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A COMPARISON OF EMISSIONS-REDUCTION STRATEGIES TO IMPROVE
LIVABILITY IN FREIGHT-CENTRIC COMMUNITIES

by

James Lewis Mersereau

A Thesis

Submitted in Partial Fulfillment of the
Requirement for the Degree of
Master of Science

Major: Civil Engineering

The University of Memphis

December 2014

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Dedication

This work is dedicated to my family, with special recognition for my wife, who has supported me daily in my pursuits.

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Mr. Christopher Boyd, Air Quality Specialist, Pollution Control Section, Shelby County Health Department.

Abstract

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In 2009, the U.S. Department of Transportation, the U.S. Environmental Protection Agency, and the U.S. Department of Housing and Urban Development entered into an interagency “Partnership for Sustainable Communities” to cooperatively increase transportation mode choices while reducing transportation costs, protecting the environment, and providing greater access to affordable housing through the incorporation of six principals of livability (U.S. Department of Transportation, 2014a). This study focuses on strategies to reduce vehicle emissions and improve livability along the Lamar Corridor in Memphis, Tennessee, a location that was designated by the U.S. Government in 2010 as an area to be targeted for livability improvements (Daniels & Meeks, 2010). The results of this study indicate that a common method to reduce emissions at freight terminals, a typical facility along the Lamar Corridor, may actually increase emissions along the corridor itself. Additionally, specific emphasis on the use of alternative fuels as a method to reduce emissions may be warranted.

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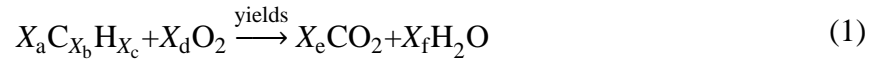
A Comparison of Emissions-Reduction Strategies to Improve Livability in Freight-Centric Communities

Introduction

In 2009, the U.S. Department of Transportation, the U.S. Environmental Protection Agency, and the U.S. Department of Housing and Urban Development entered into an interagency “Partnership for Sustainable Communities” at the direction of President Barack Obama in order to cooperatively increase transportation mode choices while reducing transportation costs, protecting the environment, and providing greater access to affordable housing through the incorporation of the six principals of livability (U.S. Department of Transportation, 2014a). These six principals include: providing more transportation choices; promoting equitable, affordable housing; enhancing economic competitiveness; supporting existing communities; coordinating and leveraging federal policies and investment; and valuing communities and neighborhoods (U.S. Department of Transportation, 2014a).

According to the Federal Highway Administration, “livability in transportation is about leveraging the quality, location, and type of transportation facilities and services available to help achieve broader community goals such as... enhancing the natural environment through... enhanced air quality, and decreased green house [sic] gasses” (Rue et al., 2011, p. 6). Transportation accounts for 71% of petroleum consumption in the United States, with non-light duty vehicles accounting for half of this (U.S. Department of Energy, 2013n). Additionally, expected growth in freight demand by 2050 would effectively double the fuel consumption at current vehicle efficiency levels (U.S. Department of Energy, 2013n). Both diesel and gasoline, derived from petroleum,

function as fuels in internal combustion engines through the combustion of hydrocarbons (Piecyk, Cullinane, & Edwards, 2012, p. 32). In each case, perfect combustion would result in



where X represents the appropriate coefficients and subscripts to balance the equation and a through f denoting potentially different values of X . Diesel equates to hydrocarbons with a carbon content ranging from C_8 to C_{25} and gasoline equates to hydrocarbons with a carbon content ranging from C_4 to C_{12} (U.S. Department of Energy, 2013f).

Unfortunately, due to incomplete combustion and the inclusion of other chemicals in the fuels, other products exist, namely particulate matter (PM), heavy metals (HM), ammonia (NH_3), sulfur dioxide (SO_2), oxides of nitrogen (NO_x), volatile organic compounds (VOC), carbon monoxide (CO), methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O) (Piecyk, Cullinane, & Edwards, 2012, p. 34). According to Piecyk et al. (2012), these pollutants can affect the environment on three distinct levels: global, regional, and local (p. 34). Globally, NO_x , VOC, CO, CH_4 , CO_2 , and N_2O all serve as greenhouse gasses (GHGs) whereby airborne particles retain radiant energy within the atmosphere, contributing to global warming (Piecyk et al., 2012, pp. 34-35). Regionally, NH_3 , SO_2 , and NO_x all contribute to the formation of acid rain, while NO_x , VOC, and CO all cause smog (Piecyk et al., 2012, pp. 34, 36). Finally, on a local level, a variety of effects can occur from the pollution, as shown in Table 1.

Table 1

Local Effects from Diesel and Gasoline Combustion

Cause	Effect
NO _x	Emphysema
Uncombusted Hydrocarbons, VOC	Cancer
NO _x and VOC forming Ozone (O ₃)	Respiratory problems and nausea
PM	Respiratory problems, cardiovascular problems, asthma, cancer
CO	Cardiovascular problems
SO ₂	Eye, ear, nose, and throat irritation; respiratory problems

Note. Adapted from “Assessing the external impacts of freight transport,” pp. 34-37, by M. Piecyk, S. Cullinane, & J. Edwards in A. McKinnon, M. Brown, & A. Whiteing (Eds.), *Green Logistics: Improving the Environmental Sustainability of Logistics*, 2012, London: Kogan Page.

