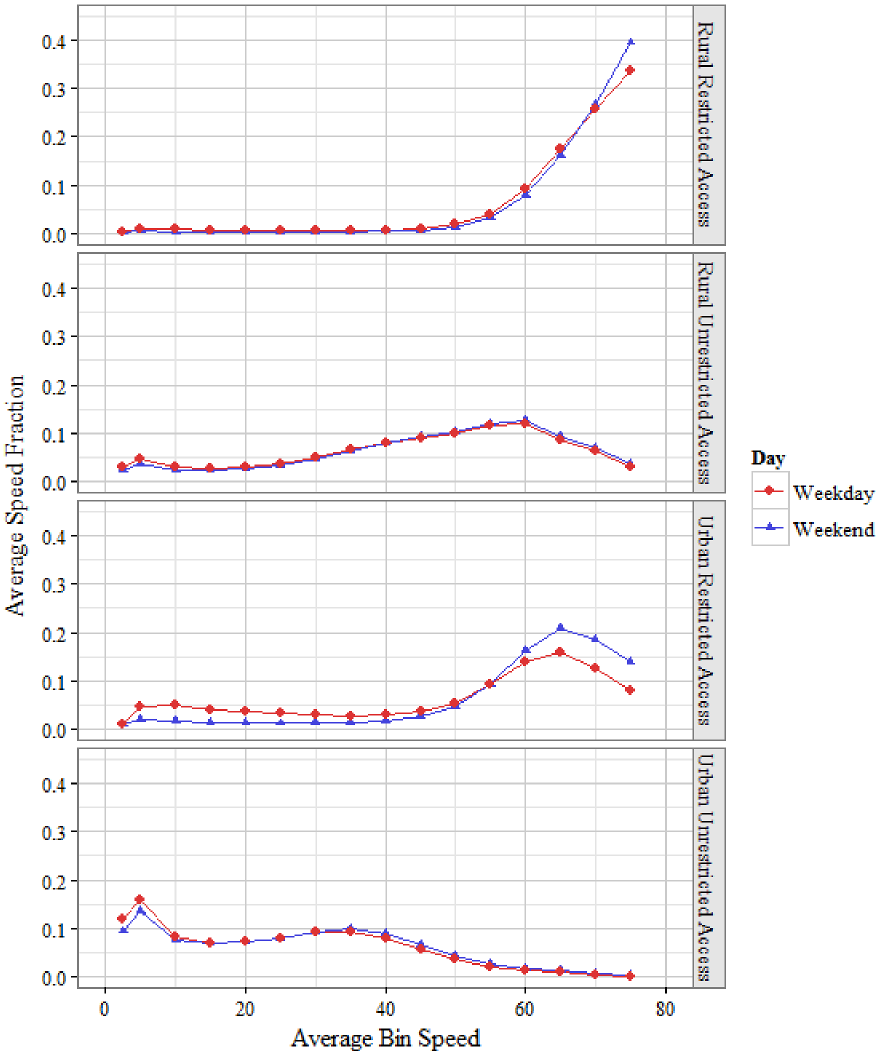
A	B	C	D	E	F	G	H	I	J	K	L
Road Type (4 levels)	Month (12 levels)	Weekday/ Weekend (2 levels)	Hour of the Day (24 levels)	Segment	Data Point	Segment Length (feet)	Time in Segment (s)	Average Speed in Segment (mph)	Average Speed Bin (mph) (20 levels)	Total of Segment Lengths for this Speed Bin (feet)	Total of Segment Times for this Speed Bin (s)
Urban Unrestricted	April	Weekday	14:00:00 to 14:59:59	A	5	300	15	13.64	15	550	27
				B	16	250	12	14.20			
				A	1	300	10	20.45	20	1800	60
				B	11	250	8	21.31			
				B	12	250	9	18.94			
				B	15	250	8	21.31			
				B	18	250	8	21.31			
				B	20	250	9	18.94			
				B	21	250	8	21.31			
				A	2	300	9	22.73	25	1650	47
				A	3	300	8	25.57			
				A	4	300	9	22.73			
				B	13	250	7	24.35			
				B	14	250	7	24.35			
				B	19	250	7	24.35			
				B	17	250	6	28.41	30	250	6

Using the table delivered by TomTom, ERG calculated the time-based average speed distribution for each road type, day, and hour of the day using the average speed bin (Column J) and the total of segment times (Column L)[i]. ERG calculated the average speed distribution according to the 16 speed bins used in MOVES. Figure 9-1 plots the average speed distribution for one hour (5 pm) stored in the averageSpeedDistribution table in MOVES, which contains average speed distributions for each hour of the day (24 hours). We are using the TomTom data to represent national default average speed distribution in MOVES.

Comment [Rev82]: A consistent method at the national level can have a significant bias and still be useful, as long as the bias is consistent over time. That is, you can look at percentage changes over time and even if the magnitude of the predicted value is consistently off by 20%, the results are useful. The problem here is that regional agencies will likely use the same distributions in county or regional EI development. I would suggest that the guidance here inform regional and project level users that they need to develop their own speed distributions.

[i] MOVES uses time-based speed because the emission rates are time-based (e.g. gram/hour).

Figure 9-1 Average speed distribution for hour = 17 (5 pm)
for source types (11 through 54) stored in the AvgSpeedDistribution table in MOVES



9.2. Heavy-Duty Average Speed Distributions

It has been shown that combination trucks travel at approximately 92% of the speed of light-duty vehicles on restricted access roads[47]. Since the TomTom data was developed from light-duty vehicles, the average speed distribution for both short-haul and long-haul combination trucks was adjusted on rural and urban restricted road types.

Comment [Rev83]: Trucks operate in the two right-hand lanes. Field studies clearly show that the speed distributions in these lanes are very different than inside lanes, and trucks speed distributions can also differ in these lanes. A more appropriate data source is the ATA data set collected from trucks. I do not recommend "adjusting" the TomTom data for use here.

You also do not need to show all of the equations below to tell the audience that you manually adjusted the values by [tell the audience in one paragraph of text]. You would be better off just showing the initial and shifted results in a comparative table. Providing all of these equations is an oversell of the quality of the data and the assumptions made. These equations can be moved to an Appendix if you decide move forward with this method.

The average speed for each roadway type, day type, and hour can be calculated by multiplying the average speed of each bin by the corresponding distribution of time as shown in Equation 29. Here, $\bar{v}$ is the average speed of the distribution, v_i is the average speed of bin i, and ρ_i is the proportion of time spent in bin i.

$$\bar{v} = \sum v_i \cdot \rho_i$$
$$= 2.5 \cdot \rho_1 + 5 \cdot \rho_2 + \cdots + 70 \cdot \rho_{15} + 75 \cdot \rho_{16}$$
Equation 17

To adjust the average speed for heavy-duty combination trucks, we redistributed the proportion of time spent in each speed bin such that its contribution to the average speed was 92% of the light-duty speed, as shown in Equation 18. This redistributed proportion of time in each speed bin is given by ρ_i'.

$$\bar{v}_{\text{combination}} = (.92)\ \bar{v}_{\text{light-duty}}$$
$$= \sum v_i \cdot \rho_i'$$
Equation 18

To perform this redistribution, we defined two new variables, α and β, where α_i is the fraction of ρ_i that is shifted down one speed bin, and β_i is the fraction of ρ_i shifted down two speed bins. The new distribution at speed bin i (given by ρ_i') starts with the original distribution (ρ_i), gains the proportions moved down from the higher speed bins ($\alpha_{i+1} \cdot \rho_{i+1}$ and $\beta_{i+2} \cdot \rho_{i+2}$), and loses the proportion that is moved to a lower speed bin ($\alpha_i \cdot \rho_i$ and $\beta_i \cdot \rho_i$). This is shown in Equation 31:

$$\rho_i' = \rho_i + (\alpha_{i+1} \cdot \rho_{i+1}) + (\beta_{i+2} \cdot \rho_{i+2}) - (\alpha_i \cdot \rho_i) - (\beta_i \cdot \rho_i)$$
Equation 19

For speed bins with an average speed of less than or equal to 60 mph, we only needed to shift distributions using a fraction of one speed bin (or 5 mph). Thus we only calculated α_i and set $\beta_i = 0$. Mathematically, reducing a bin's average speed by a certain fraction (η) can be expressed with Equation 20:

$$(1-\eta) \cdot v_i = \alpha_i \cdot (v_i - 5) + (1 - \alpha_i) \cdot v_i$$
Equation 20

Essentially, the fraction that is moved to the next slower bin (α_i) is multiplied by the slower speed (note that each of the speed bins are 5 mph apart, so this is $v_i - 5$), and the fraction that remains ($1 - \alpha_i$) is multiplied by the original speed v_i. Since the average speed of the combination trucks is 92% slower, $(1-\eta) = 92\%$ and $\eta = 0.08$.

By rearranging terms from equation 20, and solving for α_i we obtain:

$$\alpha_i = \frac{v_i \cdot \eta}{5}$$
Equation 21

However, for speed bins ≥65 mph, Equation 21 yields α_i greater than 1. Since that logically can't happen, some of the distribution needed to be moved to the second next slower speed bin to fully account for the 8% speed reduction. This is mathematically shown in Equation 22~~Equation 22~~, which is the logical extension of Equation 20:

$$(1 - \eta) \cdot v_i = \beta_i \cdot (v_i - 10) + \alpha_i \cdot (v_i - 5) + (1 - \alpha_i - \beta_i) \cdot v_i \qquad \text{Equation 22}$$

The difference between Equation 20**Error! Reference source not found.** and Equation 21 is that an additional fraction (β_i) is removed from the original speed bin and is given the speed of two speed bins slower (or 10 mph slower). With this additional factor, there is an infinite combination of solutions that could satisfy Equation 22~~Equation 22~~. We solved this problem with a linear equation solver by setting Equation 22~~Equation 22~~ to a constraint (see Equation 23~~Equation 23~~), adding the constraint that $\alpha_i + \beta_i$ are less than or equal to 1 (Equation 24), and choosing the solution that minimized β_i.

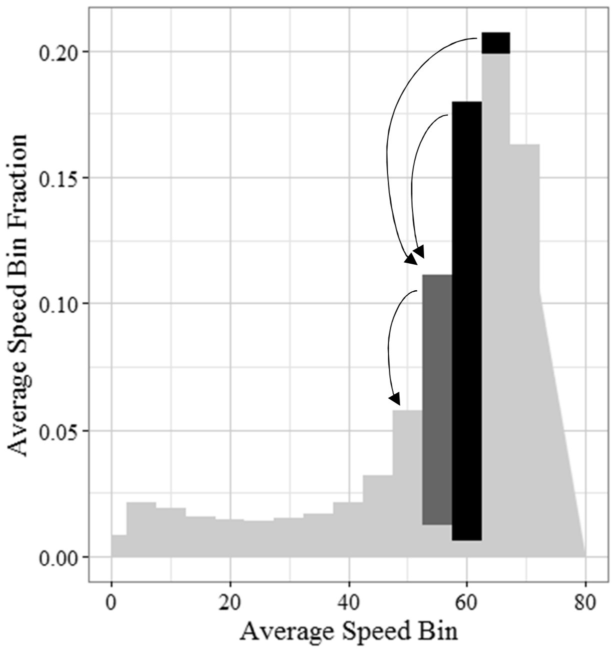
$$\alpha_i \cdot (v_i - 5) + \beta_i \cdot (v_i - 10) + v_i \cdot (\eta - \alpha_i - \beta_i) = 0 \qquad \text{Equation 23}$$

$$\alpha_i + \beta_i \leq 1 \qquad \text{Equation 24}$$

This linear program was used to solve for α_i and β_i for each speed bin between 65 and 75 mph. With α_i and β_i known for each bin, the new distributions ρ_i' were calculated.

Comment [Rev84]: As noted above, this is just not needed. The basis behind the assertions are not well founded.

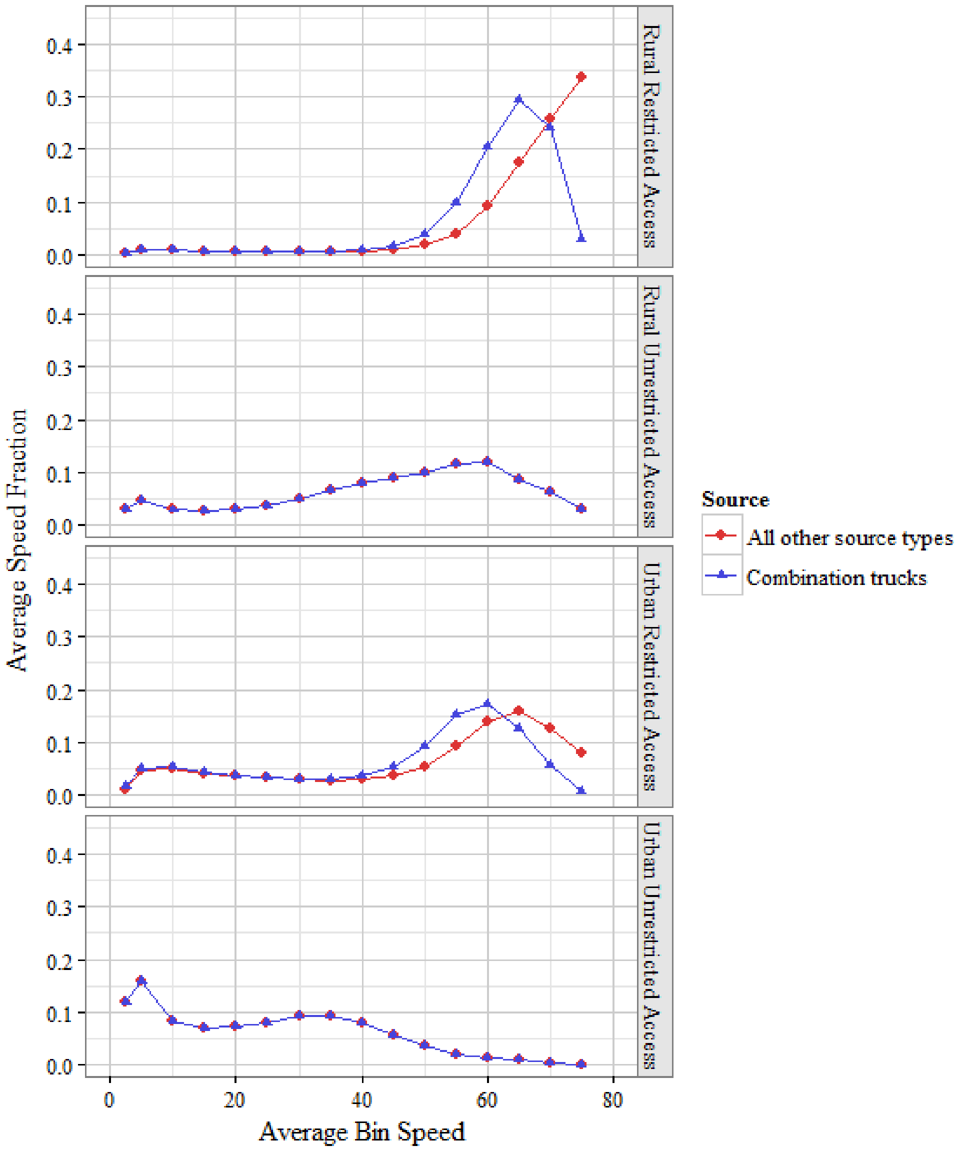
Figure 9-2 An illustration of adjustments made to the average speed bin 55 mph. Here, the original speed distribution is shown in light gray. The darker gray is the proportion of speed bin 55 that is moved out to the slower speed bin 50 mph, and the black areas are the distributions from speed bin 60 and 65 that are moved in to speed bin 55 mph.



An additional adjustment was made for the highest speed bins because we assumed that the maximum speed bin had a triangular distribution with an average speed of 75 mph (see Figure 9-2). In the new distribution, all of the maximum speed bin fraction was redistributed to the 65 and 70 mph bins. Therefore, the new maximum speed bin (70 mph) was also assumed to have a triangular distribution. Geometrically, $1/9^{th}$ of a triangular distribution averaging 70 mph is faster than 72.5 mph. Since the 75 mph speed bin is defined as any speed ≥72.5 mph, $1/9^{th}$ of the new 70 mph fraction (ρ'_{15}) was reclassified as the new fraction for the 75 mph bin.

This process was repeated for both short- and long-haul combination trucks on restricted-access road types for every hour and day type combination. See Figure 9-3 for an example illustration of the results of this analysis.

Figure 9-3 Average weekday speed distribution for hour = 17 (5 pm) by source type stored in the avgSpeedDistribution table in MOVES.



Comment [Rev85]: Jump to this point from the note above and move all calculation discussions to an Appendix. This is all you need, coupled with caveats.

[Add cautions and caveats here].

10. Driving Schedules and Ramps

Drive schedule refers to a second-by-second vehicle speed trajectory. A drive schedule typically includes all vehicle operation from the time the engine starts until the engine is keyed off, both driving (travel) and idling time. Extended idle time that occurs at specific locations (such as a school bus yard or truck stop) is generally excluded from driving schedules, but idle time at intersections is included. Drive schedules are used in MOVES to ~~determine~~ select the operating mode distribution for most MOVES running processes ~~for~~ in estimating ~~calculation of~~ emissions and energy consumption.

~~In brief, there is an emission rate (in grams per hour of vehicle operation) for each operating mode of vehicle operation.~~ Driving schedules are used to assign ~~Each~~ each second of vehicle operation ~~is assigned~~ to an operating mode bin, as a function of vehicle velocity in each second and the specific power (VSP), or scaled tractive power (STP) for heavy-duty vehicles~~, is calculated from the driving schedules~~. ~~This~~ The distinction between VSP and STP is discussed in Section 14. Proper assignment of vehicle activity to operating mode bin is important, because different emission rates (in grams per hour of vehicle operation) are associated with each operating mode bin. The average speed distribution discussed in Chapter 9 are ~~is~~ used to weight the operating mode distributions taken ~~determined~~ from driving schedules with different average speeds ~~into~~ to create a composite operating mode distribution that represents overall travel by vehicles for source type, road type, day, and hour. ~~The distribution of operating modes is used by MOVES to weight the emission rates to account for the vehicle operation.~~

Comment [Rev86]: It might be helpful to show emission rate by op mode bin here. A bar plot illustrating the three upswings from low to high across the mode bins would be useful.

Comment [Rev87]: Please confirm

Comment [Rev88]: Given the problems noted in Chapter 9 above, the weighting of average speed bins in Chapter 10 suffer from the same problems.

10.1. Driving Schedules

A key feature of MOVES is the capability to accommodate a number of drive schedules to represent driving patterns across source type, roadway type and average speed. For the national default case, MOVES2014 employs 49 different drive schedules with various average speeds, mapped to specific source types and roadway types. In the past, ~~if~~ when there was no ~~appropriate~~ applicable driving schedule to use for modeling an average speed bin, MOVES would use the ~~nearest~~ schedule with average speed. MOVES2014 now ~~requires~~ employs driving schedules that can be used as the upper bound and the lower bound for all average speed bins. New default driving schedules have been added ~~to assure~~ so that all average speed bins have ~~appropriate~~ applicable driving schedules for all ~~the~~ MOVES average speed bins. Composite operating mode distributions are now created for each source type and road type by weighting the contributions of the subset of the 49 drive schedules that apply to the selected source types, matching the assumed onroad distribution of average speeds with the average speeds of the applicable cycles.

Comment [Rev89]: I moved this up, but turned off revision marks so that the proposed edits would be retained.