With the significant contribution of freight transportation to air emissions, it is important to consider strategies to reduce these negative externalities on community livability. One strategy is to tackle emissions through environmental public policy. Another is to address the issue through the typical freight transportation planning process. Freight transportation planning typically occurs on three levels: short-term or operational planning, medium-term or tactical planning, and long-term or strategic planning (Böse, 2011, p. 4). Short-term or operational planning relates to day-to-day operations decisions, medium-term or tactical planning relates to basic resource strategy, and long-term or strategic planning relates to decisions about the services offered (Böse, 2011, p. 4). Research has been done on the effectiveness of various emissions-reduction strategies at the various levels: on the operational level, this typically concerns techniques to modify driver behavior; on the tactical level, this typically concerns techniques to optimize the utilization of existing resources. On the strategic level, fleet renewal serves as the principal strategy. It should be clarified that in this context, fleet renewal does not

refer to incremental improvement of vehicles (an optimization of existing equipment – tactical level planning), but replacement. Fleet renewal would be considered strategic level planning due to barriers that can limit a business' services offered, especially if alternative fueled vehicles are considered. Due to the variety of players involved in the typical supply chain, the low number of fueling stations available for alternatively fueled vehicles, variation of tax incentives across the country, and the limited number of heavy-duty vehicles available, adoption of alternatively fueled heavy-duty vehicles has not been widespread outside of short-haul use in transit, garbage removal, and last-mile delivery (Cardwell & Krauss, 2013).

However, despite these limitations, the current low-cost of natural gas due to hydraulic fracturing within the United States is pushing an expansion of the use of the fuel in the transportation sector (Cardwell & Krauss, 2013). The United States Energy Information Administration expects under ideal market conditions, natural gas vehicles could potentially account for 32% of heavy-duty vehicles by 2035, up from 0.2% in 2010 (U.S. Department of Energy, 2012a, p. 40). Citigroup more aggressively forecasts that 30% of heavy-duty vehicles would run on natural gas by 2020 (Cardwell & Krauss, 2013). The comparative low-cost of alternative fuels has not only lead to customers pressuring transportation providers to investigate its usage, notably by Walmart and Nike, but providers have begun to recognize the benefits as well (Cardwell & Krauss, 2013). United Parcel Service of America, Inc. (UPS), after extensive study, has announced plans to shift 1 billion vehicle miles to alternatively fueled vehicles by 2017, and to do so, it is purchasing natural gas long-haul vehicles, partnering with fuel providers to help build-out the natural gas infrastructure, and purchasing electric short-haul vehicles (Goossens,

2013). UPS' chief sustainability officer indicated that the company expects to achieve a 40% cost reduction within its trucking fleet through these changes (Goossens, 2013).

Although natural gas has received much press due to hydraulic fracturing, a variety of alternatively fueled medium- and heavy-duty vehicles are currently in use in the United States. According to the United States Energy Information Administration, the following breakdown shown in Figure 1 of alternatively fueled medium- and heavy-duty vehicles existed nationally in 2011, the year for which the most current data is available.

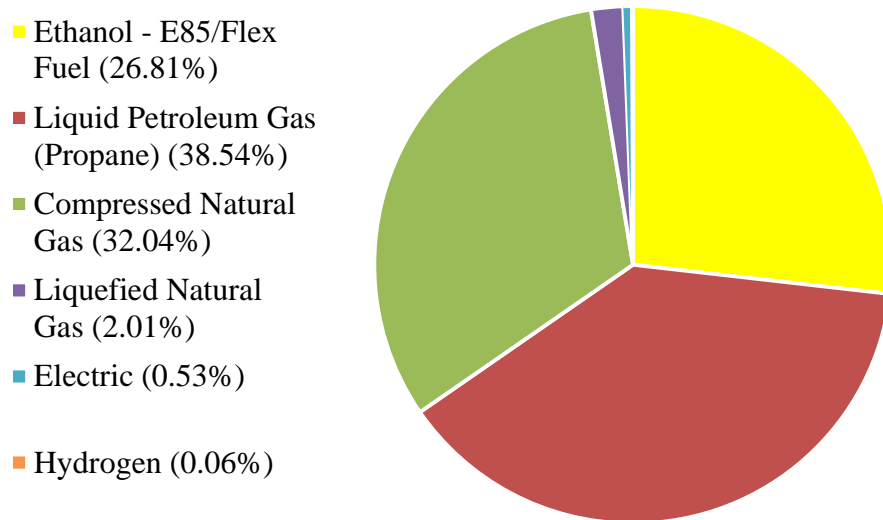


Figure 1. Alternatively Fueled Medium- and Heavy-Duty Vehicles by Fuel Type. Data adapted from *How many alternative fuel and hybrid vehicles are there in the U.S.?* by the U.S. Energy Information Administration, May 16, 2013.

With growth in the usage of alternative fuels projected among medium- and heavy-duty vehicles, strategic level fleet replacement must be considered a practical possibility.

Concerning the tactical level, the optimization of existing resources, significant savings can be made. Tactical level decisions typically focus on two areas, dispatch and

maintenance, and aim to eliminate unnecessary fuel consumption. Proper regular maintenance, such as proper tire inflation, using the recommended oil, and engine tune-ups can effect a vehicle's fuel economy up to 40% (U.S. Department of Energy, 2012b). Providing incremental retrofits to vehicles during regular maintenance can also result in improvements. For example, many long-haul truck drivers resting due to legal requirements idle their engines overnight to provide electricity, heating, and cooling at a cost of 685 million gallons per year (Gaines, Vyas, & Anderson, 2006, pp. 94-95). Equipping these vehicles with idle-reduction technologies like shore power connections during regular maintenance periods can reduce this consumption. Work-day idling, which typically occurs when drivers attempt to process paperwork, eat lunch, obtain loading dock assignments, wait for access to terminal facilities, wait for inspections, and during loading and unloading accounts for a cost of 2.49 billion gallons per year (Gaines et al., 2006, pp. 95-96). To eliminate work-day idling, dispatch techniques can be employed. Walmart utilizes drop-and-hook to eliminate delays associated with loading and unloading at its facilities, while gate scheduling and take-a-number systems allow for vehicles to be turned off while waiting for access to terminals due to the elimination of uncertainty of facility availability (Gaines et al., 2006, p. 96). Additional dispatch techniques such as route optimization have resulted in significant savings: UPS eliminated 63.5 miles of superfluous driving (U.S. Department of Energy, 2013m).

The city of Memphis, Tennessee is a major freight transportation hub due to its geographic location near the center of the United States, access to five Class I railroads, the second largest cargo airport in the world, and the fourth largest inland port in the United States (Airports Council International, 2014, p. 4; Intermodal Freight

Transportation Institute, 2012; Port of Memphis, 2014). The Lamar Corridor is a 6.5 mile section of U.S. Highway 78 in Memphis that travels from I-240 south toward the Tennessee-Mississippi border. The area is home to the Memphis International Airport, the FedEx World Hub, the BNSF Railway Memphis Intermodal Facility, as well as other manufacturing, warehouse, and commercial land uses that generate high levels of freight traffic (Cambridge Systematics, Inc., 2011). The Lamar Corridor is highlighted in red in Figure 2.

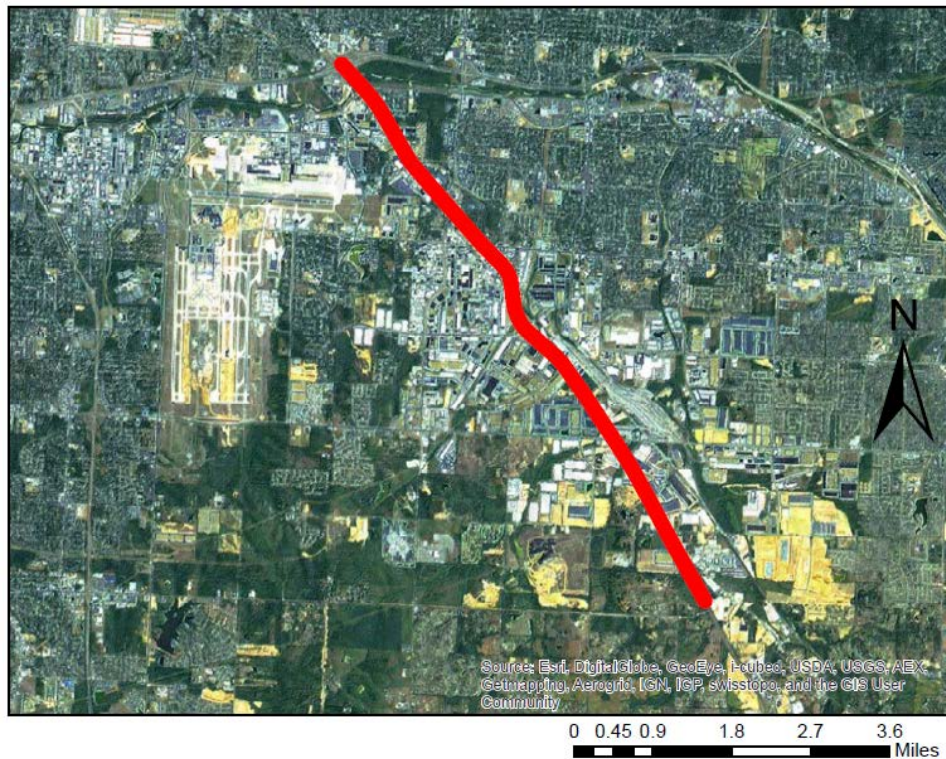


Figure 2. Lamar Corridor in Memphis, Tennessee

The area has been recognized by the Partnership for Sustainable Communities as a target area for livability improvements due to “blight, concentrated poverty and crime, and poor aesthetics and connectivity” due to poor land use planning in the area resulting with

neighborhoods being juxtaposed with the previously mentioned industrial and commercial activities (U.S. Department of Transportation, 2014b). This identification resulted in funding the Aerotropolis/Lamar Corridor Initiative at a level of \$1,260,905 through the U.S. Housing and Urban Development and the U.S. Department of Transportation grants in 2010 to study planning methods to improve livability in the area (Daniels & Meeks, 2010).