MOVES stores all of the drive schedule information in four database tables. DriveSchedule provides the drive schedule name, identification number, and the average speed of the drive schedule. DriveScheduleSecond contains the second-by-second vehicle trajectories for each schedule. In some cases the vehicle trajectories are not contiguous; as detailed below, they may be formed from several unconnected microtrips that overall represent driving behavior. DriveScheduleAssoc defines the set of schedules which are available for each combination of source use type and road type. Ramps use operating mode distributions directly and do not use drive schedules to calculate operating modes. The RoadOpModeDistribution table lists operating mode distributions used for ramps for each source use type, road type and speed bin.

Tables 10-1 to 10-6The tables below list the driving schedules used in MOVES2014. Note that Ssome driving schedules are used for both restricted access (freeway) and unrestricted access (non-freeway) driving. In most cases, these represent atypical conditions, such as extreme congestion or unrealistic free flow speeds. In these conditions, we assume that the road type itself has little impact on the expected driving behavior (driving schedule). Normally, these conditions represent only a small portion of overall driving. Similarly, some driving schedules are used for multiple source types where vehicle specific information was not available. The 49 unique cycles are identified by ID and appear 78 times in these tables (34 cycles are used only once and others are used two, three, or four times).

In the past, when there was no applicable driving schedule to use for modeling an average speed bin, MOVES would use the schedule with average speed. MOVES2014 now employs driving schedules that can be used as the upper bound and the lower bound for all average speed bins. New default driving schedules have been added so that all average speed bins have applicable driving schedules for all MOVES average speed bins.

Comment [Rev90]: I moved this up to first paragraph

Table 10-1 Driving Cycles for Motorcycles, Cars, Passenger Cars and Light Commercial Trucks (11,21,31,32)

ID	Cycle Name	Average Speed	Unrestricted Access		Restricted access	
			Rural	Urban	Rural	Urban
101	LD Low Speed 1	2.5	X	X	X	X
1033	Final FC14LOSF	8.7			X	X
1043	Final FC19LOSAC	15.7			X	X
1041	Final FC17LOSD	18.6	X	X		
1021	Final FC11LOSF	20.6			X	X
1030	Final FC14LOSC	25.4	X	X		
153	LD LOS E Freeway	30.5			X	X
1029	Final FC14LOSB	31.0	X	X		
1026	Final FC12LOSE	43.3		X		
1020	Final FC11LOSE	46.1			X	X
1011	Final FC02LOSDF	49.1	X			
1025	Final FC12LOSD	52.8		X		
1019	Final FC11LOSD	58.8			X	X
1024	Final FC12LOSC	63.7	X	X		
1018	Final FC11LOSC	64.4			X	X
1017	Final FC11LOSB	66.4			X	X
1009	Final FC01LOSAF	73.8	X	X	X	X
158	LD High Speed Freeway 3	76.0	X	X	X	X

Table 10-2 Driving Cycles for Intercity Buses (41)

ID	Cycle Name	Average Speed	Unrestricted access		Restricted access	
			Rural	Urban	Rural	Urban
398	CRC E55 HHDDT Creep	1.8	X	X	X	X
404	New York City Bus	3.7	X	X		
201	MD 5mph Non-Freeway	4.6	X	X	X	X
405	WMATA Transit Bus	8.3	X	X		
202	MD 10mph Non-Freeway	10.7	X	X	X	X
203	MD 15mph Non-Freeway	15.6	X	X	X	X
204	MD 20mph Non-Freeway	20.8	X	X	X	X
205	MD 25mph Non-Freeway	24.5	X	X	X	X
206	MD 30mph Non-Freeway	31.5	X	X	X	X
251	MD 30mph Freeway	34.4	X	X	X	X
252	MD 40mph Freeway	44.5	X	X	X	X
253	MD 50mph Freeway	55.4	X	X	X	X
254	MD 60mph Freeway	60.4	X	X	X	X
255	MD High Speed Freeway	72.8	X	X	X	X
397	MD High Speed Freeway Plus 5 mph	77.8	X	X	X	X

Table 10-3 Driving Cycles for Transit and School Buses (42,43)

ID	Cycle Name	Average Speed	Unrestricted access		Restricted access	
			Rural	Urban	Rural	Urban
398	CRC E55 HHDDT Creep	1.8	X	X	X	X
201	MD 5mph Non-Freeway	4.6			X	X
404	New York City Bus	3.7	X	X		
202	MD 10mph Non-Freeway	10.7			X	X
405	WMATA Transit Bus	8.3	X	X		
401	Bus Low Speed Urban*	15	X	X		
203	MD 15mph Non-Freeway	15.6			X	X
204	MD 20mph Non-Freeway	20.8			X	X
205	MD 25mph Non-Freeway	24.5			X	X
402	Bus 30 mph Flow*	30	X	X		
206	MD 30mph Non-Freeway	31.5			X	X
251	MD 30mph Freeway	34.4			X	X
252	MD 40mph Freeway	44.5			X	X
403	Bus 45 mph Flow*	45	X	X		
253	MD 50mph Freeway	55.4	X	X	X	X
254	MD 60mph Freeway	60.4	X	X	X	X
255	MD High Speed Freeway	72.8	X	X	X	X
397	MD High Speed Freeway Plus 5 mph	77.8	X	X	X	X

* To be consistent with the speed distributions described in Section 9. 9, this speed represents the average for the traffic the bus is traveling in, not the average speed of the bus, which is lower due to stops.

Table 10-4 Driving Cycles for Refuse Trucks (51)

ID	Cycle Name	Average Speed	Unrestricted access		Restricted access	
			Rural	Urban	Rural	Urban
398	CRC E55 HHDDT Creep	1.8			X	X
501	Refuse Truck Urban	2.2	X	X		
301	HD 5mph Non-Freeway	5.8			X	X
302	HD 10mph Non-Freeway	11.2	X	X	X	X
303	HD 15mph Non-Freeway	15.6	X	X	X	X
304	HD 20mph Non-Freeway	19.4	X	X	X	X
305	HD 25mph Non-Freeway	25.6	X	X	X	X
306	HD 30mph Non-Freeway	32.5	X	X	X	X
351	HD 30mph Freeway	34.3	X	X	X	X
352	HD 40mph Freeway	47.1	X	X	X	X
353	HD 50mph Freeway	54.2	X	X	X	X
354	HD 60mph Freeway	59.4	X	X	X	X
355	HD High Speed Freeway	71.7	X	X	X	X
396	HD High Speed Freeway Plus 5 mph	77.8	X	X	X	X

Table 10-5 Driving Cycles for Single Unit Trucks and Motor Homes (52,53,54)

ID	Cycle Name	Average Speed	Unrestricted access		Restricted access	
			Rural	Urban	Rural	Urban
398	CRC E55 HHDDT Creep	1.8	X	X	X	X
201	MD 5mph Non-Freeway	4.6	X	X	X	X
202	MD 10mph Non-Freeway	10.7	X	X	X	X
203	MD 15mph Non-Freeway	15.6	X	X	X	X
204	MD 20mph Non-Freeway	20.8	X	X	X	X
205	MD 25mph Non-Freeway	24.5	X	X	X	X
206	MD 30mph Non-Freeway	31.5	X	X	X	X
251	MD 30mph Freeway	34.4	X	X	X	X
252	MD 40mph Freeway	44.5	X	X	X	X
253	MD 50mph Freeway	55.4	X	X	X	X
254	MD 60mph Freeway	60.4	X	X	X	X
255	MD High Speed Freeway	72.8	X	X	X	X
397	MD High Speed Freeway Plus 5 mph	77.8	X	X	X	X

Table 10-6 Driving Cycles for Combination Trucks (61,62)

ID	Cycle Name	Average Speed	Unrestricted access		Restricted access	
			Rural	Urban	Rural	Urban
398	CRC E55 HHDDT Creep	1.8	X	X	X	X
301	HD 5mph Non-Freeway	5.8	X	X	X	X
302	HD 10mph Non-Freeway	11.2	X	X	X	X
303	HD 15mph Non-Freeway	15.6	X	X	X	X
304	HD 20mph Non-Freeway	19.4	X	X	X	X
305	HD 25mph Non-Freeway	25.6	X	X	X	X
306	HD 30mph Non-Freeway	32.5	X	X	X	X
351	HD 30mph Freeway	34.3	X	X	X	X
352	HD 40mph Freeway	47.1	X	X	X	X
353	HD 50mph Freeway	54.2	X	X	X	X
354	HD 60mph Freeway	59.4	X	X	X	X
355	HD High Speed Freeway	71.7	X	X	X	X
396	HD High Speed Freeway Plus 5 mph	77.8	X	X	X	X

The default drive schedules for light-duty vehicles listed in the tables above were developed from several sources. "LD LOS E Freeway (ID 153)" and "HD High Speed Freeway" were retained from MOBILE6 and are documented in report M6.SPD.001.[48] "LD Low Speed 1" is a historic cycle used in the development of speed corrections for MOBILE5 and is meant to represent extreme stop-and-go "creep" driving. "LD High Speed Freeway 3" was developed for MOVES to represent very high speed restricted access driving. It is a 580-second segment of restricted access driving from an in-use vehicle instrumented as part of EPA's On-Board Emission Measurement "Shootout" program,[49] with an average speed of 76 mph and a maximum speed of 90 mph. Fifteen new light-duty "Final" cycles were developed by a contractor for MOVES based on urban and rural data collected in California in 2000 and 2004.[38] The new cycles were selected to best cover the range of road types and average speeds modeled in MOVES.

Comment [Rev91]: Insert all IDs into the text that follows to make them easier to find.

Comment [Rev92]: All of this assumes that the driving cycles are representative of these average speed cutpoints. I agree that the approach is probably better than the previous approach of using a "close" cycle, but no compelling argument has been made that the weighting of the cycles employed in the latest algorithms matches real world composite driving for a facility. Some of the cycles were generated to make sure that we have adequate emission rate data for the model bins, not necessarily to be representative of onroad operations. As noted before, this is not as big a deal at the national level (provided that all analyses back-cast emissions for previous years and do not mix these outputs with the results of previous analyses that employed MOVES2010). However, there is no compelling reason to advocate that this default approach be used in regional or local analyses without corroboration.

Most of the driving schedules used for buses are borrowed directly from driving schedules used for single unit trucks (described below). The "New York City Bus"[50] and "WMATA Transit Bus"[51] drive schedules are included for urban driving that includes transit type bus driving behavior. The "CRC E55 HHDDT Creep" [52] cycle was included to cover extremely low speeds. The "Bus 30 mph Flow" and "Bus 45 mph Flow" cycles used for transit and school buses were developed by EPA based on Ann Arbor Transit Authority buses instrumented in Ann Arbor, Michigan.[53] The bus "flow" cycles were developed using selected non-contiguous snippets of driving from one stop to the next stop, including idle, to create cycles with the desired average driving speeds. The bus "flow" cycles have a nominal speed used for selecting the driving cycles that does not include the idle time and only considers the free-flow speed between stops. The actual average speed of the cycle (including stops) are shown in Section 20. ~~20~~ (Appendix D: SCC Mappings~~Appendix D~~). Note that the "Bus Low Speed Urban" bus cycle is the last 450 seconds of the standard New York City Bus cycle.

The "Refuse Truck Urban" cycle represents refuse truck driving with many stops and a maximum speed of 20 mph, but an average speed of 2.2 mph. This cycle was developed by West Virginia University for the State of New York. The CRC EFF HHDDT Creep cycle was used instead for restricted access driving of refuse trucks at extremely low speeds. All of the other driving cycles used for refuse trucks were borrowed from driving cycles developed for heavy-duty combination trucks, described below.

> **Comment [Rev93]:** The creep cycle was designed to assess emission rates for high inertial load lug operations required to get freight loads moving at low speeds (in freight yards as I recall). Matching this by average speed bin, based upon TomTom data, and weighting that bin may be a huge stretch and may even overstate emissions. Unfortunately, the only way to assess whether the method is viable is to do verification data collection, probably by extensive video analysis.

Single unit and combination trucks use driving cycles developed specifically for MOVES, based on work performed for EPA by Eastern Research Group (ERG), Inc. and documented in the report "Roadway-Specific Driving Schedules for Heavy-Duty Vehicles."[54] ERG analyzed data from 150 medium and heavy-duty vehicles instrumented to gather instantaneous speed and GPS measurements. ERG segregated the driving into restricted access and unrestricted access driving for medium and heavy-duty vehicles, and then further stratified vehicles trips according the pre-defined ranges of average speed covering the range of vehicle operation. The medium duty cycles are used with single unit trucks and heavy-duty cycles are used with combination trucks.

The schedules developed by ERG are not contiguous schedules which could be run on a chassis dynamometer, but are made up of non-contiguous "snippets" of driving (microtrips) meant to represent target distributions. For use with MOVES, we modified the schedules' time field in order to signify when one microtrip ended and one began. The time field of the driving schedule table increments two seconds (instead of one) when each new microtrip begins. This two-second increment signifies that MOVES should not regard the microtrips as contiguous operation when calculating accelerations.

> **Comment [Rev94]:** This does not help the assertion that the average speed modal activity can be paired as asserted.

Both single unit and combination trucks use the CRC EFF HHDDT Creep cycle for all driving at extremely low speeds. At the other end of the distribution, none of the existing driving cycles for heavy-duty trucks included average speeds sufficiently high to cover the highest speed bin used by MOVES. To construct such cycles, EPA started with the highest speed driving cycle available from the ERG analysis and added 5 mph to each point, effectively increasing the average speed of the driving cycle without increasing the acceleration rate at any point. We have checked the feasibility of these new driving cycles (396 and 397) using simulations with the EPA's Greenhouse Gas Emissions Model (GEM)[55] for medium- and heavy-duty vehicle compliance. GEM is a forward-looking full vehicle simulation tool that calculates fuel economy and GHG emissions from an input drive trace and series of vehicle parameters. One of the aspects of forward-looking models is that the driver model is designed to demand torque until the vehicle drive trace is met. Our results indicate that the simulated vehicles were easily able to follow the speed demands of the proposed driving cycles without exceeding maximum torque or power.

> **Comment [Rev95]:** This concerns me. Need to verify the impact of weighting by average speed into the modal bins match what we see on freeways and arterials, especially at the low end.

> **Comment [Rev96]:** This is probably OK.

None of the driving schedules used to represent restricted access (freeway) driving contain vehicle operation on entrance or exit ramps. The effect of ramp operation is added separately in MOVES.

10.2. Ramp Activity

Ramp activity is the driving behavior of vehicles that occurs on entrance and exit ramps as vehicles enter or leave restricted access roads. It includes all of the activity between operation on the unrestricted road and operation on the restricted road.

None of the driving schedules used to represent restricted access (freeway) driving contain vehicle operation on entrance or exit ramps~~. The~~ ; vehicle activity and emissions from ~~effect of~~ ramp operation ~~is~~ are ~~calculated~~ handled separately. Instead of using driving schedules to generate operating mode distributions for ramps, each average speed bin on ramps is assigned ~~has an associated~~ an operating mode distribution ~~that~~ to reflect~~s~~ the power demand expected from ramp operation associated with each nominal average speed for each of the source types. The operating mode distributions used for ramps in MOVES2014 ~~were estimated~~ are designed to represent the driving connecting to and from a freeway with the given average speed. These operating mode distributions (i.e. the fractions of time spent in each of the operating modes for each source type on each road type at each average speed) can be found in the in the default MOVES2014 database (RoadOpModeDistribution table).

Each set of ramp operating modes is associated with a corresponding average speed that does not include ramp operation. ~~Since o~~Operating modes for ramp emissions are -affected by the distribution of the average speed bins on the surrounding roads. And operating modes on surrounding roads are affected by weaving into and out of ramp sections. However, the impact of ramps on adjacent freeways and arterials is already addressed in the selection of the driving cycles associated with activity on those facilities for the average speed distributions. Hence, ~~,~~ the determination of average speeds for restricted access roads (both urban and rural) should not include the time or distance of vehicles on ramps. ~~However, the VMT on ramps should be included with restricted access VMT.~~

The emission impact of ramp activity is combined with the other driving activity found in the restricted access (freeway) driving cycles using a ramp fraction. This fraction defines the fraction of all time spent on a road that occurs on entrance and exit ramps. The fraction used (8%) in MOVES2014 is derived from the ramp fraction value developed originally for the MOBILE6 model.[56]

Comment [Rev97]: It is unclear whether the schedule includes any activity on weaving lanes (lanes that run between an entry ramp and the next exit ramp when ramps are close together My assumption has always been (based upon Sierra Research presentation years ago) that weaving areas upstream of ramps were part of the freeway activity (and freeway driving cycles) and that ramps began at the gore area. Is there any way to confirm this and state it in the text?

Comment [Rev98]: It would be helpful to establish how these distributions were developed.

Comment [Rev99]: A clear definition of start and end of ramp is warranted for user application. Perhaps some diagrams would support this. As I recall, the ramp cycles used car following data collected from gore area to the arterial and vice-versa, including any off-freeway weaving areas. It may be important to let the reader know that the HCM "area of influence" (about 450m upstream and downstream of the ramp) is not included in ramp activity but in freeway activity.

Comment [Rev100]: Now this is a clarity issue for the reader. This needs a detailed description tying back to Table 2-4 to explain what is meant here. Most MPOs are now tracking VMT on ramp links separately for EI development.

Comment [Rev101]: The 8% value is not well supported. "The Ada County model does not track ramp VMT. Ramp VMT was assumed to be 8.7 percent of freeway VMT, based on a Charlotte Department of Transportation analysis (CDOT, 1997) that estimated ramp VMT to be 19.4 percent of freeway VMT in the central business district, 8.7 percent in commercial areas, and 2.4 percent in residential areas." After re-reading the reference report, another data source is clearly warranted for this estimate. Percentages in that report are also by VMT not time.

This needs a caveat. This is what we use for the national evaluations. Do not use the default for County or project-level analyses. Use local data.

11. Hotelling Activity

MOVES2014 defines "hotelling" as any long period of time that heavy-duty drivers spend at their vehicles during mandated down times during long distance deliveries by tractor/trailer combination heavy-duty trucks. During the mandatory down time, drivers can stay in motels or other accommodations, but most of these trucks have sleeping spaces built into the cab of the truck and drivers stay with their vehicles. Hotelling hours are included in MOVES2014 in order to account for use of the truck engine (referred to as "extended idling") to power air conditioning, heat, and other accessories and account for the use of auxiliary power units (APU), which are small on-board power generators.

Comment [Rev102]: Differentiate between hotelling and extended idle here. Only combinations have hotelling, but all vehicles can have extended idling.

In MOVES2014, only the long haul combination truck source use type (sourceTypeID 62) is assumed to have any hotelling activity. All of these long haul combination trucks are currently diesel fueled. Therefore, All all source use types other than long haul combination diesel trucks have hotelling activity fractions set to zero.

11.1. National Default Hotelling Rate

Federal law limits long haul truck drivers to 10 hours driving followed by a mandatory 8 8-hour rest period. These regulations are described in the Federal Register.[57] In long-haul operation, drivers will also stop periodically along their routes. For MOVES, the total hours of hotelling are estimated by using the national estimate of VMT by long haul combination trucks divided an estimated average speed to calculate total hours of driving. The total hours of driving divided by 10 gives the number of 8-hour rest periods needed and thus the national total hotelling hours.

Comment [Rev103]: May need to reconcile this source with updated regulations. I have not read them.

Comment [Rev104]: This should probably come from ATRI data sources. The uncertainty that has already crept in from the average speed data source is now entering the hotelling equation. If the average speed values are off, the hotelling values are also off.

A method is needed to allocate these total hotelling hours to locations. For MOVES2014, we decided to determine a "hotelling rate" (hours of hotelling per mile of travel) that could be was used, in combination with VMT information to allocate the hotelling hours. We calculate a The hotelling rate was defined as the national total national hours of hotelling divided by the national total national miles driven by long haul trucks on rural restricted access (freeways) roads. While Driving driving time on all roads does contribute contributes to the total hotelling hours calculation. However, most locations used for hotelling are located near the roadways (restricted access) most travelled by long haul trucks. In order tTo prevent large amounts of hotelling to be from being allocated to congested urban areas, we decided to only use the VMT on rural restricted roads were used as the surrogate for in allocating the total hotelling hours.

The hotelling rate (hotelling hours per mile of rural restricted access travel by long haul combination trucks) is applied to the estimate of rural restricted access VMT by long haul combination trucks to estimate the default hotelling hours for any location, month or day. The allocation of hotelling to specific hours of the day is described below in Section 12.5.

Comment [Rev105]: Moved down below

The MOVES2014 default hotelling rate was calculated using default national total VMT estimates for calendar year 2011 shown in Table 11-1.

$$Total\ Hours = \frac{Total\ Vehicle\ Miles\ Traveled}{Average\ Speed} \qquad \text{Equation 25}$$

$$Total\ Trips = \frac{Total\ Hours}{10\ hours\ per\ trip} \qquad \text{Equation 26}$$

$$Hotelling\ Hours = Total\ Trips * 8\ hours\ per\ trip \qquad \text{Equation 27}$$

$$Hotelling\ Rate = \frac{Hotelling\ Hours}{Total\ Rural\ Restricted\ Miles\ Traveled} \qquad \text{Equation 28}$$

Where:

- Total Hours is the ~~calculated~~ time long haul combination trucks spend driving, by dividing estimated VMT (miles) miles by estimated average speeds (miles/hour).
- Total Vehicle Miles Traveled is the total miles traveled by diesel long haul combination trucks in the nation in calendar year 2011 on all road types taken from MOVES defaults.
- Average Speed is an estimate of the average speed (distance divided by time) for diesel long haul combination trucks on all road types while operating.
- Total Trips is the calculated number of trips by long haul combination trucks, based upon estimated hours divided by an assumed 10-hour trip (which is assumed to precede hotelling).
- Hotelling Hours is the calculated amount of rest time for long haul combination trucks.
- Rural Restricted Miles is the total miles traveled by diesel long haul combination trucks on only rural restricted access roads (freeways) in calendar year 2011 using MOVES defaults.

Comment [Rev106]: Data source not provided

Table 11-1 Calculation of Hotelling Hours from Long Haul Combination Truck VMT

Description	Annual Value	units
Rural Restricted	31392300000	miles
Rural Unrestricted	34301700000	miles
Urban Restricted	32243100000	miles
Urban Unrestricted	28848900000	miles
Total annual VMT	126786000000	miles
Hours (58.3 mph)	2174716981	hours
Trips (10 hrs per trip)	217471698	Trips
Hotelling hours (8 hrs per trip)	1739773585	hours
Hotelling hours per ~~mile for~~ mile of rural restricted road~~s~~	0.055414	rate

Comment [Rev107]: This needs an independent data source for verification given the assumptions. It would be very useful to go back into the Oak Ridge and DOE data to assess this. However, ATA/ATRI data might be used here.

For the MOVES default, all hotelling activity is assumed to occur in counties with travel on rural restricted access roads), and thus will occur primarily in rural areas of states.

The national rate of hotelling hours per mile of rural restricted access roadway VMT is stored in the HotellingCalendarYear table for each calendar year. The same value calculated for 2011 is used as the default for all calendar years. The County Data Manager includes the HotellingActivityDistribution table which provides the opportunity for states to provide their own estimates of hotelling hours specific to their location and time. Whenever possible states and local areas should obtain and use more accurate local estimates of hotelling hours when modeling local areas.

The overall hotelling rate (total hotelling hours divided by total miles of rural restricted access travel by long haul combination trucks) is applied to rural restricted access VMT estimates for long haul combination trucks over time and space to estimate the default hotelling hours for any location, month, or day. The allocation of hotelling to specific hours of the day is described below in Section 12.5.

Comment [Rev108]: This paragraph is moved down from its previous location above, with proposed edits added.

11.2. Hotelling Activity Distribution

Hotelling differs from simple parking. In MOVES, hotelling hours are divided into operating modes, which define the emissions associated with the type of hotelling activity. Long haul trucks are often equipped with sleeping berths and other amenities to make the drive rest periods more comfortable. These amenities require power for operation. This power can be obtained by running the main truck engine (extended idle) or by use of smaller on-board power generators known as ~~(~~auxiliary power units~~,~~ (APUs). Some truck stop locations include power hookups (truck stop electrification) to allow use of amenities without running either the truck engines or APUs. Some of rest time may occur without use of amenities at all. Table 11-2 shows the hotelling operating modes used in MOVES.

Table 11-2 Hotelling Activity Operating Modes

OpModeID	Description
200	Extended Idling of Main Engine
201	Hotelling Diesel Auxiliary Power Unit (APU)

OpModeID	Description
203	Hotelling Battery or AC (plug in)
204	Hotelling All Engines and Accessories Off

The HotellingActivityDistribution table contains the MOVES default values for the distribution of hotelling activity to the operating modes.

Table 11-3 Default Hotelling Activity Distributions

beginModelYearID	endModelYearID	opModeID	opModeFraction
1960	2009	200	1
1960	2009	201	0
1960	2009	203	0
1960	2009	204	0
2010	2050	200	0.7
2010	2050	201	0.3
2010	2050	203	0
2010	2050	204	0

All of the hotelling hours for long haul trucks of model years before 2010 are assumed to use extended idle to power accessories. Starting with the 2010 model year, the trucks are assumed to use extended idle 70 percent of the time and use APUs 30% of the time based on EPA's assessment of technologies used by tractor manufacturers to comply with the Heavy-Duty Greenhouse Gas standards.

Comment [Rev109]: No information on the source of the splits is provided. No basis for evaluation of assumptions. One would think that given the SMARTWAYS program, Diesel Collaboration Groups, and other EPA funding sources that the 200 fraction would decline at least slightly over time.... Also, there appear to be no seasonal adjustments made with respect to temperature or humidity.

12. Temporal Distributions

MOVES is designed to estimate emissions for every hour of every day type in every month of the year. The vehicle miles traveled (VMT) are provided for MOVES2014 in terms of annual miles. These miles are allocated to months, days, and hours using allocation factors (distributions), either default values or values provided by users.

Default values for most temporal VMT allocations are derived from a 1996 report from the Office of Highway Information Management (OHIM).[58] The report describes analysis of a sample of 5,000 continuous traffic counters distributed through the United States. EPA obtained the data used in the report and used it to generate the VMT temporal distribution inputs in the form needed for MOVES2014.

The OHIM report does not specify VMT by vehicle type, so MOVES uses the same values for all source types, except motorcycles, as described below. In MOVES, daily truck hotelling hours are calculated as proportional to source hours operating (SHO) calculated by MOVES from the VMT and speed distributions for long haul combination trucks. However, the hours of hotelling activity in each hour of the day are not proportional to VMT, as described in Section 12.5.

The temporal distribution for engine start and corresponding engine soak (parked) distributions are calculated from vehicle activity data stored in the SampleVehicle and SampleVehicleTrip tables of the MOVES database. These tables contain a set of vehicle trip activity information from over 37,000 trips, taken from a sample of vehicles intended to be representative of activity for each source type. Evaporative emissions are also affected by the time of day and the duration of parking. Some of the vehicles in the samples take no trips.

Table 12-1 Sample Vehicle Day Table Sample Sizes

Source Type		Vehicle Sample	
sourceTypeID	**Description**	**Weekday (dayID 5)**	**Weekend (dayID 2)**
11	Motorcycle	2214	983
21	Passenger Car	821	347
31	Passenger Truck	834	371
32	Light Commercial Truck	773	345
41	Intercity Bus	190	73
42	Transit Bus	110	14
43	School Bus	136	59
51	Refuse Truck	205	65
52	Single Unit Short-haul Truck	112	58
53	Single Unit Long-haul Truck	123	50
54	Motor Home	5431	2170
61	Combination Short-haul Truck	130	52
62	Combination Long-haul Truck	122	49

Comment [Rev110]: This bit of text is needed in many places earlier in the report. It helps the reader know what they can consider changing.

Comment [Rev111]: Hourly operating profiles for HD Trucks are very different. The ATA has these data from instrumented trucks.

Comment [Rev112]: Source not provided for evaluation

Comment [Rev113]: Need to introduce each table in text and explain to the audience what they will see before presenting the table.

12.1. VMT Distribution by Month of the Year

In MOVES, VMT is entered as an annual value and allocated to month using the MonthVMTFraction table. For MOVES, we use the data from the 1996 OHIM report, Figure 2.2.1 "Travel by Month, 1970-1995," but modified to fit MOVES specifications. The table shows VMT/day taken from the OHIM report, normalized to one for January. For MOVES, we need the fraction of total annual VMT in each month. The report values of VMT per day were used to calculate the VMT in a month using the number of days in each month. The calculations assume a non-leap year (365 days).

Table 12-2 MonthVMTFraction

Month	Normalized VMT/day	MOVES Distribution
January	1.0000	0.0731
February	1.0560	0.0697
March	1.1183	0.0817
April	1.1636	0.0823
May	1.1973	0.0875
June	1.2480	0.0883
July	1.2632	0.0923
August	1.2784	0.0934
September	1.1973	0.0847
October	1.1838	0.0865
November	1.1343	0.0802
December	1.0975	0.0802
Sum		**1.0000**

FHWA does not report monthly VMT information by vehicle classification. But it is clear that in many regions of the United States, motorcycles are driven much less frequently in the winter months. For MOVES2014 an allocation for motorcycles was derived using monthly national counts of fatal motorcycle crashes from the National Highway Traffic Safety Administration Fatality Analysis System for 2010[59]. This allocation increases motorcycle activity (and emissions) in the summer months and decreases them in the winter compared to the other source types. These default values for motorcycles are only a national average and do not reflect the strong regional differences that would be expected due to climate.

Table 12-3 MonthVMTFraction for Motorcycles

Month	Month ID	Distribution
January	1	0.0262
February	2	0.0237
March	3	0.0583
April	4	0.1007
May	5	0.1194
June	6	0.1269
July	7	0.1333
August	8	0.1349
September	9	0.1132
October	10	0.0950
November	11	0.0442
December	12	0.0242
Sum		**1.0000**

12.2. VMT Distribution by Type of Day

The DayVMTFraction distribution divides the weekly VMT into two day types. The 1996 OHIM report provides VMT percentage values for each day and hour of a typical week for urban and rural roadway types for various regions of the United States. Since the day –of-the-week data obtained from the OHIM report is not disaggregated by month or source type, the same values were used for every month and source type. MOVES uses the 1995 data ~~displayed in~~ from Figure 2.3.2 of the OHIM report.

The DayVMTFraction needed for MOVES has only two categories; week days (Monday, Tuesday, Wednesday, Thursday and Friday) and weekend (Saturday and Sunday) days. The OHIM reported percentages for each day of the week were summed in their respective categories and converted to fractions. The OHIM report explains that data for "3am" refers to data collected from 3am to 4am. Thus data labeled "midnight" belongs to and was summed with the upcoming day.

Table 12-4 DayVMTFractions

Fraction	Rural	Urban
Weekday	0.72118	0762365
Weekend	0.27882	0.237635
Sum	**1.00000**	**1.000000**

Comment [Rev114]: Numerous travel diary studies indicate that three categories Monday vs T/W/Th vs. Friday exhibit different travel patterns.

We assigned the "Rural" fractions to the rural road types and the "Urban" fractions to the urban road types. The fraction of weekly VMT reported for a single weekday in MOVES will be one-fifth of the weekday fraction and the fraction of weekly VMT for a single weekend day will be one-half the weekend fraction.

12.3. VMT Distribution by Hour of the Day

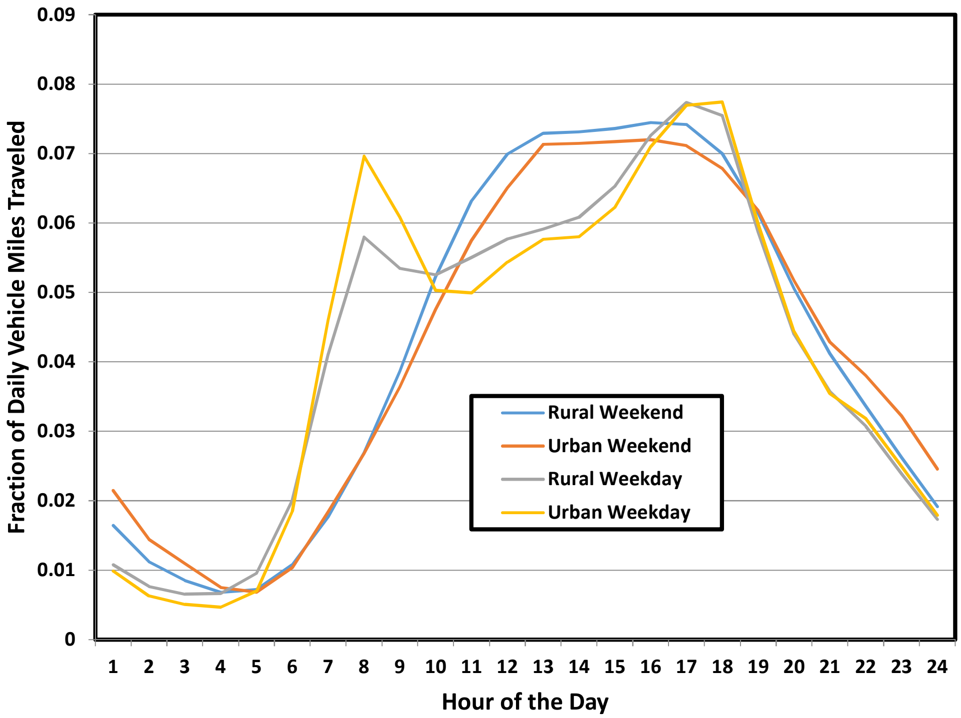
HourVMTFraction uses the same data as for DayVMTFraction. We converted the OHIM report's VMT data by hour of the day in each day type to percent of day by dividing by the total VMT for each day type, as described for the DayVMTFraction. The OHIM report explains that data for "3am" refers to data collected from 3am to 4am. Thus data labeled "midnight" belongs to and was included with the upcoming day.

There are separate sets of HourVMTFractions for "urban" and "rural" road types, but unrestricted and unrestricted roads use the same HourVMTFraction distributions. All source types use the same HourVMTFraction distributions. [Describe table below and flow of data into the figure]

Table 12-5 Distribution of VMT by Hour of the Day

hourID	Description	Urban		Rural	
		Weekday	Weekend	Weekday	Weekend
1	Hour beginning at 12:00 midnight	0.0098621	0.0214739	0.0107741	0.0164213
2	Hour beginning at 1:00 AM	0.00627248	0.0144428	0.0076437	0.0111921
3	Hour beginning at 2:00 AM	0.00505767	0.0109684	0.0065464	0.0085415
4	Hour beginning at 3:00 AM	0.00466686	0.0074945	0.0066348	0.00679328
5	Hour beginning at 4:00 AM	0.00699469	0.0068385	0.0095399	0.00721894
6	Hour beginning at 5:00 AM	0.018494	0.0103588	0.0200551	0.0107619
7	Hour beginning at 6:00 AM	0.0459565	0.0184303	0.0410295	0.01768008
8	Hour beginning at 7:00 AM	0.0696444	0.0268117	0.0579722	0.0268751
9	Hour beginning at 8:00 AM	0.0608279	0.0363852	0.0534711	0.0386587
10	Hour beginning at 9:00 AM	0.0502862	0.0475407	0.0525478	0.0522389
11	Hour beginning at 10:00 AM	0.0499351	0.0574664	0.0550607	0.0631739
12	Hour beginning at 11:00 AM	0.0543654	0.0650786	0.0576741	0.0699435
13	Hour beginning at 12:00 Noon	0.0576462	0.0713228	0.0591429	0.0729332
14	Hour beginning at 1:00 PM	0.0580319	0.0714917	0.0608019	0.0731218
15	Hour beginning at 2:00 PM	0.0622554	0.0717226	0.0652985	0.0736159
16	Hour beginning at 3:00 PM	0.0710049	0.0720061	0.0726082	0.0744608
17	Hour beginning at 4:00 PM	0.0769725	0.0711487	0.0773817	0.0742165
18	Hour beginning at 5:00 PM	0.077432	0.0678874	0.0754816	0.0700091
19	Hour beginning at 6:00 PM	0.059783	0.0617718	0.0587059	0.0614038
20	Hour beginning at 7:00 PM	0.0443923	0.0516882	0.0439864	0.0505043
21	Hour beginning at 8:00 PM	0.0354458	0.0428658	0.0357309	0.0412072
22	Hour beginning at 9:00 PM	0.031824	0.0380302	0.0307428	0.0336373
23	Hour beginning at 10:00 PM	0.0249419	0.0322072	0.0238521	0.0262243
24	Hour beginning at 11:00 PM	0.0179068	0.0245677	0.0173177	0.0191666
	Sum of All Fractions	**1.000**	**1.000**	**1.000**	**1.000**

Figure 12-1 Hourly VMT Fractions by Day Type and Road Type



[It would be useful to compare these data to a number of travel diary studies and the naturalistic driving study.]

12.4. Engine Starts and Parking

To properly estimate engine start emissions and evaporative fuel vapor losses, it is important to estimate the number of starts by time of day, and the duration of time between vehicle trips. The time between trips with the engine off is referred to as "soak time". To determine typical patterns of trip starts and ends, MOVES uses information from instrumented vehicles. This data is stored in two tables in the MOVES default database. We have made only minor changes for MOVE2014.

The first table, SampleVehicleDay, lists a sample population of vehicles, each with an identifier (vehID), an indication of vehicle type (sourceTypeID), and an indication (dayID) of whether the vehicle is part of the weekend or weekday vehicle population. Some vehicles were added to this table to increase the number of vehicles ~~in~~ each day which do not take any trips, to better match a ~~recent~~ 1997 study of vehicle activity in Georgia.[60] This change is described in greater detail in the report describing evaporative emissions in MOVES2014.[61]

The second table, SampleVehicleTrip, lists the trips in a day made by each of the vehicles in the SampleVehicleDay table. It records the vehID, dayID, a trip number (tripID), the hour of the trip (hourID), the trip number of the prior trip (priorTripID), and the times at which the engine was turned on and off for the trip. The keyOnTime and keyOffTime are recorded in minutes since midnight of the day of the trip. 439 trips (about 1.1%) were added to this table to assure that at least one trip is undertaken ~~done~~ by a vehicle from each source type in each hour of the day, to assure that emission rates will be calculated in each hour. Light-duty vehicle trip and soak data was copied to all the other source types (11, 41, 42, 43, 51, 52, 53, 54, 61, and 62) for both weekdays (dayID 5) and weekends (dayID 2) for hours with no trips.

Comment [Rev115]: HDVs operate on very different schedules....

To account for overnight soaks, many first trips reference a prior trip with a null value for keyOnTime and a negative value for keyOffTime. The SampleVehicleDay table also includes some vehicles that have no trips in the SampleVehicleTrip table to account for vehicles that sit for one or more days without driving at all.