In order to examine the impact at both the tactical level and strategic level of techniques to reduce air pollution due to freight activity, traffic microsimulations will be conducted of the freight-centric Lamar Avenue Freight Corridor (U.S. Highway 78) utilizing Quadstone Paramics. Strategically, fleet renewal can be simulated as the vehicle types in the model can be changed. Tactically, dispatch decisions can be modeled through smoothing the medium- and heavy-duty demand on the network in order to simulate a constant arrival pattern at terminal facilities, thus avoiding congestion at the gate. Due to uncertainty regarding driver behavior, simulations at the operational level will not be conducted. Subsequently, the travel data outputs will be imported into the U.S. Environmental Protection Agency's Motor Vehicle Emission Simulator (MOVES) for evaluation. Modeled scenarios will include the base scenario (no gate strategies, complete reliance on gasoline/diesel), adoption of gate strategies, and adoption of various alternative fueled vehicles (hydrogen, LNG, CNG, biodiesel, propane, E85 "Flex Fuel", and electric). Based upon the currently available alternative fuel stations in the Mid-South region and available medium- and heavy-duty vehicles, an attempt will be made to simulate a typical mixed alternative fueled fleet serving the Memphis-area. Finally, a cost analysis will be performed to assess the impact of each scenario, utilizing the

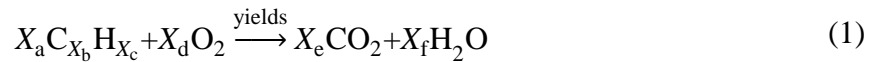
methodology derived by Piecyk, McKinnon, and Allen with the Chartered Institute of Logistics and Transport (UK) (2012). In this way, the effectiveness of the implementation of strategic and tactical changes to improve air quality along the Lamar Corridor may be evaluated.

Literature Review

With the significant contribution of freight transportation to air emissions, it is important to consider strategies to reduce these negative externalities on community livability. This can be accomplished through the typical freight transportation planning process. Freight transportation planning typically occurs on three levels: short-term or operational planning, medium-term or tactical planning, and long-term or strategic planning (Böse, 2011, p. 4). Short-term or operational planning relates to day-to-day operations decisions, medium-term or tactical planning relates to basic resource strategy, and long-term or strategic planning relates to decisions about the services offered (Böse, 2011, p. 4). Research has been done on the effectiveness of various emissions-reduction strategies at the various levels: on the operational level, this typically concerns techniques to modify driver behavior; on the tactical level, this typically concerns techniques to optimize the utilization of existing resources. On the strategic level, fleet renewal serves as the principal strategy. It should be clarified that in this context, fleet renewal does not refer to incremental improvement of vehicles (an optimization of existing equipment – tactical level planning), but replacement. Fleet renewal would be considered strategic level planning due to barriers that can limit a business' services offered, especially if alternative fueled vehicles are considered. Due to the variety of players involved in the typical supply chain, the low number of fueling stations available for alternatively fueled

vehicles, variation of tax incentives across the country, and the limited number of heavy-duty vehicles available, adoption of alternatively fueled heavy-duty vehicles has not been widespread outside of short-haul use in transit, garbage removal, and last-mile delivery (Cardwell & Krauss, 2013).

Both diesel and gasoline, derived from petroleum, function as fuels in internal combustion engines through the combustion of hydrocarbons (Piecyk et al., 2012, p. 32). In each case, perfect combustion would result in



where X represents the appropriate coefficients and subscripts to balance the equation and a through f denoting potentially different values of X . Diesel equates to hydrocarbons with a carbon content ranging from C_8 to C_{25} and gasoline equates to hydrocarbons with a carbon content ranging from C_4 to C_{12} (U.S. Department of Energy, 2013f).

Unfortunately, due to incomplete combustion and the inclusion of other chemicals in the fuels, other products exist, namely particulate matter (PM), heavy metals (HM), ammonia (NH_3), sulfur dioxide (SO_2), oxides of nitrogen (NO_x), volatile organic compounds (VOC), carbon monoxide (CO), methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O) (Piecyk et al., 2012, p. 34). It is important to note that due to the fact that emissions are a direct result from fuel combustion, extensive study has been conducted on the topic from two different approaches on the issue: reduction of fuel consumption, driven by the cost of fuel whereby reduced emissions are an added public benefit; and reduction of emissions public policy, driven by the impact the pollutants have on public health and society.

Environmental Impact of Transportation Emissions

Transportation accounts for 19% of energy usage globally and 23% of global combustion-produced CO₂ emissions (Girod et al., 2013, p. 596). The U.S. Department of Energy (2013n) expects the quantity of fuel consumed by transportation to effectively double by 2050, based upon by current freight demand projections. Air pollution from the combustion process has many negative side effects on local, regional, and global scales. Regionally, air pollution from the combustion process can result in smog primarily from the reaction of nitrogen dioxide (NO₂) and sunlight during high-pressure weather systems, and acid rain primarily from the reaction of sulfur dioxide (SO₂) and nitrogen dioxide (NO₂) with water in rain (Piecnyk et al., 2012, p. 36). Smog can restrict the lungs while acid rain affects the growth of both marine and land-based plants and wildlife (Piecnyk et al., 2012, p. 36). Globally, carbon dioxide (CO₂), methane (CH₄), nitrous oxides (NO_x), hydrofluorocarbons (HFC), perfluorocarbons (PFC), and sulfur hexafluoride (SF₆) are greenhouse gasses, gasses that in the atmosphere allow more sunlight to pass through the atmosphere than allow radiant energy out, thereby contributing to global warming (Piecnyk et al., 2012, p. 35). Locally, the combustion of diesel and gasoline can result in the health issues shown in Table 2.

Table 2

Local Effects from Diesel and Gasoline Combustion

Cause	Effect
NO _x	Emphysema
Uncombusted Hydrocarbons, VOC	Cancer
NO _x and VOC forming Ozone (O ₃)	Respiratory problems and nausea
PM	Respiratory problems, cardiovascular problems, asthma, cancer
CO	Cardiovascular problems
SO ₂	Eye, ear, nose, and throat irritation; respiratory problems

Note. Adapted from “Assessing the external impacts of freight transport,” pp. 34-37, by M. Piecyk, S. Cullinane, & J. Edwards in A. McKinnon, M. Brown, & A. Whiteing (Eds.), *Green Logistics: Improving the Environmental Sustainability of Logistics*, 2012, London: Kogan Page.

Of these local-level pollutants, the U.S. Environmental Protection Agency (2011) considers particulate matter (PM), especially that smaller than 2.5 µm in diameter (PM_{2.5}), and ozone (O₃) to be the most severe threats to human health (p. 3). In 2010, it is estimated that 4,300 premature deaths in the United States were caused by conditions directly resulted from O₃ inhalation, while 160,000 premature deaths were caused by conditions caused by PM_{2.5} inhalation (U.S. Environmental Protection Agency, 2011, p. 14). Utilizing the U.S. Environmental Protection Agency’s Community Multi-scale Air Quality (CMAQ) Model and data from the 2005 U.S. Environmental Protection Agency National Emissions Inventory, the most recent data available at the time of the study, Caiazzo, Ashok, Waitz, Yim, and Barrett (2013) sought to determine the number of deaths as a result of emissions by sector (pp. 199-200). A linear relationship determined by the U.S. Environmental Protection Agency and confirmed in European research showed that a 10 µg/m³ change in PM_{2.5} would result in a 1% change in the number of

deaths from respiratory diseases (Caiazzo et al., 2013, p. 200). The change in number of deaths from respiratory diseases due to O₃, Δy, determined by

$$\Delta y = y_0 \times \left(1 - \frac{1}{e^{\beta \times \Delta O_3}} \right) \quad (2)$$

(where y₀ is the baseline mortality rate for respiratory diseases, β is a regional coefficient, and ΔO₃ is the change in O₃ concentration, as developed by the U.S. Environmental Protection Agency), Caiazzo et al. (2013) could determine the deaths caused by pollution from each sector examined by removing the contributing causes from CMAQ (p. 200). Of the six sectors studied (electricity generation, industry, commercial/residential, road transportation, marine transportation, and rail transportation), road transportation accounted for the second highest population-weighted concentrations of PM_{2.5} and the highest population-weighted concentrations of O₃ (Caiazzo et al., 2013, p. 202). In the state of Tennessee, these two pollutants accounted for 1,053 and 277 deaths respectively (Caiazzo et al., 2013, pp. 203, 205).

Environmental Public Policy to Achieve Emissions Reductions

Market-based systems. Market-based systems attempt to reduce emissions through the manipulation of fuel costs. A carbon tax system is an environmental policy tool that imposes taxes based on the carbon content of various fuels, whereby the price of said fuel is inflated at the point of purchase by the tax in order to discourage its use (Hoeller & Wallin, 1991, p. 92). Girod et al. (2013) sought to project future emissions in 2050 due to transportation, and subsequently examine the use of a carbon tax system to reduce emissions, through the comparison of five global emissions models that each account for transportation differently: the Global Change Assessment Model (GCAM), the Global Energy Transition (GET) model, the International Energy Agency Mobility Model

(IEA/MoMo), the Targets IMage Energy Regional (TIMER) model, and the Prospective Outlook on Long-term Engery Systems (POLES) model (p. 596). The differences between how these models account for transportation are presented in Table 3.