The data and processing algorithms used to populate these tables are detailed in two contractor reports.[62,63] The data comes from a variety of instrumented vehicle studies, summarized in Table 12-6. This data was cleaned, adjusted, sampled and weighted to develop a distribution intended to represent average urban vehicle activity.

Table 12-6 Source Data for Sample Vehicle Trip Information

Study	Study Area	Study Years	Vehicle Types	Vehicle Count
3-City FTP Study	Atlanta, GA; Baltimore, MD; Spokane, WA	1992	Passenger cars & trucks	321
Minneapolis	Minneapolis/St. Paul, MN	2004-2005	Passenger cars & trucks	133
Knoxville	Knoxville, TN	2000-2001	Passenger cars & trucks	377
Las Vegas	Las Vegas, NV	2004-2005	Passenger cars & trucks	350
Battelle	California, statewide	1997-1998	Heavy-duty trucks	120
TxDOT	Houston, TX	2002	Diesel dump trucks	4

Comment [Rev116]: 120 trucks is not likely to be representative. ATRI should have detailed data by truck class for large trucks. Additional short haul truck soures are needed

For vehicle classes that were not represented in the available data, the contractor synthesized trips using trip-per-operating hour information from the EPA MOBILE6 model and soak time and time-of-day information from source types that did have data. The application of synthetic trips is summarized in Table 12-7.

Comment [Rev117]: This is a stretch

Table 12-7 Synthesis of Sample Vehicles for Source Types Lacking Data

Source Type	Based on Direct Data?	Synthesized From
Motorcycles	No	Passenger Cars
Passenger Cars	Yes	n/a
Passenger Trucks	Yes	n/a
Light Commercial Trucks	No	Passenger Trucks
Intercity Buses	No	Combination long-haul trucks
Transit Buses	No	Single unit short-haul trucks
School Buses	No	Single unit short-haul trucks
Refuse Trucks	No	Combination short-haul trucks
Single unit short-haul trucks	Yes	n/a
Single unit long-haul trucks	No	Combination long-haul trucks
Motor homes	No	Passenger Cars
Combination short-haul trucks	Yes	n/a
Combination long-haul trucks	Yes	n/a

Comment [Rev118]: Detailed data should be available from the general transit feed services

Comment [Rev119]: Data should be available from the Atlanta school bus study

The resulting trip-per-day estimates are summarized in Table 12-8. The same estimate for trips per day is used for all ages of vehicles in any calendar year.

Table 12-8 Starts per Day by Source Type

Source Type	MOVES2014 Weekday	MOVES2014 Weekend
Motorcycles	0.78	0.79
Passenger Cars	5.89	5.30
Passenger Trucks	5.80	5.06
Light Commercial Trucks	6.05	5.47
Intercity Buses	2.77	0.88
Transit Buses	4.58	3.46
School Buses	5.75	1.26
Refuse Trucks	3.75	0.92
Single unit short-haul trucks	6.99	1.28
Single unit long-haul trucks	4.29	1.29
Motor homes	0.57	0.57
Combination short-haul trucks	5.93	1.16
Combination long-haul trucks	4.29	1.29

MOVES2014 now has inputs in the County Data Manager that allows users to specify the number of engine starts in each month, day type and hour of the day, as well as by source type and vehicle age. These user inputs override the default values provided by MOVES.

The same trip information that is used to determine the number of engine starts is also used to determine the vehicle soak time. “Soak time” is the time between trips when the engine is off. The soak times are used to estimate the activity in each of the operating modes for engine start emissions. The base emission rate for engine starts is based on a 12 hour soak period. All engine soaks greater than 12 hours assume the same engine start emission rate as for 12 hours. However, for all engine soaks less than 12 hours, the base engine start emission rate is adjusted based on soak time bins (operating modes).[3,4] The distribution of operating modes in each hour of the day is part of the calculation used to determine the engine start emissions for that hour of the day.

A more complete discussion of the relationship between engine soak time and emissions will be found in the MOVES report covering engine start emission rates used in MOVES.[3]

Comment [Rev120]: More recent data are needed.

12.5. Hourly Hotelling Activity

The hotelling hours in each day should not track the miles traveled in each hour, since hotelling occurs only when drivers are not driving. Instead, the fraction of hours spent hotelling by time of day can be derived from other sources. In particular, the report, *Roadway-Specific Driving Schedules for Heavy-Duty Vehicles*,[54] combines data from several instrumented truck studies and contains detailed information about truck driver behavior. While none of the trucks were involved in long haul interstate activity, for lack of better data, we have assumed that long haul truck trips have the same hourly truck trip distribution as the heavy heavy-duty trucks that were studied.

For each hour of the day, we estimated the number of trips that would end in that hour, based on the number of trips that started 10 hours earlier. The hours of hotelling in that hour is the number that begin in that hour, plus the number that began in the previous hour, plus the number that began in the hour before that, and so on, up to the required eight hours of rest time. Table 12-9 shows the number of trip starts and inferred trip ends over the hours of the day in the sample of trucks assuming all trips are 10 hours long. For example, the number of trip ends in hour 1 is the same as the number of trip starts 10 hours earlier in hour 15 of the previous day.

Table 12-9 Hourly Distribution of Truck Trips used to calculate hotelling hours

hourID	Hour of the Day	Trip Starts	Trip Ends
1	Hour beginning at 12:00 midnight	78	171
2	Hour beginning at 1:00 AM	76	167
3	Hour beginning at 2:00 AM	65	144
4	Hour beginning at 3:00 AM	94	98
5	Hour beginning at 4:00 AM	107	71
6	Hour beginning at 5:00 AM	131	73
7	Hour beginning at 6:00 AM	194	71
8	Hour beginning at 7:00 AM	230	52
9	Hour beginning at 8:00 AM	279	85
10	Hour beginning at 9:00 AM	267	48
11	Hour beginning at 10:00 AM	275	78
12	Hour beginning at 11:00 AM	240	76
13	Hour beginning at 12:00 Noon	201	65
14	Hour beginning at 1:00 PM	211	94
15	Hour beginning at 2:00 PM	171	107
16	Hour beginning at 3:00 PM	167	131
17	Hour beginning at 4:00 PM	144	194
18	Hour beginning at 5:00 PM	98	230
19	Hour beginning at 6:00 PM	71	279
20	Hour beginning at 7:00 PM	73	267
21	Hour beginning at 8:00 PM	71	275
22	Hour beginning at 9:00 PM	52	240
23	Hour beginning at 10:00 PM	85	201
24	Hour beginning at 11:00 PM	48	211

An estimate of the distribution of truck hotelling duration times is derived from a 2004 CRC paper[64] based on a survey of 365 truck drivers at 6 different locations. Table 12-10 lists the fraction of trucks in each duration bin. Some trucks are hotelling for more than the required eight hours, but some are hotelling for less than eight hours.

Table 12-10 Distribution of Truck Hotelling Activity Duration

Duration (hours)	Fraction of Trucks
2	0.227
4	0.135
6	0.199
8	0.191
10	0.156
12	0.057
14	0.014
16	0.021
Total	**1.000**

We assume that all hotelling activity begins at the trip ends shown in Table 12-9. But not all trip ends have the same number of hotelling hours. The distribution of hotelling durations from Table 12-10 is applied to the hotelling that occurs at each of these trip ends.

Table 12-11 illustrates the hotel activity calculations based on the number of trip starts and trip ends. The hours of hotelling in any hour of the day is the number of trip ends in the current hour plus the trip ends from the previous hours that are still hotelling. However, since not all trips begin and end precisely on the hour, we have discounted the oldest hour included in the calculation by 60 percent to account for those unsynchronized trips.

For example, there are 171 trip ends in hourID 1. If all trip ends idle for two hours, the number of hours is 171 (for hourID 1) and 40 percent of 211 (for hourID 24), and thus 171 + (0.4*211) = 255.4 hours of hotelling. Similarly, the number of hours can be calculated for other hotelling time periods. For four hour hotelling periods, the hotelling hours would be 171 + 211 + 201 + (0.4*240) = 679. Only the oldest hour of the day is discounted.

This calculation accounts for the time in the current hour of the day which is a result of hotelling from trips that ended in the current hour and trips that ended in previous hours. This approach assumes that all hotelling begins at the trip end. For example, in the hour of the day 1 for the four hours hotelling bin, the trip ends in hourID 22 contribute to the hours of hotelling in hourID 1, since these trip ends are still hotelling (four hours) after the trip end. The trip ends in hourID 21 do not contribute to the four hours hotelling bin, since it has been more than four hours since the trip ends occurred.

The initial calculated hours assume that all trucks idle the same amount of time, indicated by the hotelling hours bin. The distribution (weight) from Table 12-10 is applied to the hour estimate in each hotelling hours bin to calculate the weighted total idle hours for each hour of the day.

~~We assume that all hotelling activity begins at the trip ends shown in Table 12-9. The distribution of hotelling durations from Table 12-10 is applied to these trip ends. These calculations are shown in~~

~~Table 12-11. The column "2 hours" adds the number of trip ends in the previous 2 hours, assuming all trips will have 2 hours of hotelling after their trip ends, the column "4 hours" adds the trips ends in the previous 4 hours, etc. The first hour of hotelling in each category is reduced by 60% to account for the fact that not all of the trips actually ended at the beginning of the hour. The total hotelling hours is the product of the total hours in each column multiplied by the fraction of trucks with each duration from Table 12-10.~~

Comment [Rev121]: This text was deleted for this review when replaced by the green text above in the updated document I received.

Table 12-11 Calculation of Hourly Distributions of Hotelling Activity

hourID	Trip Starts	Trip Ends*	2 hours	4 hours	6 hours	8 hours	10 hours	12 hours	14 hours	16 hours	Total Hours	Distribution
1	78	171	255.4	679	1204.8	1736	2120.4	2343.6	2495.4	2638.2	1276	0.0628
2	76	167	235.4	629.4	1100	1643.6	2118.6	2408.8	2593	2739.2	1234	0.0611
3	65	144	210.8	566.4	990	1515.8	2047	2431.4	2654.6	2806.4	1166	0.0577
4	94	98	155.6	477.4	871.4	1342	1885.6	2360.6	2650.8	2835	1056	0.0526
5	107	71	110.2	379.8	735.4	1159	1684.8	2216	2600.4	2823.6	930	0.0458
6	131	73	101.4	299.6	621.4	1015.4	1486	2029.6	2504.6	2794.8	823	0.0407
7	194	71	100.2	254.2	523.8	879.4	1303	1828.8	2360	2744.4	728	0.0357
8	230	52	80.4	224.4	422.6	744.4	1138.4	1609	2152.6	2627.6	630	0.0306
9	279	85	105.8	237.2	391.2	660.8	1016.4	1440	1965.8	2497	581	0.0289
10	267	48	82	213.4	357.4	555.6	877.4	1271.4	1742	2285.6	507	0.0255
11	275	78	97.2	231.8	363.2	517.2	786.8	1142.4	1566	2091.8	479	0.0238
12	240	76	107.2	236	367.4	511.4	709.6	1031.4	1425.4	1896	457	0.0221
13	201	65	95.4	238.2	372.8	504.2	658.2	927.8	1283.4	1707	434	0.0221
14	211	94	120	266.2	395	526.4	670.4	868.6	1190.4	1584.4	447	0.0221
15	171	107	144.6	296.4	439.2	573.8	705.2	859.2	1128.8	1484.4	476	0.0238
16	167	131	173.8	358	504.2	633	764.4	908.4	1106.6	1428.4	526	0.0255
17	144	194	246.4	469.6	621.4	764.2	898.8	1030.2	1184.2	1453.8	635	0.0323
18	98	230	307.6	597.8	782	928.2	1057	1188.4	1332.4	1530.6	767	0.0374
19	71	279	371	755.4	978.6	1130.4	1273.2	1407.8	1539.2	1693.2	933	0.0458
20	73	267	378.6	853.6	1143.8	1328	1474.2	1603	1734.4	1878.4	1068	0.0526
21	71	275	381.8	913	1297.4	1520.6	1672.4	1815.2	1949.8	2081.2	1194	0.0594
22	52	240	350	893.6	1368.6	1658.8	1843	1989.2	2118	2249.4	1268	0.0628
23	85	201	297	822.8	1354	1738.4	1961.6	2113.4	2256.2	2390.8	1289	0.0645
24	48	211	291.4	762	1305.6	1780.6	2070.8	2255	2401.2	2530	1308	0.0645
Totals	**3428**	**3428**	**4799**	**11655**	**18511**	**25367**	**32223**	**39079**	**45935**	**52791**	**20213**	**1.0000**

* Assumes all trip ends occur 10 hours after trips start and all trips are 10 hours long.

The first hour of hotelling in each hour bin column sum is reduced by 60% to account for trip ends in a column that are not a full hour.

The distribution calculated using this method is similar to the behavior observed in a dissertation[65] at the University of Tennessee, Knoxville. This study observed the trucks parking at the Petro truck travel center located at the I40/I75 and Watt Road interchange between mid-December 2003 and August 2004. Rather than use a study at a specific location, MOVES2014 uses the more generic simulated values to determine the diurnal distribution of hotelling behavior. The distribution of total hotelling hours to hours of the day is calculated from the total hotelling hours and stored in the SourceTypeHour table of the default MOVES2014 database.

Comment [Rev122]: Good support. Should be done for items noted earlier in the report as needing additional confirmation.

MOVES2014 uses this same default hourly distribution from Table 12-11 ~~Table 12-11~~ for all days and locations, as shown below in Figure 12-2~~Figure 12-2~~. Note, this distribution of hotelling by hour of the day is similar to the inverse of the VMT distribution used for these trucks by hour of the day.

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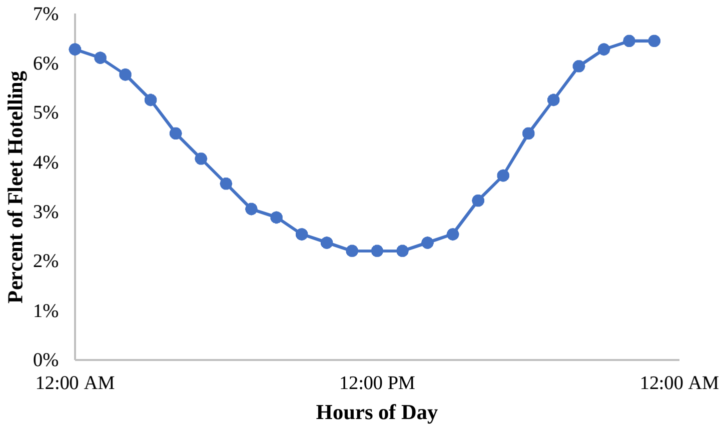
Figure 12-2 Truck hotelling distribution by hour of the day in MOVES2014



12.6. Single and Multiday Diurnals

The evaporative vapor losses from gasoline vehicle fuel tanks are affected by many factors, including the number of hours a vehicle is parked without an engine start, referred to as engine soak time. Most modern gasoline vehicles are equipped with emission control systems designed to capture most evaporative vapor losses and store them. These stored vapors are then burned in the engine once the vehicle is operated. However, the vehicle storage capacity for evaporative vapors is limited and multiple days of parking (diurnals) will overload the storage capacity of these systems, resulting in larger losses of evaporative vapors in subsequent days.

The soak time calculations are discussed in Section 12.4. The detailed description of the calculation for the number of vehicles that have been soaking for more than a day and the amount of time that the vehicles have been soaking can be found in the MOVES technical report on evaporative emissions.[63]

Comment [Rev123]: Same issues as before. However, this is not a real problem for diesel vehicles, which could be noted here and above.

13. Geographical Allocation of Activity

MOVES is designed to model activity at a "domain" level and then to allocate that activity to "zones." The MOVES2014 default database is populated for a domain of the entire United States (including Puerto Rico and the Virgin Islands), and the default zones correspond to individual counties. The MOVES design only allows for one set of geographic allocations to be stored in the default database. While geographic allocations clearly change over time, the MOVES defaults were developed using the data from calendar year 2011, and are used for all calendar years. For this reason, the MOVES default allocation of activity is rarely used for any official purpose by either EPA or local areas. National-level emissions can be generated with calendar year specific geographical information by running each year separately, with different user-input allocations for each run. County- and Project-level calculations do not use the default geographical allocation factors at all. Instead, County and Project scales require that the user input local total activity for each individual year being modeled. The MOVES geographic allocation factors are stored in two tables, Zone and ZoneRoadType.

Comment [Rev124]: Discuss in introduction

Field Code Changed

13.1. Source Hours Operating Allocation to Zones

Most of the emission rate calculations in MOVES2014 are based on emission rates by time units (hour). Using time units for emissions is the most flexible approach, since the activity for some processes (like leaks and idling) and some source types (like nonroad generators) are more naturally in units of time. As a result, MOVES converts mileage activity data to hours in many cases in order to produce the hours needed for emissions calculations.

The national total source hours of operation (SHO) are calculated from the estimates of VMT and average speed as described in sections above. This total VMT for each roadtype is allocated to county using the SHOAllocFactor field in the ZoneRoadType table. The allocation factors are derived using 2011 VMT and MOVES default VMT.

In particular, the MOVES2014 default estimates for the VMT by county come from Version 1 of the 2011 National Emission Inventory (NEI) analysis.[44] These estimates are based on the Highway Performance Monitoring System (HPMS) state level data collected by the Federal Highway Administration[66] annually for use in transportation planning. The HPMS state level VMT is distributed to the individual counties in each state as part of the NEI analysis. This data is reviewed and updated by the states as necessary prior to use in the NEI. The default inputs for SHOAllocFactor in MOVES2014 were calculated using the VMT estimates obtained from Version 1 of the 2011 NEI[67] for each county by road type.

Comment [Rev125]: Discuss method.

Vehicle miles traveled can be converted to hours of travel using average speeds. The average speed estimates were taken directly from the AvgSpeedDistribution table of the MOVES default database. The default average speed distributions do not vary by county or source type, but do vary by road type (distributions of which vary by county), day type (weekday and weekend day) and hour of the day. The 2011 NEI VMT was aggregated into the four MOVES road types in each county. The VMT by road type in each county was then allocated to day type and hour of the day using the day type and hour distributions from the MOVES default database tables, DayMVTFraction and HourVMTFraction.

Using the nominal speeds for each average speed bin in the AvgSpeedDistribution table for each hour of each day type and the corresponding VMT, the hours of vehicle operation (SHO) can be calculated for each hour of the day on each road type for each day type in each county. The average speed distribution is in units of time, so the distribution must be converted to units of distance to be applied to the VMT values. For this step, we multiplied each value of each distribution (in terms of time) by the corresponding nominal average speed value for that average speed bin to calculate distance (distance = hours * miles/hour). Then we divided each distance value in the distribution by the sum of all distance values in that distribution to calculate the average speed distribution in terms of distance.

Finally, we multiplied the total VMT corresponding to each average speed distance distribution (by road type, by day type, by hour of the day) by each of the values in the distribution to calculate the VMT corresponding to each average speed bin. We then then calculated operating hours by dividing the VMT in each average speed bin by the corresponding nominal average speed value.

$$\text{SHO} = \text{VMT (miles)} / \text{Speed (miles per hour)} \qquad \text{Equation 29}$$

Once the hours of operation have been calculated, the hours in each county were summed by road type. The allocation factor for each county was calculated by dividing the county hours for each road type by the national total hours of operation for each road type.

$$\text{SHOAllocFactor} = \text{County SHO} / \text{National SHO} \qquad \text{Equation 30}$$

The county allocation values for each roadway type sum to one (1.0) for the nation. The same SHOAllocFactor set is the default for all calendar years at the National scale. County- and Project-level calculations do not use the default SHOAllocFactor allocations at all. Instead, County and Project scales require that the user input all local activity.