Table 3

Differences in Transportation Modeling Components of Five Global Emissions Models

	TIMER	GCAM	POLES	GET	IEA/MoMo
Travel Demand	Population, Income, Travel Expenditures, Service Prices	Population, Income, Service Prices	Population, Fuel Prices, Income	Population, Income	Population, Vehicle Purchases, Travel Trends
Travel Mode Split	Logit Model of Vehicle Costs and Time Value Costs	Logit Model of Vehicle Costs and Time Value Costs	Substitution based upon Fuel Price	Historical Trends as related to GDP Growth	Historical Trends
Freight Demand	Industrial Value Added, Fuel Prices	GDP, Service Prices	GDP, Fuel Prices	GDP	GDP
Freight Mode Split	Logit Model of Vehicle Costs and Time Value Costs	Logit Model of Vehicle Costs	Substitution based upon Fuel Price	Historical Trends as related to GDP Growth	Historical Trends
Energy Efficiency	Logit Model for Vehicles with Different Fuels and Energy Efficiency	Logit Model for Vehicles with Different Fuels and Energy Efficiency	Dependent on Fuel Prices	Historical Trends	Historical Trends of Load Factors and Vehicle Composition
Fuel Mix	Determined by Vehicle and Mode Shares	Determined by Vehicle and Mode Shares	Determined by Vehicle and Mode Shares	Cost Minimization of the Energy System	Determined by Vehicle and Mode Share
Fuel Price	Endogenous	Endogenous	Endogenous	Exogenous	Exogenous

Note. Adapted from “Climate impact of transportation: A model comparison,” by B. Girod, D. P. van Vuuren, M. Grahn, A. Kitous, S. H. Sim, & P. Kyle, June 2013, *Climactic Change*, 118(3), p. 599. Copyright 2013 by Springer Science+Business Media Dordrecht. Adapted with permission.

Girod et al. (2013) sought to isolate transportation in the system by removing all other inputs, and as such, transportation-related emissions are not included; the process modeled “tank to wheel” emissions rather than “well to wheel”, whereby the refining process would be considered (p. 597). Each model showed considerable increase in CO₂ emissions, as shown in Figure 3.

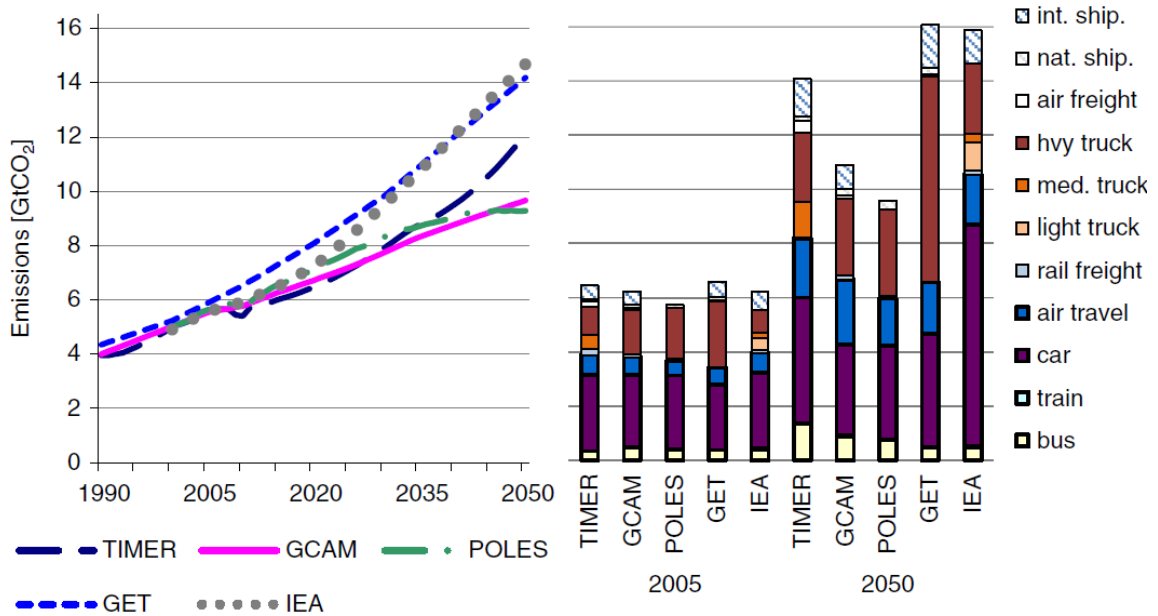


Figure 3. Global Transportation CO₂ Emissions Projections from Five Different Models. Adapted from “Climate impact of transportation: A model comparison,” by B. Girod, D. P. van Vuuren, M. Grahn, A. Kitous, S. H. Sim, & P. Kyle, June 2013, *Climactic Change*, 118(3), p. 600. Copyright 2013 by Springer Science+Business Media Dordrecht. Reproduced with permission.

Despite the variation in the models, it is important to note that all models project significant growth of emissions to 2050, and that on-road sources remain the largest contributor (p. 606). Additionally, none of the models predict any significant market share for alternative fuels until after 2050, with the most significant market share

expected by GCAM and POLES due to fossil fuel price increases (pp. 602-603). Through the utilization of a carbon tax system, significant reductions on the order of 24% to 55% may be achieved, as shown in Figure 4 (p. 607).