13.2. Engine Start Allocations to Zones

Field Code Changed

The allocation of the domain-wide count of engine starts to zones is stored in the StartAllocFactor in the Zone table. In the default database for MOVES2014, the domain is the nation and the zones are counties. There is no national source for data on the number of trip starts by county, so for MOVES2014, we have used VMT to ~~determine~~ allocate starts~~this allocation~~. VMT for each county was taken from the most recent National Emission Inventory analysis for calendar year 2011.[67]

VMT estimates for each county in each state and the allocation is calculated using the following formula, where i represents each individual county and I is the set of all US counties.

$$\text{CountyAllocation}_i = \text{CountyVMT}_i \Big/ \sum_{i \epsilon I} \text{CountyVMT}_i \qquad \text{Equation 31}$$

The county allocation values sum to one (1.0) for the nation. The same StartAllocFactor set is the default for all calendar years at the National scale. County- and Project-level calculations do not use the default StartAllocFactor allocations at all. Instead, County and Project scales require that the user input all local activity.

13.3. Parking Hours Allocation to Zones

The allocation of the domain-wide hours of parking (engine off) to zones is stored in the SHPAllocFactor in the Zone table. In the default database for MOVES2014, the domain is the nation and the zones are the counties. There is no national source for hours of parking by county, so for MOVES2014, we have used the same VMT-based allocation as used for the allocation of starts in the StartAllocFactor (see above).

The county allocation values for parking hours sum to one (1.0) for the nation. The same SHPAllocFactor set is the default for all calendar years at the National scale. County- and Project-level calculations do not use the default SHPAllocFactor allocations at all. Instead, County and Project scales require that the user input all local activity.

In MOVES2014, hotelling hours (including extended idling and auxiliary power unit usage) are calculated from long haul combination truck VMT in each location and does have its own allocation factors.

14. Vehicle Mass and Road Load Coefficients

The MOVES model calculates emissions using a weighted average of emisson rates by operating mode. This level of detail is required for microscale modeling, which in MOVES is called project level analysis. For running exhaust emissions, the operating modes are defined by either Vehicle Specific Power (VSP) or Scaled Tractive Power (STP). Both VSP and STP are calculated based on a vehicle's speed and acceleration but differ in how they are scaled (or normalized). VSP is used for light-duty vehicles (source types 11-32) and STP is used for heavy-duty vehicles (source types 41-62).

The SourceUseTypePhysics table describes the vehicle characteristics needed for the VSP and STP calculations, including average vehicle mass, a fixed mass factor, and three road load coefficients for each source type averaged over all ages. MOVES uses these to calculate VSP and STP for each source type according the equations:

$$VSP = \left(\frac{A}{M}\right) \cdot v + \left(\frac{B}{M}\right) \cdot v^2 + \left(\frac{C}{M}\right) \cdot v^3 + (a + g \cdot \sin\theta) \cdot v \qquad \text{Equation 32}$$

$$STP = \frac{Av + Bv^2 + Cv^3 + M \cdot v \cdot (a_t + g \cdot sin\theta)}{f_{scale}} \qquad \text{Equation 33}$$

where A, B, and C are the road load coefficients in units of kW-s/m, kW-s^2/m^2, and kW-s^3/m^3 respectively. A is associated with tire rolling resistence, B with mechanical rotating friction as well as higher order rolling resistance losses, and C with aerodynamic drag. M is the source mass for the source type in metric tons, g is the acceleration due to gravity $(9.8\ m/s^2)$, v is the instantaneous vehicle speed in m/s, a is the instantaneous vehicle acceleration in m/s^2, $\sin\theta$ is the (fractional) road grade, and f_{scale} is a scaling factor.

When mapping actual emissions data to VSP bins with Equation 32, the vehicle's measured weight is used as the source mass factor. In contrast, when calculating average VSP distributions for an entire source type with MOVES, the average source type mass is used instead. STP is calculated with Equation 33, which is very similar to the VSP equation except the denominators are different. In the case of VSP, the power is normalized by the mass of the vehicle ($f_{scale} = M$). For heavy-duty vehicles using STP, f_{scale} depends on their regulatory class and is used to bring the numerical range of tractive power into the same numerical range as the VSP values when assigning operating modes. Class 40 trucks use $f_{scale} = 2.06$, which is equal to the mass of source type 32 in metric tons. This is because operating modes for passenger trucks and light-commercial trucks are assigned operating modes using VSP, and using a fixed mass factor of 2.06 essentially calculates VSP-based emission rates. Running operating modes for all the heavy-duty source types (buses, single unit, and combination trucks) are assigned using STP with $f_{scale} = 17.1$, which is roughly equivalent to the average running weight in metric tons of all heavy-duty vehicles. Additional discussion regarding VSP and STP are provided in the MOVES light-duty[3] and heavy-duty[4] emission rate reports, respectively.

In both cases, operating mode distributions are derived from combining second-by-second speed and acceleration data from a specific drive schedule with the proper coefficients for a specific source type. More information about drive schedules can be found in Section 10.1. The following sections detail the derivation of values used in Equation 32 and Equation 33.

14.1. Source Mass and Fixed Mass Factor

The two mass factors stored in the SourceUseTypePhysics table are the source mass and fixed mass factor. The source mass represents the average weight of a given source type, which includes the weight of the vehicle, occupants, fuel, and payload (M in the equations above), and the fixed mass factor represents the STP scaling factor (f_{scale} in the equations above).

While the source masses for light-duty were unchanged from MOVES2010b, all of the heavy-duty source masses were updated with newer data. Please see Section 22. 21 (Appendix E: MOVES2010b Source MassesAppendix E) for a discussion of the MOVES2010b source masses. The heavy-duty source masses for 2014+ model year vehicles heavy-duty vehicles were first updated to account for the 2014 Medium and Heavy-Duty Greenhouse Gase Rule, assuming that new technologies and reduced vehicle weights will be implemented by manufacturers to meet the standards as discussed in (see Section 14.2. 14.2). Then the The heavy-duty source masses were updated with 2011 Weigh-in-Motion (WIM) data made available through FHWA's Vehicle Travel Information System (VTRIS). These data are available from FHWA by state, road type, and HPMS truck type (single unit or combination). The average national mass by truck type was calculated by weighting the masses with VMT by state and road type using FHWA's *Highway Statistics* VM-2 table. These average values then needed to be allocated from the HPMS truck classification to source types. This allocation was performed using the percent difference between the average WIM HPMS mass and the average MOVES2010b HPMS mass.[j] The MOVES2010b average masses were calculated by weighting the source type masses with the updated 2011 VMT. The percentage difference between the average single unit truck mass in MOVES2010b and the WIM data was then applied to the source masses of Single Unit Short-haul Trucks, Single Unit Long-haul Trucks, Refuse Trucks, and Motor Homes. Likewise, the percentage difference between the average combination truck mass in MOVES2010b and the WIM data was applied to the source masses of Combination Short-haul Trucks and Combination Long-haul Trucks, including the 2014+ model year groups. These differences are shown in Table 14-1, and the resulting source type masses are presented in Table 14-4.

Table 14-1 Weigh-in-Motion (WIM) Truck Masses Weighted by VMT

HPMS Category	Average Weight (lbs)	% Change from MOVES2010b
Single Unit Trucks	20,107	11.7%
Combination Trucks	52,907	-21.7%

[j] For the WIM analysis, we only compared to the MOVES2010b masses because the 2014 Medium and Heavy-Duty Rule impact is not assumed to begin phase-in until 2014.

14.2. Road Load Coefficients

The information available on road load coefficients varied by regulatory class. Motorcycle road load coefficients were parameterized, in accordance with standard practice, using the following emperical equations[68,69]:

$$A = 0.088 \cdot M \quad \text{Equation 34}$$

$$B = 0 \quad \text{Equation 35}$$

$$C = 0.00026 + 0.000194 \cdot M \quad \text{Equation 36}$$

For light-duty vehicles, the road load coefficients were calculated according to the following empirical equations:[70]

$$A = \frac{0.7457}{50 \cdot 0.447} \cdot 0.35 \cdot TRLHP_{@50\text{mph}} \quad \text{Equation 37}$$

$$B = \frac{0.7457}{(50 \cdot 0.447)^2} \cdot 0.10 \cdot TRLHP_{@50\text{mph}} \quad \text{Equation 38}$$

$$C = \frac{0.7457}{(50 \cdot 0.447)^3} \cdot 0.55 \cdot TRLHP_{@50\text{mph}} \quad \text{Equation 39}$$

In each of the above equations, the first factor is the appropriate unit conversion to allow A, B, and C to be used in Equation 32 and Equation 33, the second factor is the power distribution into each of the three load categories, and the third is the tractive road load horsepower rating (TRLHP). Average values for A, B, and C for source types 21, 31, and 32 were derived from applying TRLHP values recorded in the Mobile Source Observation Database (MSOD)[71] to Equation 37 through Equation 39. While we expect light-duty road load coefficients to improve over time due to the Light-Duty Greenhouse Gas Rule, the impact of these changes have been directly incorporated into the emission and energy rates. Therefore, these coefficients remain constant over time in the MOVES (if not in the real-world) to avoid double counting the impacts of actual road load improvements in the fleet.

For the heavier vehicles, no road load parameters were available in the MSOD. For these source types, relationships of road load coefficent to vehicle mass came from a study done by V.A. Petrushov,[72] as shown in Table 14-2. These relationships are grouped by regulatory class; source type values were determined by weighting the combination of MOVES2010b weight categories that comprise the individual source types. The final SourceMass, FixedMassFactor and road load coefficients for all source types are listed in Table 14-4.

Table 14-2 Road Load Coefficients for Heavy-Duty Trucks, Buses, and Motor Homes for 1960-2013 Model Year Vehicles

Coefficient	8500 to 14000 lbs (3.855 to 6.350 metric ton)	14000 to 33000 lbs (6.350 to 14.968 metric ton)	>33000 lbs (>14.968 metric ton)	Buses and Motor Homes
$A\left(\frac{kW\text{-}s}{m}\right)$	$0.0996 \cdot M$	$0.0875 \cdot M$	$0.0661 \cdot M$	$0.0643 \cdot M$
$B\left(\frac{kW\text{-}s^2}{m^2}\right)$	0	0	0	0
$C\left(\frac{kW\text{-}s^3}{m^3}\right)$	$0.00289 + 5.22 \times 10^{-5} \cdot M$	$0.00193 + 5.90 \times 10^{-5} \cdot M$	$0.00289 + 4.21 \times 10^{-5} \cdot M$	$0.0032 + 5.06 \times 10^{-5} \cdot M$

In MOVES2014, the vehicle mass and road load coefficient were updated for 2014 and later model year heavy-duty vehicles to account for the 2014 Medium and Heavy-Duty Greenhouse Gase Rule.[73] Table 14-3~~Table 14-3~~ contains the combination long-haul tractor and vocational vehicle tire rolling resistance, coefficient of drag, and weight reductions expected from the technologies which could be used to meet the standards. The value in the table reflects a 400 pound mass reduction. As discussed in the regulatory impact analysis for the final rulemaking, EPA used a sales mix of 10 percent Class 7 low roof, 10 percent Class 7 high roof, 45 percent Class 8 low roof, and 35 percent Class 8 high roof based on feedback from the manufacturers.

Comment [Rev126]: Probably should note somewhere that these values should be monitored over time.

The values in the table reflect a modeling assumption that 8 percent of all tractors (19.7 percent of short-haul tractors) would be considered vocational tractors and therefore will only be required to meet the vocational vehicle standards and not show any aerodynamic or weight improvement. The weight reduction applied to short-haul tractors is 321 pounds, which is calculated from the 400 pound weight reduction assumed for non-vocational tractors, reduced by 19.7 percent. The tire rolling resistance reduction is assumed to be 5 percent based on the data derived in the tire testing program conducted by EPA. Comparatively tire rolling resistance is reduced by 9.6 percent for long-haul tractors and 7 percent for short-haul tractors while aerodynamic drag is reduced 12.1 percent for long-haul tractors and 5.9 percent for short-haul tractors in model year 2014 and later. For further details on these assumptions about reductions in source mass and road load coefficients, please see the rulemaking documents [cites]. Discussion of incorporating the rule's energy reductions from engine technology improvements into MOVES can be found in the MOVES2014 Heavy-Duty Emission Rate Report.[4]

Table 14-3 Estimated Reductions in Rolling Resistance and Aerodynamic Drag Coefficients from Reference Case for Alternative 3 (Model Years 2014 and Later)

Truck Type	Reduction In Tire Rolling Resistance Coefficient From Baseline	Reduction In Aerodynamic Drag Coefficient From Baseline	Weight Reduction (lbs)
Combination long-haul	9.6%	12.1%	400
Combination short-haul	7.0%	5.9%	321
Vocational vehicles (Single-unit trucks, refuse trucks, motor homes, buses, and light commercial trucks)	5.0%	0%	0

Comment [Rev127]: These are large. Is there a basis in the rulemaking report and a nexus between the standards and improvements in tire technology?

These changes are represented in MOVES2014 through new aerodynamic coefficients and weights, and they primarily affect short- and long-haul combination truck source types beginning in MY 2014. The average vehicle mass and road load coefficients are updated by source type through the beginModelYearID and endModelYearID fields in the SourceUseTypePhysics table.

Table 14-4 SourceUseTypePhysics Table

sourceTypeID	Begin Model Year	End Model Year	Rolling Term A (kW-s/m)	Rotating Term B (kW-s^2/m^2)	Drag Term C (kW-s^3/m^3)	Source Mass (metric tons)	Fixed Mass Factor (metric tons)
11	1960	2050	0.0251	0	0.0003	0.2850	0.2850
21	1960	2050	0.1565	0.0020	0.0005	1.4788	1.4788
31	1960	2050	0.2211	0.0028	0.0007	1.8669	1.8669
32	1960	2050	0.2350	0.0030	0.0007	2.0598	2.0598
41	1960	2013	1.2952	0	0.0037	19.5937	17.1
41	2014	2050	1.2304	0	0.0037	19.5937	17.1
42	1960	2013	1.0944	0	0.0036	16.5560	17.1
42	2014	2050	1.0397	0	0.0036	16.5560	17.1
43	1960	2013	0.7467	0	0.0022	9.0699	17.1
43	2014	2050	0.7094	0	0.0022	9.0699	17.1
51	1960	2013	1.5835	0	0.0036	23.1135	17.1
51	2014	2050	1.5043	0	0.0036	23.1135	17.1
52	1960	2013	0.6279	0	0.0016	8.5390	17.1
52	2014	2050	0.5965	0	0.0016	8.5390	17.1
53	1960	2013	0.5573	0	0.0015	6.9845	17.1
53	2014	2050	0.5294	0	0.0015	6.9845	17.1
54	1960	2013	0.6899	0	0.0021	7.5257	17.1
54	2014	2050	0.6554	0	0.0021	7.5257	17.1
61	1960	2013	1.5382	0	0.0040	22.9745	17.1
61	2014	2050	1.4305	0	0.0038	22.8289	17.1
62	1960	2013	1.6304	0	0.0042	24.6010	17.1
62	2014	2050	1.4739	0	0.0037	24.4196	17.1

15. Air Conditioning Activity Inputs

~~This report describes three~~ Three inputs are used in ~~determining~~ estimating the impact of air conditioning on emissions. The ACPenetrationFraction is the fraction of vehicles equipped with air conditioning. FunctioningACFraction describes the fraction of these vehicles in which the air conditioning system is working correctly. The ACActivityTerms relate air conditioning use to local heat and humidity. More information on air conditioning effects is provided in the MOVES technical report on adjustment factors.[74]

15.1. ACPenetrationFraction

The ACPenetrationFraction is a field in the SourceTypeModelYear table. Default values, by source type and model year were taken from MOBILE6.[75] Market penetration data by model year were gathered from Ward's Automotive Handbook for light-duty vehicles and light-duty trucks for model years 1972 through the 1995 for cars and 1975-1995 for light trucks. Rates in the first few years of available data are quite variable, so values for early model years were estimated by applying the 1972 and 1975 rates for cars and trucks, respectively. Projections beyond 1995 were developed by calculating the average yearly rate of increase in the last five years of data and applying this rate until a predetermined cap was reached. A cap of 98 percent was placed on cars and 95 percent on trucks under the assumption that there will always be vehicles sold without air conditioning, more likely trucks than cars. No data was available on heavy-duty trucks. While VIUS asks if trucks are equipped with A/C, "no response" was coded the same as "no," making the data unusable for this purpose. For MOVES, the light-duty vehicle rates were applied to passenger cars, and the light-duty truck rates were applied to all other source types (except motorcycles, for which A/C penetration is assumed to be zero).

Comment [Rev128]: This is initial market penetration. Don't scrappage rates differ for a/c vs non-a/c? The approach used earlier for MCs could be used to assess the assertion that a/c penetration rates increase over time for a given MY.

Field Code Changed

Comment [Rev129]: Good catch, I had missed that in the past.

Table 15-1 AC Penetration Fractions in MOVES2014

	Motorcycles	Passenger Cars	All Trucks and Buses
1972-and-earlier	0	0.592	0.287
1973	0	0.726	0.287
1974	0	0.616	0.287
1975	0	0.631	0.287
1976	0	0.671	0.311
1977	0	0.720	0.351
1978	0	0.719	0.385
1979	0	0.694	0.366
1980	0	0.624	0.348
1981	0	0.667	0.390
1982	0	0.699	0.449
1983	0	0.737	0.464
1984	0	0.776	0.521
1985	0	0.796	0.532
1986	0	0.800	0.544
1987	0	0.755	0.588
1988	0	0.793	0.640
1989	0	0.762	0.719
1990	0	0.862	0.764
1991	0	0.869	0.771
1992	0	0.882	0.811
1993	0	0.897	0.837
1994	0	0.922	0.848
1995	0	0.934	0.882
1996	0	0.948	0.906
1997	0	0.963	0.929
1998	0	0.977	0.950
1999+	0	0.980	0.950

15.2. FunctioningACFraction

The FunctioningACFraction field in the SourceTypeAge table indicates the fraction of the air-conditioning equipped fleet with fully functional A/C systems, by source type and vehicle age. A value of 1 means all systems are functional. This is used in the calculation of total energy to account for vehicles without functioning A/C systems. Default estimates were developed for all source types using the “unrepaired malfunction” rates used for 1992-and-later model years in MOBILE6. The MOBILE6 rates were based on the average rate of A/C system failure by age reported in a consumer study and assumptions about repair frequency during and after the warranty period. The MOBILE6 rates were applied to all source types except motorcycles, which were assigned a value of zero for all years.

Comment [Rev130]: There is no basis for this assumption. However, I have no better basis to provide

Table 15-2 FunctioningACFraction by Age (All Source Types except Motorcycles)

ageID	functioningACFraction
0	1
1	1
2	1
3	1
4	0.99
5	0.99
6	0.99
7	0.99
8	0.98
9	0.98
10	0.98
11	0.98
12	0.98
13	0.96
14	0.96
15	0.96
16	0.96
17	0.96
18	0.95
19	0.95
20	0.95
21	0.95
22	0.95
23	0.95
24	0.95
25	0.95
26	0.95
27	0.95
28	0.95
29	0.95
30	0.95

15.3. ACActivityTerms

In the MonthGroupHour table, ACActivityTerms A, B, and C are coefficients for a quadratic equation that calculates air conditioning activity demand as a function of the heat index. These terms are applied in the calculation of the A/C adjustment in the energy consumption calculator. The methodology and the terms themselves were originally derived for MOBILE6 and are documented in the report, *Air Conditioning Activity Effects in MOBILE6*.[75] They are based on analysis of air conditioning usage data collected in Phoenix, Arizona, in 1994.