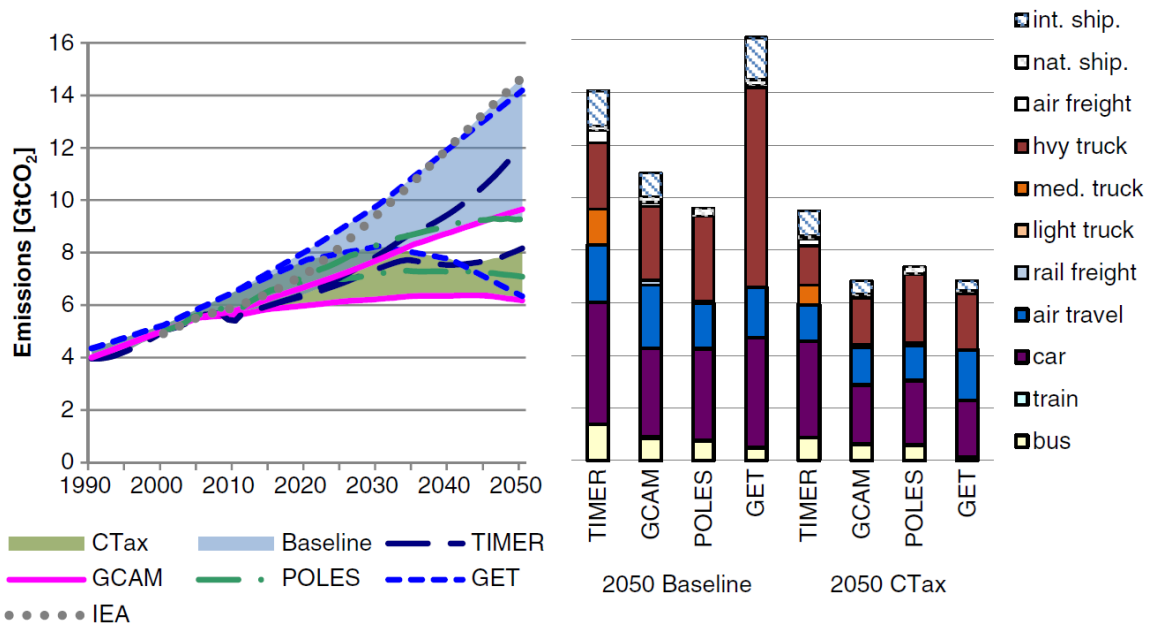
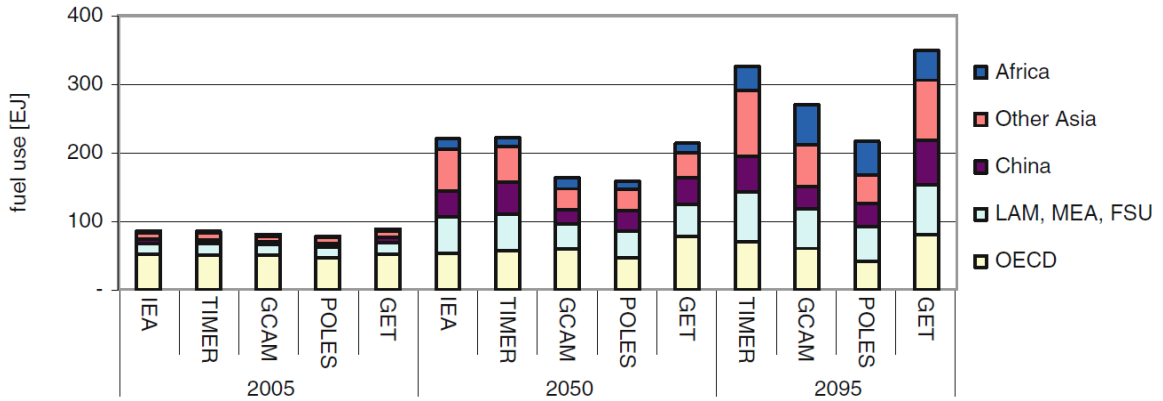


Figure 4. Projections on the Effect of a Carbon Tax on Transportation Emissions. Adapted from “Climate impact of transportation: A model comparison,” by B. Girod, D. P. van Vuuren, M. Grahn, A. Kitous, S. H. Sim, & P. Kyle, June 2013, *Climactic Change*, 118(3), p. 605. Copyright 2013 by Springer Science+Business Media Dordecht. Reproduced with permission.

It is important to notice that despite the reductions in emissions, on-road sources remain the largest contributor. Additionally, the IEA/MoMo model was not run for the carbon tax scenario (p. 1). Interestingly, GET and GCAM predict high fuel prices to induce a greater shift to alternative fuels while POLES and TIMER predict vehicle efficiency gains, though the largest amount of emissions reductions occur due reduced transportation demand as many users are priced out of the system (p. 604). All five

models project relatively stable levels of fuel use under the base scenario among the 34 industrialized members of the Organization for Economic Cooperation and Development (OCED), as shown in Figure 5.