In MOVES, ACActivityTerms are allowed to vary by monthGroup and Hour, in order to provide the possibility of different A/C activity demand functions at a given heat index by season and time of day (this accounts for differences in solar loading observed in the original data). However, for MOVES2014, the default data uses one set of coefficients for all MonthGroups and Hours. These default coefficients represent an average A/C activity demand function over the course of a full day. The coefficients are listed in Table 15-3.

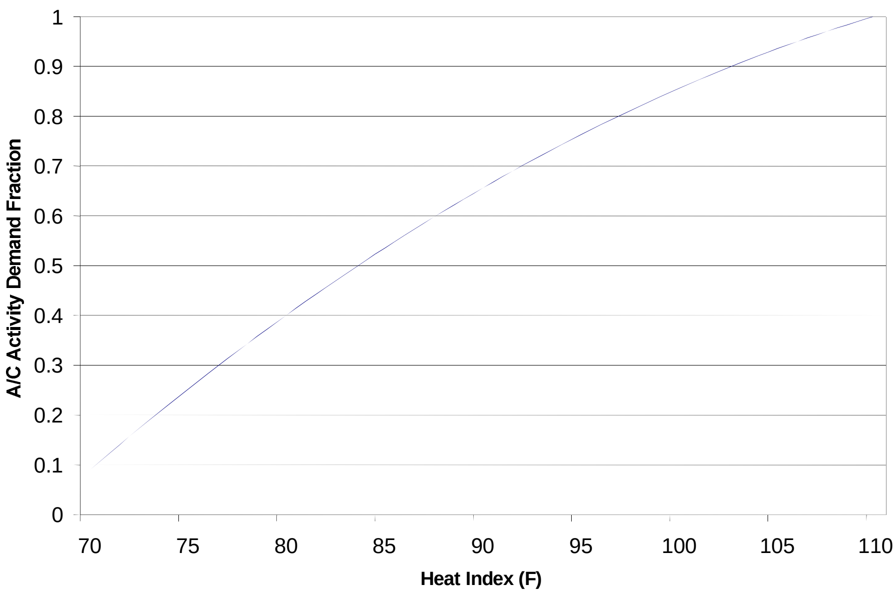
Comment [Rev131]: No basis is established for this action

Table 15-3 Air Conditioning Activity Coefficients

A	B	C
-3.63154	0.072465	-0.000276

The A/C activity demand function that results from these coefficients is shown in Figure 15-1. A value of 1 means the A/C compressor is engaged 100 percent of the time; a value of 0 means no A/C compressor engagement.

Figure 15-1 Air Conditioning Activity Demand as a Function of Heat Index



16. Conclusion and Areas for Future Research

Properly characterizing emissions from vehicles requires a detailed understanding of the cars and trucks that make up the vehicle fleet and their patterns of operation. The national default information in MOVES2014 provide a reliable basis for estimating national emissions. The most important of these inputs are well-established: base year VMT and population estimates come from long-term, systematic national measurements by US Department of Transportation. The emission characteristics for the most prevalent vehicle classes are well-known; base year age distributions are well-measured, and driving activity has been the subject of much study in recent years.

Still, the fleet and activity inputs do have significant limitations, and the uncertainties and variability in this local data can contribute significant uncertainty in resulting emission estimates. Thus it is often appropriate to replace many of the MOVES fleet and activity defaults with local data as explained in EPA's Technical Guidance.[2]

The fleet and activity defaults also are limited by the necessity of forecasting future emissions. EPA utilizes annual US Department of Energy forecasts of vehicle sales and activity, but the inputs for MOVES2014 were developed for a 2011 base year, and much of the source data is from 2011 and earlier. This information needs to be updated periodically to assure that the model defaults reflect the latest available data and projections on the US fleet.

Updating the vehicle fleet data will be complicated by the fact that one of the primary data sources for this document, the Census Bureau's Vehicle Inventory and Use Survey, has been discontinued. EPA is currently working with DOT and other federal agencies to revive this survey. Doing so becomes more important as the data gathered from the last survey (2002) ages.

A related complication is the cost of data. Collecting data on vehicle fleet and activity is expensive, especially when the data is intended to accurately represent the entire United States. Even when EPA does not generate data directly (for example, compilations of state vehicle registration data) obtaining the information needed for MOVES can be costly and, thus, dependent on budget choices.

In addition to these general limitations, there are also specific MOVES data elements that could be improved with additional research, including,

- Real-world highway driving cycles and operating mode distributions,
- Off-network behavior including vehicle starts and soaks,
- Truck hotelling, particularly extended engine idling and APU use,
- Idling while loading/unloading, in traffic queues (i.e. tolls), or elsewhere
- VSP/STP adjustments for speed, road grade, and loading,
- Activity changes with age, such as mileage accumulation rates, start activity, and soak distributions.
- Updated estimates of vehicle scrappage rates used to project vehicle age distributions
- Further incorporation of data from instrumented vehicle studies
- Summaries from large-scale instrumented vehicle studies,

- Vehicle identification and sorting by size, sector, and vocation,
- Activity weighting of source mass averages,
- Air conditioning system usage, penetration and failure rates,
- Vehicle type distinctions in temporal activity,
- Heavy truck and bus daily trip activity patterns,
- Ramp activity and operating mode distributions.

We expect many of these MOVES data limitations can be addressed through analysis of data captured on instrumented vehicles. The recent emergence and availability of large streams of activity data from GPS devices, data loggers, and other onboard diagnostic systems will likely lead to a better understanding of travel behavior. These data streams often provide frequent sampling of real-world driving for a large number of vehicles, so they are ideally suited for improving the nationally representative default inputs in MOVES. EPA is actively acquiring such data for future MOVES updates.

Future updates to vehicle population and activity defaults will need to continue to focus on the most critical elements required for national fleet-wide estimates, namely gasoline light-duty cars and trucks, and diesel heavy-duty trucks. Information collection on motorcycles, refuse trucks, motor homes, diesel light-duty vehicles and gasoline heavy-duty vehicles will be a lower priority. In addition to updating the model defaults, we will need to consider whether the current MOVES design continues to meet our modeling needs. Simplifications to the model to remove categories, such as source types or road types, might make noticeable improvements in run time without affecting the validity of fleet-wide emission estimates.

Comment [Rev132]: It would be helpful to prioritize the list above by relative importance.

At the same time, the fundamental MOVES assumption that vehicle activity varies by source type and not by fuel type or other source bin characteristic may be challenged by the growing market share of alternative fuel vehicles, such as electric vehicles, which may have distinct activity patterns. As we progress with MOVES, the development of vehicle population and activity inputs will continue to be an essential area of research.

17. Appendix A: Projected Source Type Populations by Year

Table 17-1: Source type populations (in thousands), as derived from HPMS populations in §5.2. and the age distribution algorithm in §7.1.2.2.

Year	Motorcycle	Passenger Car	Passenger Truck	Light Comm. Truck	Intercity Bus	Transit Bus	School Bus	Refuse Truck	Single Unit Short-haul	Single Unit Long-haul	Motor Home	Combination Short-haul	Combination Long-haul
2012	8571	128033	86859	21393	18	69	617	185	6194	260	1559	1191	1280
2013	8687	129764	87924	21791	19	72	643	195	6525	274	1643	1234	1332
2014	8706	130054	88014	21960	20	74	663	203	6777	285	1708	1258	1377
2015	8747	130666	88345	22167	21	77	691	213	7093	299	1788	1306	1439
2016	8844	132117	89259	22492	22	80	720	223	7392	312	1863	1354	1503
2017	8943	133583	90198	22803	22	82	740	230	7589	322	1915	1380	1555
2018	9018	134715	90934	23043	23	84	753	235	7709	328	1946	1390	1600
2019	9098	135907	91718	23279	23	86	766	239	7824	333	1977	1400	1645
2020	9178	137105	92513	23508	23	87	780	243	7953	335	2012	1410	1690
2021	9260	138317	93324	23730	24	88	794	247	8093	340	2053	1422	1737
2022	9337	139471	94098	23939	24	90	809	252	8242	345	2095	1437	1783
2023	9416	140653	94892	24150	25	92	824	256	8385	351	2134	1453	1828
2024	9498	141880	95725	24361	25	93	838	260	8510	352	2168	1466	1872
2025	9585	143179	96598	24591	26	95	853	264	8638	357	2204	1482	1918
2026	9680	144593	97557	24833	26	97	867	267	8752	362	2239	1495	1964
2027	9781	146100	98575	25092	27	98	879	269	8846	366	2266	1505	2005
2028	9888	147713	99664	25368	27	99	889	272	8927	371	2288	1514	2040
2029	9996	149317	100741	25649	27	100	900	274	9017	375	2312	1527	2073
2030	10103	150922	101823	25925	28	101	912	277	9114	376	2340	1546	2104
2031	10215	152591	102952	26209	28	103	922	280	9209	377	2368	1567	2131
2032	10328	154280	104098	26493	28	104	931	283	9286	381	2385	1585	2152
2033	10439	155930	105216	26772	28	105	942	286	9378	385	2405	1609	2174
2034	10538	157420	106225	27024	29	106	956	290	9493	391	2432	1639	2203
2035	10633	158833	107181	27263	29	108	969	293	9599	396	2457	1669	2232

2036	10724	160194	108102	27494	30	109	983	296	9698	401	2482	1701	2260
2037	10813	161523	109001	27720	30	111	996	299	9795	405	2508	1733	2288
2038	10901	162835	109888	27944	30	113	1009	301	9887	409	2532	1766	2315
2039	10983	164062	110717	28153	31	114	1021	304	9968	413	2553	1794	2342
2040	11055	165135	111441	28338	31	115	1034	306	10051	416	2573	1822	2371
2041	11155	166628	112449	28594	32	117	1047	309	10147	420	2596	1849	2402
2042	11256	168135	113466	28852	32	118	1060	312	10243	424	2620	1876	2435
2043	11357	169655	114490	29115	32	120	1074	315	10342	428	2646	1901	2470
2044	11460	171189	115523	29380	33	121	1087	318	10442	432	2672	1925	2507
2045	11564	172737	116567	29647	33	123	1101	321	10543	436	2698	1950	2544
2046	11668	174299	117620	29916	34	124	1115	324	10646	440	2725	1975	2581
2047	11774	175875	118683	30187	34	126	1129	328	10749	445	2751	2001	2619
2048	11880	177465	119756	30460	34	127	1143	331	10853	449	2778	2028	2656
2049	11988	179069	120838	30735	35	129	1158	334	10958	453	2805	2055	2695
2050	12096	180688	121931	31013	35	131	1172	337	11064	458	2832	2083	2733

18. Appendix B: Fuel Type and Regulatory Class Fractions for 1960-1981

As noted in the text, all the fuel type and regulatory class distributions in the SampleVehiclePopulation table for model year 1981 and earlier have not changed from MOVES2010b. Those fuel type distributions between 1960 and 1981 for each source type have been summarized in Table 18-1~~Table 18-1~~ and Table 18-2~~Table 18-2~~. Many of the data sources for the fuel type fractions are the same in MOVES2010b and MOVES2014. Truck diesel fractions in Table 18-1~~Table 18-1~~ are derived using a MOVES2010b sample vehicle counts dataset—similar to the MOVES2014 one—but with 1999 Polk vehicle registrations and the 1997 VIUS, except for refuse trucks and motor homes. We assumed 96 percent of refuse trucks were manufactured to run on diesel fuel in 1980 and earlier according to the average diesel fraction from VIUS across all model years. We also assumed that 15 percent of motor homes are diesel powered based on information from the Recreation Vehicle Industry Association (RVIA), as previously noted ~~above~~ in Section 6.2.2.5.

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Table 18-1 Diesel Fractions for Trucks*

	Source Type						
Model Year	**Passenger Trucks (31)**	**Light Commercial Trucks (32)**	**Refuse Trucks (51)**	**Single Unit Trucks (52 & 53)**	**Motor Homes (54)**	**Short-haul Combination Trucks (61)**	**Long-haul Combination Trucks (62)**
1960-1979	0.0139	0.0419	0.96	0.2655	0.15	0.9146	1.0000
1980	0.0124	0.1069	0.96	0.2950	0.15	0.9146	1.0000
1981	0.0178	0.0706	0.96	0.3245	0.15	0.9146	1.0000

* All other trucks are assumed to be gasoline powered

Like in MOVES2010b, lacking both emission rate and population data we assume in MOVES2014 that all motorcycles will be gasoline powered, all intercity buses will be diesel powered over all model years, and all transit buses will be run on diesel from 1960 to 1981. School bus fuel type fractions are reused from MOBILE6, originally based on 1996 and 1997 Polk data. Passenger cars are split between gasoline and diesel for 1960-1981 using the MOVES2010b sample vehicle counts dataset.

Table 18-2 Diesel Fractions for Non-truck Source Types*

	Source Type				
Model Year	**Motorcycles (11)**	**Passenger Cars (21)**	**Intercity Buses (41)**	**Transit Buses (42)**	**School Buses (43)**
1960-1974	0	0.0069	1.000	1.000	0.0087
1975	0	0.0180	1.000	1.000	0.0087
1976	0	0.0165	1.000	1.000	0.0086
1977	0	0.0129	1.000	1.000	0.0240
1978	0	0.0151	1.000	1.000	0.0291
1979	0	0.0312	1.000	1.000	0.0460
1980	0	0.0467	1.000	1.000	0.0594
1981	0	0.0764	1.000	1.000	0.2639

* All other vehicles are assumed to be gasoline powered

The 1960-1981 regulatory class distributions are difficult to represent succinctly, but they have been derived from the MOVES2010b sample vehicle counts dataset as well, with a few exceptions. Motorcycles (sourceTypeID 11 and regClassID 10) and passenger cars (sourceTypeID 21 and regClassID 20) have one-to-one relationships between source types and regulatory classes for all model years for both MOVES2010b and MOVES2014. Passenger trucks (sourceTypeID 31) and light commercial trucks (sourceTypeID 32) are split between fuel type and regulatory class (regClassID 30 and 40) as shown in Table 18-3~~Table 18-3~~.

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Table 18-3 Percentage by regulatory class and fuel type for passenger trucks (sourceTypeID 31) and light commercial truck (sourceTypeID 32)

	Passenger Trucks (31)				Light Commercial Trucks (32)			
	Gasoline		Diesel		Gasoline		Diesel	
Model Year	**LDT (30)**	**LHD (40)**	**LDT (30)**	**LHD (40)**	**LDT (30)**	**LHD (40)**	**LDT (30)**	**LHD (40)**
1960-1966	81%	19%	38%	62%	24%	76%	7%	93%
1967	90%	10%	38%	62%	72%	28%	7%	93%
1968	88%	12%	38%	62%	67%	33%	7%	93%
1969	100%	0%	38%	62%	91%	9%	7%	93%
1970	99%	1%	38%	62%	80%	20%	7%	93%
1971	96%	3%	38%	62%	94%	6%	7%	93%
1972	96%	4%	38%	62%	75%	25%	7%	93%
1973	95%	5%	38%	62%	59%	41%	7%	93%
1974	95%	5%	38%	62%	65%	35%	7%	93%
1975	97%	3%	38%	62%	72%	28%	7%	93%
1976	95%	5%	38%	62%	88%	12%	7%	93%
1977	89%	11%	38%	62%	79%	21%	7%	93%
1978	85%	15%	38%	62%	81%	19%	7%	93%
1979	87%	13%	38%	62%	78%	22%	7%	93%
1980	90%	10%	38%	62%	74%	26%	40%	60%
1981	96%	4%	38%	62%	89%	11%	12%	88%

Comment [Rev133]: The variability in these two columns is high and values are not consistent. The audience is left wondering whether the underlying basis is reasonable.

The bus and motor home source types each have a single regulatory class distribution for all model years, as described in Section 6.2.2. The 1960-1981 regulatory class distributions for diesel-fueled single unit and combination trucks have been summarized in Table 18-4~~Table 18-4~~

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below. All 1960-1981 gasoline-fueled single unit and combination trucks fall into the medium heavy-duty (MHD) regulatory class (regClassID 46).

Table 18-4 Percentage of MHD Trucks (regClassID 46) among Diesel-fueled Single Unit and Combination Trucks*

	Source Type			
Model Year	**Refuse Trucks (51)**	**Single Unit Trucks (52&53)**	**Short-haul Comb. Trucks (61)**	**Long-haul Comb. Trucks (62)**
1960-1972	100%	0%	0%	0%
1973	100%	3%	8%	0%
1974	0%	6%	30%	0%
1975	0%	14%	3%	0%
1976	0%	44%	13%	0%
1977	0%	43%	31%	0%
1978	0%	36%	18%	0%
1979	0%	34%	16%	0%
1980	0%	58%	29%	5%
1981	0%	47%	31%	6%

*For these source types, all remaining trucks are in the HHD regulatory class (regClassID 47).

19. Appendix C: 1990 Age Distributions

19.1. Motorcycles

The motorcycle age distributions are based on Motorcycle Industry Council estimates of the number of motorcycles in use, by model year, in 1990. However, data for individual model years starting from 1978 and earlier were not available. A logarithmic regression curve (R^2 value = 0.82) was fitted to available data, which was then used to extrapolate age fractions for earlier years beginning in 1978.

19.2. Passenger Cars

To ~~determine~~ estimate the 1990 age fractions for passenger cars, we began with Polk NVPP® 1990 data on car registration by model year. However, this data presents a snapshot of registrations on July 1, 1990, and we needed age fractions as of December 31, 1990. To adjust the values, we used monthly data from the Polk new car database to estimate the number of new cars registered in the months July through December 1990. Model Year 1989 cars were added to the previous estimate of “Age 1” cars and Model Year 1990 and 1991 cars were added to the “Age 0” cars. Also the 1990 data did not detail model year for ages 15+. Hence, regression estimates were used to extrapolate the age fractions for individual ages 15+ based on an exponential curve (R^2 value =0.67) fitted to available data.

19.3. Trucks

For the 1990 age fractions for passenger trucks, light commercial trucks, refuse trucks, short-haul and long-haul single unit trucks and short-haul and long-haul combination trucks, we used data from the TIUS92 (1992 Truck Inventory and Use Survey) database. Vehicles in the TIUS92 database were assigned to MOVES source types as summarized in Table 19-1. Like VIUS97, TIUS92 does not include a model year field and records ages as 0 through 10 and 11-and-greater. Because we needed greater detail on the older vehicles, we followed the practice used for the 1999 fractions and determined the model year for some of the older vehicles by using the responses to the questions “How was the vehicle obtained?” (TIUS field “OBTAIN”) and “When did you obtain this vehicle?” (TIUS field “ACQYR”) and we adjusted the age-11-and-older vehicle counts by dividing the original count by model year by the fraction of the older vehicles that were coded as “obtained new.”

Table 19-1 VIUS 1997 Codes Used for Distinguishing Truck Source Types

Source Type	Axle Arrangement	Primary Area of Operation	Body Type	Major Use
Passenger Trucks	2 axle/4 tire (AXLRE= 1,5,6,7)	Any	Any	personal transportation (MAJUSE=20)
Light Commercial Trucks	2 axle/4 tire (AXLRE= 1,5,6,7)	Any	Any	any but personal transportation
Refuse Trucks	Single Unit (AXLRE=2-4, 8-16)	Off-road, local or short-range (AREAOP <=4)	Garbage hauler (BODTYPE=30)	Any
Single Unit Short-haul Trucks	Single Unit (AXLRE=2-4, 8-16)	Off-road, local or short-range (AREAOP<=4)	Any except garbage hauler	Any
Single Unit Long-haul Trucks	Single Unit (AXLRE=2-4, 8-16)	Long-range (AREAOP>=5)	Any	Any
Combination Short-haul Trucks	Combination (AXLRE>=17)	Off-road, local or medium (AREAOP<=4)	Any	Any
Combination Long-haul Trucks	Combination (AXLRE>=17)	Long-range (AREAOP>=5)	Any	Any

19.4. Intercity Buses

For 1990, we were not able to identify a data source for estimating age distributions of intercity buses. Because the purchase and retirement of these buses is likely to be driven by general economic forces rather than trends in government spending, we will use the1990 age distributions that were derived for short-haul combination trucks, as described above.

19.5. School Buses and Motor Homes

To determine the age fractions of School Buses and Motor Homes, we used information from the Polk TIP® 1999 database. School Bus and Motor Home counts were available by model year. Unlike the Polk data for passenger cars, these counts reflect registration at the end of the calendar year and, thus, did not require adjustment. We converted model year to age and calculated age fractions. Because we did not have access to 1990 data, these fractions were used for 1990.

19.6. Transit Buses

For 1990 Transit Bus age distributions, we used the MOBILE6 age fractions since 1990 data on transit buses was not available from the Federal Transit Administration database. MOBILE6 age fractions were based on fitting curves through a snapshot of vehicle registration data as of July 1, 1996, which was purchased from R.L. Polk Company. To develop a general curve, the 1996 model year vehicle populations were removed from the sample because it did not represent a full year, and a best-fit analysis was performed on the remaining population data. The best-fit analyses resulted in age distribution estimates for vehicles ages 1 through 25+. However, since the vehicle sales year begins in October, the estimated age 1 population was multiplied by 0.75 to account for the fact that approximately 75% of the year's sales will have occurred by July 1st of a given calendar year.

Both Weibull curve fitting and exponential curve fitting were used to create the age distributions. The nature of the Weibull curve fitting formula is to produce an "S" shaped curve, which is relatively flat for the first third of the data, decreases rapidly for the next third, and flattens again for the final third. While using this formula resulted in a better overall fit for transit buses, the flatness of the final third for each curve resulted in unrealistically low vehicle populations for the older vehicle ages. For this reason, the original Weibull curve was used where it fit best, and exponential curves were fit through the data at the age where the Weibull curves began to flatten. Table 19-2 presents the equations used to create the age distribution and the years in which the equations were used.

Comment [Rev134]: The Weibull approach is typically taken to represent failures, with an initial shakeout period, a stable period, and a failure period associated with aging. The approach taken here is really curve fitting, but without a rationale behind the approach. Hence, any curve set or smoothing approach could be employed to best fit the data. One concern, discussed earlier, is that failure curves probably differ by technology and therefore model year as technologies enter the fleet over time.

Table 19-2 Curve Fit Equations for Registration Distribution by Age

Vehicle Age	Equation
1-17	$y = 3462 * e^{-\left(\left(\frac{age}{17.16909475}\right)^{12.53214119}\right)}$
18-25+	$24987.0776 * e^{-0.2000 * age}$

20. Appendix D: ~~Driving Schedules and~~ SCC Mappings

Comment [Rev135]: This text can be integrated into Section 8 rather than serving as an Appendix

~~20.1. SCC Mappings~~

The Source Classification Code (SCC) used before MOVES2014 do not cleanly map to the source types used by MOVES. In the 10-digit SCC, the first seven digits (SCC7) indicate the vehicle classification. The SCC vehicle classifications were mapped to the source types used by MOVES by calculating the fraction VMT for each source type found in each SCC classification result in a national MOVES2010b run for calendar year 2011. The factors calculated from the MOVES201b run are shown in .

Table 20-1 Mapping of Previous SCC Vehicle Classifications to MOVES Source Types for Calculation of Road Type Distributions

Comment [Rev136]: It would help the reader if you put boxes around the groups that sum to 1.

SCC (7 digits)	Description	Source Type	Description	2011 Fractions
2201001	Gasoline Light-Duty Vehicles (Passenger Cars)	21	Passenger Car	1.000000
2201020	Gasoline Light-Duty Trucks (0-6,000 lbs. GVWR)	31	Passenger Truck	0.779270
2201020	Gasoline Light-Duty Trucks (0-6,000 lbs. GVWR)	32	Light Commercial Truck	0.220730
2201040	Gasoline Light-Duty Trucks (6,001-8,500 lbs. GVWR)	31	Passenger Truck	0.779269
2201040	Gasoline Light-Duty Trucks (6,001-8,500 lbs. GVWR)	32	Light Commercial Truck	0.220731
2201070	Gasoline Heavy-Duty Gasoline Vehicles (8501 lbs. and greater GVWR)	31	Passenger Truck	0.450274
2201070	Gasoline Heavy-Duty Gasoline Vehicles (8501 lbs. and greater GVWR)	32	Light Commercial Truck	0.267803
2201070	Gasoline Heavy-Duty Gasoline Vehicles (8501 lbs. and greater GVWR)	42	Transit Bus	0.000664
2201070	Gasoline Heavy-Duty Gasoline Vehicles (8501 lbs. and greater GVWR)	43	School Bus	0.002476
2201070	Gasoline Heavy-Duty Gasoline Vehicles (8501 lbs. and greater GVWR)	51	Refuse Truck	0.000509
2201070	Gasoline Heavy-Duty Gasoline Vehicles (8501 lbs. and greater GVWR)	52	Single Unit Short-haul Truck	0.221958
2201070	Gasoline Heavy-Duty Gasoline Vehicles (8501 lbs. and greater GVWR)	53	Single Unit Long-haul Truck	0.030154
2201070	Gasoline Heavy-Duty Gasoline Vehicles (8501 lbs. and greater GVWR)	54	Motor Home	0.025802
2201070	Gasoline Heavy-Duty Gasoline Vehicles (8501 lbs. and greater GVWR)	61	Combination Short-haul Truck	0.000359
2201080	Gasoline Motorcycles	11	Motorcycle	1.000000
2230001	Diesel Light-Duty Vehicles (Passenger Cars)	21	Passenger Car	1.000000
2230060	Diesel Light-Duty Trucks (0-8,500 lbs. GVWR)	31	Passenger Truck	0.343599
2230060	Diesel Light-Duty Trucks (0-8,500 lbs. GVWR)	32	Light Commercial Truck	0.656401
2230071	Diesel Class 2b Heavy-Duty Vehicles (8501-10,000 lbs. GVWR)	31	Passenger Truck	0.364691
2230071	Diesel Class 2b Heavy-Duty Vehicles (8501-10,000 lbs. GVWR)	32	Light Commercial Truck	0.635309
2230072	Diesel Class 3, 4 & 5 Heavy-Duty Vehicles (10,001-19,500 lbs. GVWR)	31	Passenger Truck	0.305092

SCC (7 digits)	Description	Source Type	Description	2011 Fractions
2230072	Diesel Class 3, 4 & 5 Heavy-Duty Vehicles (10,001-19,500 lbs. GVWR)	32	Light Commercial Truck	0.694908
2230073	Diesel Class 6 & 7 Heavy-Duty Vehicles (19,501-33,000 lbs. GVWR)	51	Refuse Truck	0.001726
2230073	Diesel Class 6 & 7 Heavy-Duty Vehicles (19,501-33,000 lbs. GVWR)	52	Single Unit Short-haul Truck	0.623978
2230073	Diesel Class 6 & 7 Heavy-Duty Vehicles (19,501-33,000 lbs. GVWR)	53	Single Unit Long-haul Truck	0.086570
2230073	Diesel Class 6 & 7 Heavy-Duty Vehicles (19,501-33,000 lbs. GVWR)	54	Motor Home	0.025294
2230073	Diesel Class 6 & 7 Heavy-Duty Vehicles (19,501-33,000 lbs. GVWR)	61	Combination Short-haul Truck	0.194650
2230073	Diesel Class 6 & 7 Heavy-Duty Vehicles (19,501-33,000 lbs. GVWR)	62	Combination Long-haul Truck	0.067783
2230074	Diesel Class 8a & 8b Heavy-Duty Vehicles (33,001 lbs. and greater GVWR)	51	Refuse Truck	0.008531
2230074	Diesel Class 8a & 8b Heavy-Duty Vehicles (33,001 lbs. and greater GVWR)	52	Single Unit Short-haul Truck	0.100296
2230074	Diesel Class 8a & 8b Heavy-Duty Vehicles (33,001 lbs. and greater GVWR)	53	Single Unit Long-haul Truck	0.013800
2230074	Diesel Class 8a & 8b Heavy-Duty Vehicles (33,001 lbs. and greater GVWR)	54	Motor Home	0.000328
2230074	Diesel Class 8a & 8b Heavy-Duty Vehicles (33,001 lbs. and greater GVWR)	61	Combination Short-haul Truck	0.323425
2230074	Diesel Class 8a & 8b Heavy-Duty Vehicles (33,001 lbs. and greater GVWR)	62	Combination Long-haul Truck	0.553619
2230075	Diesel Buses	41	Intercity Bus	0.430859
2230075	Diesel Buses	42	Transit Bus	0.122565
2230075	Diesel Buses	43	School Bus	0.446576

21. Appendix D: Driving Schedules

~~20.2. Driving Schedules~~

A key feature of MOVES is the capability to accommodate a number of drive schedules to represent driving patterns across source type, roadway type and average speed. For the national default case, MOVES2014 employs 49 drive schedules with various average speeds, mapped to specific source types and roadway types.

T below lists the driving schedules used in MOVES2014. Some driving schedules are used for both restricted access (freeway) and unrestricted access (non-freeway) driving. Some driving schedules are used for multiple source types or multiple road types where vehicle specific information was not available.

Comment [Rev137]: Table number is missing

Table 21-12 MOVES2014 Default Driving Schedule Statistics

drive schedule id	drive schedule name	avg speed	max speed	idle time (sec)	percent of time idling	miles	time (sec)	minutes	hours
101	LD Low Speed 1	2.5	10.00	280	46.5%	0.419	602.00	10.03	0.167
153	LD LOS E Freeway	30.5	63.00	5	1.1%	3.863	456.00	7.60	0.127
158	LD High Speed Freeway 3	76.0	90.00	0	0.0%	12.264	581.00	9.68	0.161
201	MD 5mph Non-Freeway	4.6	24.10	85	29.0%	0.373	293.00	4.88	0.081
202	MD 10mph Non-Freeway	10.7	34.10	61	19.6%	0.928	311.00	5.18	0.086
203	MD 15mph Non-Freeway	15.6	36.60	57	12.6%	1.973	454.00	7.57	0.126
204	MD 20mph Non-Freeway	20.8	44.50	95	9.1%	6.054	1046.00	17.43	0.291
205	MD 25mph Non-Freeway	24.5	47.50	63	11.1%	3.846	566.00	9.43	0.157
206	MD 30mph Non-Freeway	31.5	55.90	54	5.5%	8.644	988.00	16.47	0.274
251	MD 30mph Freeway	34.4	62.60	0	0.0%	15.633	1637.00	27.28	0.455
252	MD 40mph Freeway	44.5	70.40	0	0.0%	43.329	3504.00	58.40	0.973
253	MD 50mph Freeway	55.4	72.20	0	0.0%	41.848	2718.00	45.30	0.755
254	MD 60mph Freeway	60.1	68.40	0	0.0%	81.299	4866.00	81.10	1.352
255	MD High Speed Freeway	72.8	80.40	0	0.0%	96.721	4782.00	79.70	1.328
301	HD 5mph Non-Freeway	5.8	19.90	37	14.2%	0.419	260.00	4.33	0.072
302	HD 10mph Non-Freeway	11.2	29.20	70	11.5%	1.892	608.00	10.13	0.169
303	HD 15mph Non-Freeway	15.6	38.30	73	12.9%	2.463	567.00	9.45	0.158
304	HD 20mph Non-Freeway	19.4	44.20	84	15.1%	3.012	558.00	9.30	0.155
305	HD 25mph Non-Freeway	25.6	50.70	57	5.8%	6.996	983.00	16.38	0.273
306	HD 30mph Non-Freeway	32.5	58.00	43	5.3%	7.296	809.00	13.48	0.225
351	HD 30mph Freeway	34.3	62.70	0	0.0%	21.659	2276.00	37.93	0.632
352	HD 40mph Freeway	47.1	65.00	0	0.0%	41.845	3197.00	53.28	0.888
353	HD 50mph Freeway	54.2	68.00	0	0.0%	80.268	5333.00	88.88	1.481
354	HD 60mph Freeway	59.7	69.00	0	0.0%	29.708	1792.00	29.87	0.498
355	HD High Speed Freeway	71.7	81.00	0	0.0%	35.681	1792.00	29.87	0.498
396	HD High Speed Freeway Plus 5 mph	76.7	86.00	0	0.0%	38.170	1792.00	29.87	0.498
397	MD High Speed Freeway Plus 5 mph	77.8	85.40	0	0.0%	103.363	4782.00	79.70	1.328

Table 21-12 MOVES2014 Default Driving Schedule Statistics

drive schedule id	drive schedule name	avg speed	max speed	idle time (sec)	percent of time idling	miles	time (sec)	minutes	hours
398	CRC E55 HHDDT Creep	1.8	8.24	107	42.3%	0.124	253.00	4.22	0.070
401	Bus Low Speed Urban (nominal 15 mph)	3.1	19.80	288	63.9%	0.393	451.00	7.52	0.125
402	Bus 30 mph Flow (nominal 30 mph)	11.5	33.80	109	37.5%	0.932	291.00	4.85	0.081
403	Bus 45 mph Flow (nominal 45 mph)	21.9	47.00	116	28.3%	2.492	410.00	6.83	0.114
404	New York City Bus	3.7	30.80	403	67.2%	0.615	600.00	10.00	0.167
405	WMATA Transit Bus	8.3	47.50	706	38.4%	4.261	1840.00	30.67	0.511
501	Refuse Truck Urban	2.2	20.00	416	66.9%	0.374	622.00	10.37	0.173
1009	Final FC01LOSAF Cycle (C10R04-00854)	73.8	84.43	0	0.0%	11.664	569.00	9.48	0.158
1011	Final FC02LOSDF Cycle (C10R05-00513)	49.1	73.06	34	5.0%	9.283	681.00	11.35	0.189
1017	Final FC11LOSB Cycle (C10R02-00546)	66.4	81.84	0	0.0%	9.567	519.00	8.65	0.144
1018	Final FC11LOSC Cycle (C15R09-00849)	64.4	78.19	0	0.0%	16.189	905.00	15.08	0.251
1019	Final FC11LOSD Cycle (C15R10-00068)	58.8	76.78	0	0.0%	11.922	730.00	12.17	0.203
1020	Final FC11LOSE Cycle (C15R11-00851)	46.1	71.50	1	0.1%	12.468	973.00	16.22	0.270
1021	Final FC11LOSF Cycle (C15R01-00876)	20.6	55.48	23	2.5%	5.179	905.00	15.08	0.251
1024	Final FC12LOSC Cycle (C15R04-00582)	63.7	79.39	0	0.0%	15.685	887.00	14.78	0.246
1025	Final FC12LOSD Cycle (C15R09-00037)	52.8	73.15	12	1.5%	11.754	801.00	13.35	0.223
1026	Final FC12LOSE Cycle (C15R10-00782)	43.3	70.87	0	0.0%	10.973	913.00	15.22	0.254
1029	Final FC14LOSB Cycle (C15R07-00177)	31.0	63.81	27	3.6%	6.498	754.00	12.57	0.209
1030	Final FC14LOSC Cycle (C10R04-00104)	25.4	53.09	41	8.0%	3.617	513.00	8.55	0.143
1033	Final FC14LOSF Cycle (C15R05-00424)	8.7	44.16	326	38.2%	2.066	853.00	14.22	0.237
1041	Final FC17LOSD Cycle (C15R05-00480)	18.6	50.33	114	16.1%	3.659	709.00	11.82	0.197
1043	Final FC19LOSAC Cycle (C15R08-00267)	15.7	37.95	67	7.7%	3.802	870.00	14.50	0.242

~~21.~~ 22. Appendix E: MOVES2010b Source Masses

Light-duty source masses were unchanged from MOVES2010b. In addition, the heavy-duty source masses originally come from MOVES2010b, although they have been updated as described in Section 14.1.

In MOVES2010b, weight data (among other kinds of information) were used to allocate source types to source bins using a field called weightClassID. Each source type's source mass was calculated using an activity-weighted average of their associated source bins' midpoint weights:

$$M = \frac{\sum_a \left\{ f_a \cdot \left(\frac{\sum_b \alpha_b \cdot m}{\sum_b \alpha_b} \right) \right\}}{\sum_a f_a} \qquad \text{Equation 40}$$

where M is the source mass factor for the source type, f_a is the age fraction at age a, α_b is the source bin activity fraction for source bin b, and m is the vehicle midpoint mass. Table 22-1~~Table 21-1~~ lists the vehicle midpoint mass for each weightClassID. The source bin activity fraction in MOVES2010b is a calculated value of activity based on fuel type, engine technology, regulatory class, model year, engine size, and weight class. This calculation is outside the scope of this document, but more information can be found in the MOVES2010b SDRM.

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Table 22-1 MOVES Weight Classes

WeightClassID	Weight Class Name	Midpoint Weight
0	Doesn't Matter	[NULL]
20	weight < 2000 pounds	1000
25	2000 pounds <= weight < 2500 pounds	2250
30	2500 pounds <= weight < 3000 pounds	2750
35	3000 pounds <= weight < 3500 pounds	3250
40	3500 pounds <= weight < 4000 pounds	3750
45	4000 pounds <= weight < 4500 pounds	4250
50	4500 pounds <= weight < 5000 pounds	4750
60	5000 pounds <= weight < 6000 pounds	5500
70	6000 pounds <= weight < 7000 pounds	6500
80	7000 pounds <= weight < 8000 pounds	7500
90	8000 pounds <= weight < 9000 pounds	8500
100	9000 pounds <= weight < 10000 pounds	9500
140	10000 pounds <= weight < 14000 pounds	12000
160	14000 pounds <= weight < 16000 pounds	15000
195	16000 pounds <= weight < 19500 pounds	17750
260	19500 pounds <= weight < 26000 pounds	22750
330	26000 pounds <= weight < 33000 pounds	29500
400	33000 pounds <= weight < 40000 pounds	36500
500	40000 pounds <= weight < 50000 pounds	45000
600	50000 pounds <= weight < 60000 pounds	55000
800	60000 pounds <= weight < 80000 pounds	70000
1000	80000 pounds <= weight < 100000 pounds	90000
1300	100000 pounds <= weight < 130000 pounds	115000
9999	130000 pounds <= weight	130000
5	weight < 500 pounds (for MCs)	350
7	500 pounds <= weight < 700 pounds (for MCs)	600
9	700 pounds <= weight (for MCs)	700

The following sections detail how weight classes were assigned to the various source types in MOVES.

~~21.1.~~ 22.1. Motorcycles

The Motorcycle Industry Council "Statistical Annual" provides information on displacement distributions for highway motorcycles for model years 1990 and 1998. These were mapped to MOVES engine displacement categories. Additional EPA certification data was used to establish displacement distributions for model year 2000. We assumed that displacement distributions were the same in 1969 as in 1990, and interpolated between the established values to ~~determine~~ estimate displacement distributions for all model years from 1990 to 1997 and for 1999. Values for 2000-and-later model years are based on model year 2000 certification data.

We then applied weight distributions for each displacement category as suggested by EPA motorcycle experts. The average weight estimate includes fuel and rider. The weight distributions depended on engine displacement but were otherwise independent of model year. This information is summarized in Table 22-2~~Table 21-2~~.

Table 22-2 Motorcycle Engine Size and Average Weight Distributions for Selected Model Years

Displacement Category	1969 MY distribution (assumed)	1990 MY distribution (MIC)	1998 MY distribution (MIC)	2000 MY distribution (certification data)	Weight distribution (EPA staff)
0-169 cc (1)	0.118	0.118	0.042	0.029	100%: <= 500 lbs
170-279 cc (2)	0.09	0.09	0.05	0.043	50%: <= 500 lbs 50%: 500lbs -700lbs
280+ cc (9)	0.792	0.792	0.908	0.928	30%: 500 lbs-700 lbs 70%: > 700lbs

~~21.2.~~ 22.2. Passenger Cars

Passenger car weights come from Polk. The weightClassID was assigned by adding 300 lbs to the Polk curb weight and grouping into MOVES weight bins. For each fuel type, model year, engine size, and weight bin, the number of cars was summed and fractions were computed. In general, entries for which data was missing were omitted from the calculations. Also, analysis indicated a likely error in the Polk data (an entry for 1997 gasoline-powered Bentleys with engine size 5099 and weight class 20). This fraction was removed and the 1997 values were renormalized. 1999 model year values were used for all 2000-and-later model years.

Comment [Rev138]: Basis not explained.

~~21.3.~~ 22.3. General Trucks

~~21.3.1.~~ 22.3.1. Light-Duty Trucks

~~Determining~~ Estimating weight categories for light trucks was fairly complicated. The VIUS 1997 data combines information from two different survey forms. The first form was administered for VIUS "Strata" 1 and 2 trucks: pickup trucks, panel trucks, vans (including mini-vans), utility type vehicles (including jeeps) and station wagons on truck chassis. The second form was administered for all other trucks. While both surveys requested information on engine size, only the second form requested detailed information on vehicle weight. Thus for Strata 1 and 2 trucks, VIUS classifies the trucks only by broad average weight category (AVGCK): 6,000 lbs or less, 6,001-10,000 lbs, 10,001-14,000lbs, etc. To ~~determine~~ develop a more detailed average engine size and weight distribution for these vehicles, we used an Oak Ridge National Laboratory (ORNL) light-duty vehicle database, compiled from EPA test vehicle data and Ward's Automotive Inc.[76] data, to correlate engine size with vehicle weight distributions by model year.

Comment [Rev139]: Explain that the data are used in generating their annual energy reports and add citation

In particular, for source types 31 and 32 (Passenger Trucks and Light Commercial Trucks):

- VIUS 1997 trucks of the source type in Strata 3, 4, and 5 were assigned to the appropriate MOVES weight class based on VIUS detailed average weight information.
- VIUS 1997 trucks of the source type in Strata 1 and 2 were identified by engine size and broad average weight category.
- Strata 1 and 2 trucks in the heavier (10,001-14,000 lbs, etc.) VIUS 1997 broad categories were matched one-to-one with the MOVES weight classes.
- For trucks in the lower broad categories (6,000 lbs or less and 6001-10,000 lbs), we used VIUS 1997 to determine the fraction of trucks by model year and fuel type that fell into each engine size/broad weight class combination (the "VIUS fraction")

- We assigned trucks in the ORNL light-duty vehicle database to a weightClassID by adding 300 lbs to the recorded curb weight and determining the appropriate MOVES weight class.
- For the trucks with a VIUS 1997 average weight of 6,000 lbs or less, we multiplied the VIUS 1997 fraction by the fraction of trucks with a given weightClassID among the trucks in the ORNL database that had the given engine size and an average weight of 6,000 lbs or less. Note, the ORNL database did not provide information on fuel type, so the same distributions were used for all fuels.
- Because the ORNL database included only vehicles with a GVW up to 8500 lbs, we did not use it to distribute the trucks with a VIUS 1997 average weight of 6,001-10,000 lbs. Instead these were distributed equally among the MOVES weightClassID 70, 80, 90 and 100.

Comment [Rev140]: Add basis as noted earlier

~~21.3.2.~~ 22.3.2. Single Unit Trucks

Source types 52 and 53 (Long- and Short-haul Single Unit Trucks) also included some trucks in VIUS 1997 Strata 1 and 2, thus a similar algorithm was applied.

- VIUS 1997 trucks of the source type in Strata 3, 4, and 5 were assigned to the appropriate MOVES weight class based on VIUS 1997 detailed average weight information.
- VIUS 1997 trucks of the source type in Strata 1 and 2 were identified by engine size and broad average weight category.
- Strata 1 and 2 trucks in the heavier (10,001-14,000 lbs, etc) VIUS 1997 broad categories were matched one-to-one with the MOVES weight classes.
- For trucks in the lower broad categories (6,000 lbs-or-less and 6001-10,000 lbs), we used VIUS 1997 to ~~determine~~ estimate the fraction of trucks by model year and fuel type that fell into each engine size/broad weight class combination (the "VIUS fraction")
- We did not believe the ORNL light-duty vehicle database adequately represented single unit trucks. Thus, the trucks with a VIUS 1997 average weight of 6,000 lbs or less and an engine size less than 5 liters were distributed equally among the MOVES weight classes 20, 25, 30, 35, 40, 45, 50, and 60. Because no evidence existed of very light trucks among the vehicles with larger engines (5 liter or larger), these were equally distributed among MOVES weight classes 40, 45, 50 and 60.
- The trucks with a VIUS 1997 average weight of 6,001-10,000 lbs were distributed equally among the MOVES weight classes 70, 80, 90 and 100.

~~21.3.3.~~ 22.3.3. Combination Trucks

Long- and short-haul combination trucks (source types 61 and 62) did not include any vehicles of VIUS 1997 Strata 1 or 2. Thus we used the detailed VIUS 1997 average weight information and engine size information to assign engine size and weight classes for all of these trucks.

When VIUS2002 became available, we updated values that had been based on VIUS1997. The VIUS 2002 contains an estimate of the average weight (vehicle weight plus cargo weight) of 1998-2002 model year vehicle or vehicle/trailer combination as it was most often operated when carrying a typical payload during 2002. These estimates were used to determine the MOVES weightClassID categories for these trucks. Table 4-5 shows the weight ranges used for each weightClassID. Any vehicles with a zero or missing value for the average weight and without a weight classification in the WeightAvgCK field were excluded from the analysis for determining the average weight distributions.

Since there is a smaller number of gasoline trucks among the single unit and refuse trucks, all model years (1998-2002) were combined to determine a single weight distribution to use for these model years.

The VIUS1997 based estimates were retained for light-duty trucks (source types 31 and 32) and for all model years prior to 1998.

In cases where distributions were missing (no survey information), distributions from a nearby model year with the same source type was used. Weight distributions for all 2003 and newer model years were set to be the same as for the 2002 model year for each source type.

21.4. 22.4. Buses

For intercity buses, we used information from Table II-7 of the FTA 2003 Report to Congress[41] that specified the number of buses in various weight categories. This information is summarized in below in Table 22-3Table 21-3. Note the FTA uses the term “over-the-road bus” to refer to the class of buses roughly equivalent to the MOVES intercity bus category. The FTA weight categories were mapped to the equivalent MOVES weight classes.

Table 22-3 FTA Estimate of Bus Weights

Weight (lbs)	MOVES Weight ClassID	MOVES Weight Range (lbs)	Number of buses (2000)	Bus type
0-20,000			173,536	school & transit
20,000-30,000			392,345	school & transit
30,000-40,000	400	33,000-40,000	120,721	school & transit & intercity
40,000-50,000	500	40,000-50,000	67,905	Intercity
total			754,509	

Table 22-4 1999 Bus Population Comparisons

Data Source	Total Buses	Intercity Buses	Transit Buses	School Buses
FHWA MV-1	732,189			
FHWA MV-10 (excludes PR)	728,777			592,029*
FHWA adjusted for PR				594,800
FTA NTD			55,706	
APTA[77] ***			75,087	
Polk TIP®				460,178
School Bus Fleet Fact Book				429,086
Motorcoach Census[40]**		44,200		

* Includes some church & industrial buses.
** Includes Canada.

*** Includes trolleybuses.

Using the 1999 bus population estimates in Table 22-4Table 21-4, we were able to estimate the fraction of all buses that were intercity buses and then to estimate the fraction of intercity buses in each weight bin. In particular:

Estimated number of intercity buses in 2000:

754,509 * (84,454/(84,454+55,706+592,029)) = 87,028

Estimated number of intercity buses 30,000-40,000 lbs:

87,028 - 67,905 = 19,123

Estimated intercity bus weight distribution:

Class 400 = 19,123/87,028 = 22%
Class 500 = 67,905/87,028 = 78%

This distribution was used for all model years.

For transit buses, we took average curb weights from Figure II-6 of the FTA Report to Congress[41] and added additional weight to account for passengers and alternative fuels. The resulting in-use weights were all in the range from 33,850 to 40,850. Thus all transit buses were assigned to the weight class "400" (33,000 - 40,000 lbs) for all model years. This estimate could be improved if more detailed weight information for transit buses becomes available.

Comment [Rev141]: Indicate how much weight for each assumption.

For school buses, we used information from a survey of California school buses. While this data is older and may not be representative of the national average distribution, it was the best data source available. The California data[78] provided information on number of vehicles by gross vehicle weight class and fuel as detailed in Table 22-5Table 21-5.

Table 22-5 California School Buses

	Gas	Diesel	Other	Total
LHDV	2740	4567	8	7315
MHDV	467	2065	2	2534
HHDV	892	11639	147	12678
Total	4099	18271	157	

To estimate the distribution of average weights among the MOVES weight classes, we assumed that the Light Heavy-Duty (LHDV) school buses were evenly distributed among weightClassIDs 70, 80, 90, 100, and 140. Similarly, we assumed the Medium Heavy-Duty (MHDV) school buses were evenly distributed among weightClassIDs 140, 160, 195, 260, and 330 and the Heavy Heavy-Duty (HHDV) school buses were evenly distributed among weightClassIDs 195, 260, 330, and 440.

The final default weight distributions for buses are summarized in Table 22-6Table 21-6.

Table 22-6 Weight Distributions for Buses by Fuel Type

	Intercity Buses (41)	Transit Buses (42)	School Buses (43)	
Weight Class	**Diesel**	**Diesel & Gas**	**Diesel**	**Gas**
70			0.0500	0.1337
80			0.0500	0.1337
90			0.0500	0.1337
100			0.0500	0.1337
140			0.0726	0.1565
160			0.0226	0.0228
195			0.1819	0.0772
260			0.1819	0.0772
330			0.1819	0.0772
400	0.2197	1.0000	0.1593	0.0544
500	0.7800			

~~21.5.~~ 22.5. Refuse Trucks

Because the sample of Refuse Trucks in VIUS was small, the weight distributions were calculated for model year groups rather than individual model years. As for other trucks, the WeightClass was determined from the VIUS reported average weight.

Table 22-7 Refuse Truck SizeWeight Fractions by Fuel Type

Gasoline							
Engine Size	**Weight (lbs.)**	**Pre-1997**	**1997 and Newer**				
3-3.5L	5000-6000	0.009074	0				
>5L	7000-8000	0.148826	0				
>5L	9000-10000	0.070720	0				
>5L	10000-14000	0.135759	0.324438				
>5L	14000-16000	0.199961	0.593328				
>5L	16000-19500	0.055085	0				
>5L	19500-26000	0.205341	0				
>5L	26000-33000	0.022105	0				
>5L	33000-40000	0.153129	0				
>5L	50000-60000	0	0.082234				
Sum		**1.000000**	**1.000000**				
Diesel							
Engine Size	**Weight (lbs.)**	**Pre-1998**	**1998**	**1999**	**2000**	**2001**	**2002 and Newer**
3.5-4L	10000-14000	0.007758	0	0	0	0	0
4-5L	10000-14000	0	0	0	0	0	0.006614
4-5L	14000-16000	0	0	0	0.015505	0	0
4-5L	16000-19500	0	0	0	0	0.011670	0
>5L	9000-10000	0.006867	0.009593	0	0	0	0
>5L	10000-14000	0.011727	0	0	0	0.019438	0
>5L	14000-16000	0.022960	0	0	0	0	0
>5L	16000-19500	0.063128	0	0.011367	0.047200	0	0
>5L	19500-26000	0.099782	0.035378	0.026212	0.052132	0.018329	0.026079
>5L	26000-33000	0.102077	0.019625	0.067419	0.072106	0.043877	0
>5L	33000-40000	0.237485	0.103922	0.088975	0.085991	0.042678	0.046966
>5L	40000-50000	0	0.283642	0.275467	0.165624	0.266357	0.194716
>5L	50000-60000	0.336484	0.338511	0.326902	0.384612	0.315133	0.474469
>5L	60000-80000	0.111730	0.196424	0.193238	0.176831	0.282517	0.224995
>5L	80000-100000	0	0	0.010420	0	0	0.013081
>5L	100000-130000	0	0.012904	0	0	0	0.013081
Sum		**1.000000**	**1.000000**	**1.000000**	**1.000000**	**1.000000**	**1.000000**

~~21.6.~~ 22.6. Motor Homes

No detailed information was available on average engine size and weight distributions for motor homes. We assumed all motor home engines were 5 L or larger. As a surrogate for average weight, we used information on gross vehicle weight provided in the Polk TIP® 1999 database by model year and mapped the Polk GVW Class to the MOVES weight bins. These values are likely to overestimate average weight. The Polk TIP® information did not specify fuel type, so we assumed that the heaviest vehicles in the Polk database were diesel-powered and the remainder were powered by gasoline. This led to the weight distributions in Table 22-8~~Table 21-8~~ and Table 22-9~~Table 21-9~~.

Comment [Rev142]: Explain why this is likely to over-estimate

Comment [Rev143]: I don't recall that this was mentioned earlier and it probably should be.

Table 22-8 Weight Fractions for Diesel Motor Homes by Model Year

Polk GVW bin	3	4	5	6	7	8
MOVES weight class	140	160	195	260	330	400
Model Year	Diesel					
1975-and-earlier	0.171431	0.792112	0.029828	0	0.006629	0
1976	0.637989	0.340639	0.018755	0.000436	0.002181	0
1977	0.68944	0.292308	0.012168	0.000277	0.005531	0.000277
1978	0.423524	0.574539	0	0.000387	0.00155	0
1979	0.096922	0.899344	0	0.001067	0.002667	0
1980	0.462916	0.537084	0	0	0	0
1981	0	0.941973	0	0.030174	0	0.027853
1982	0	0.868333	0	0.049	0.03	0.052667
1983	0	0.912762	0.000203	0.014845	0.030096	0.042094
1984	0	0.932659	0.000835	0.009183	0.036732	0.020592
1985	0	0.881042	0.001474	0.010761	0.083285	0.023438
1986	0	0.855457	0.013381	0.022962	0.089534	0.018667
1987	0	0.791731	0.085493	0.022498	0.087164	0.013113
1988	0	0.72799	0.148917	0.015469	0.093335	0.014289
1989	0	0.73298	0.128665	0.043052	0.082792	0.012511
1990	0	0.173248	0.614798	0.043628	0.149939	0.018387
1991	0	0	0.619344	0.063712	0.296399	0.020545
1992	0	0	0.551548	0.01901	0.385085	0.044356
1993	0	0	0.345775	0.471873	0.144844	0.037509
1994	0	0	0.45546	0.354386	0.159622	0.030531
1995	0	0	0.635861	0.163195	0.17468	0.026264
1996	0	0	0.553807	0.229529	0.184208	0.032456
1997	0	0	0.666905	0.193167	0.111299	0.028628
1998	0	0	0.267	0.335069	0.357508	0.040423
1999+	0	0	0	0.736656	0.233886	0.029458

Table 22-9 Weight Fractions for Gasoline Motor Homes by Model Year

Polk GVW bin	3	4	5	6	7	8
MOVES weight class	140	160	195	260	330	400
Model Year	Gasoline					
1975-and-earlier	1	0	0	0	0	0
1976	1	0	0	0	0	0
1977	1	0	0	0	0	0
1978	1	0	0	0	0	0
1979	1	0	0	0	0	0
1980	1	0	0	0	0	0
1981	0.747723	0.252277	0	0	0	0
1982	0.732235	0.267765	0	0	0	0
1983	0.714552	0.285448	0	0	0	0
1984	0.641577	0.358423	0	0	0	0
1985	0.692314	0.307686	0	0	0	0
1986	0.720248	0.279752	0	0	0	0
1987	0.606635	0.393365	0	0	0	0
1988	0.459429	0.540571	0	0	0	0
1989	0.551601	0.448399	0	0	0	0
1990	0.543354	0.456646	0	0	0	0
1991	0.612025	0.322022	0.065952	0	0	0
1992	0.54464	0.373999	0.081361	0	0	0
1993	0.583788	0.361277	0.054935	0	0	0
1994	0.481099	0.361146	0.157755	0	0	0
1995	0.52997	0.198479	0.271551	0	0	0
1996	0.435959	0.289453	0.274588	0	0	0
1997	0.221675	0.433334	0.344991	0	0	0
1998	0.288222	0.581599	0.13018	0	0	0
1999+	0.170133	0.392451	0.288411	0.149004	0	0

~~References~~

Comment [Rev144]: There appears to be some problem with formatting here.

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References

[1] MOVES technical reports are available online on the US EPA website (http://www.epa.gov/oms/models/moves/moves-reports.htm). Please refer to the MOVES2009 or 2010 report for any MOVES2014 report that has not been finalized and published.

[2] US Environmental Protection Agency (EPA), Office of Transportation and Air Quality, *MOVES2014 Technical Guidance: Using MOVES to Prepare Emission Inventories for State Implementation Plans and Transportation Conformity*, EPA-420-B-15-007, Ann Arbor, MI: January 2015, http://www.epa.gov/otaq/models/moves/documents/420b15007.pdf.

[3] US EPA, *Exhaust Emission Rates for Light-Duty On-road Vehicles in MOVES2014*, EPA-420-R-15-005, Ann Arbor, MI: 2015, http://www.epa.gov/otaq/models/moves/moves-reports.htm.

[4] US EPA, *Exhaust Emission Rates for Heavy-Duty On-road Vehicles in MOVES2014*, EPA-420-R-15-004, Ann Arbor, MI: 2015, http://www.epa.gov/otaq/models/moves/moves-reports.htm.

[5] US EPA, *Fuel Supply Defaults: Regional Fuels and the Fuel Wizard in MOVES2014*, EPA-420-R-15-002, Ann Arbor, MI: 2015, http://www.epa.gov/otaq/models/moves/moves-reports.htm.

[6] US EPA, *Development of Gasoline Fuel Effects in the Motor Vehicle Emissions Simulator (MOVES2009)*, EPA-420-P-09-004, Ann Arbor, MI: August 2009, http://www.epa.gov/otaq/models/moves/techdocs/420p09004.pdf.

[7] Community Modeling and Analysis Center (CMAS) and Center for Environmental Modeling for Policy Development, University of North Carolina at Chapel Hill, Sparse Matrix Operator Kernel Emission (SMOKE), last updated 28 May 2015, https://www.cmascenter.org/smoke.

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