*Figure 5. Projected Future Fuel Consumption under Base Conditions. Adapted from “Climate impact of transportation: A model comparison,” by B. Girod, D. P. van Vuuren, M. Grahn, A. Kitous, S. H. Sim, & P. Kyle, June 2013, *Climactic Change*, 118(3), p. 602. Copyright 2013 by Springer Science+Business Media Dordecht. Reproduced with permission.*

By implementing a carbon tax system whereby the price of fuel is increased, those in the non-industrialized and industrializing countries would be the most effected as their demand is expected to grow the most.

This conclusion is confirmed by research by the U.S. Environmental Protection Agency (2010a) that a similar, cap-and-trade system would only reduce transportation CO₂ emissions in the United States by 3.5% by 2030 (p. 6). Where a carbon tax system taxes fuel usage, a cap-and-trade system places limits on the quantity industries may emit through the use of permits which are purchased from the government and may be traded

on the open market (Stavins, 2001, p. 4). Typically, as with other incurred costs of production, these are passed to the consumer.

Finally, tax regulations can be successfully utilized in order to reduce emissions through encouraging the adoption of new, more efficient technologies. Such incentives first were included in the Clean Air Act of 1970 and progressively extended and expanded since its enactment (U.S. Department of Energy, 2014j). Currently, 20 such tax credits, 18 laws and regulations, and 12 programs exist at the federal level to encourage the adoption of more efficient vehicles and technologies through taxation (U.S. Department of Energy, 2014k). In Tennessee, 3 state tax credits and 13 laws and regulations exist to incentivize the adoption of more efficient vehicles and technologies through taxation (U.S. Department of Energy, 2014n). It must be noted that fuel economy regulations are included in this category. The National Highway Traffic Safety Administration's Corporate Average Fuel Economy (CAFE) program imposes fuel economy standards upon manufactures who wish to sell their vehicles in the United States, and imposes tax penalties upon those vehicles that do not meet them (U.S. Department of Energy, 2014j; U.S. Environmental Protection Agency, 2013b). Changes between the CAFE standards for 2011 and 2016 will result in vehicles being sold in 2016 consuming on average 812 fewer gallons of gasoline over their lifetime when compared to those sold in 2011 (Litman, 2013, p. 159). While medium- and heavy-duty vehicles were exempt from CAFE standards prior to the 2014 model year, the 2007 Highway Rule that required the reduction of sulfur in diesel fuel for highway use (switching to ultra-low sulfur diesel), resulting in a reduction of pollution from heavy-duty vehicles by 90% (U.S. Environmental Protection Agency, 2012a; The White House, 2014, p. 3).

Transportation demand management policy. Transportation demand management policies can result in significant reductions of emissions by improving access and mobility through incorporation of ideas like context sensitive solutions, complete streets, and ridesharing, whereby the usage of alternative modes of transportation are encouraged (Litman, 2013, p. 154). Litman (2013) attempted to compare the financial effect of conserving one liter of fuel through vehicle efficiency and by changing modes or reducing travel and found that five times the benefits were possible, as shown in Figure 6.

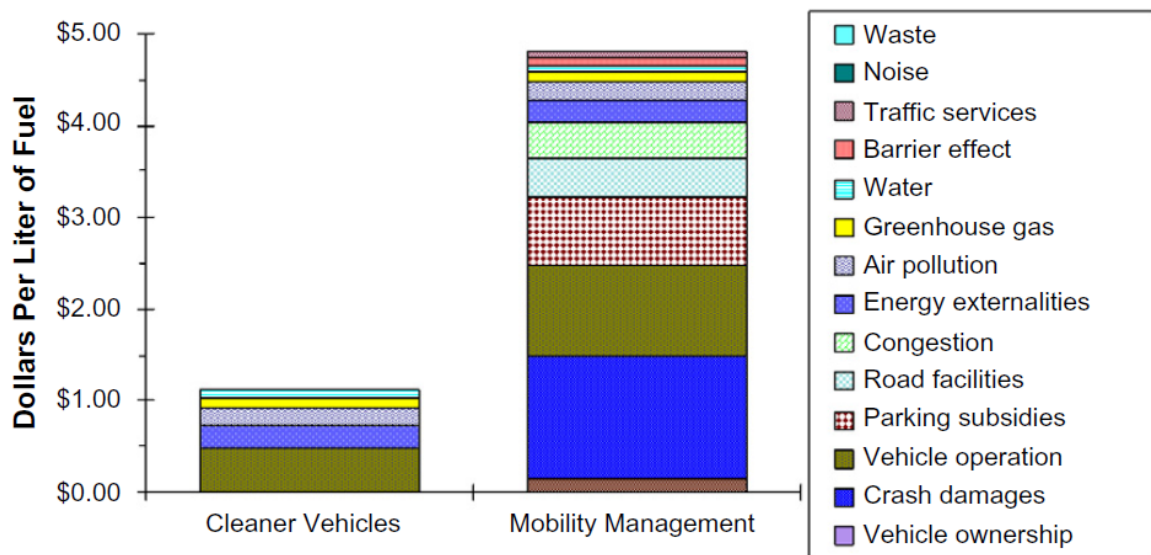


Figure 6. Benefits of Reduced Fuel Consumption Comparing Fuel Efficiency with Mobility Choices. Adapted from “Comprehensive evaluation of energy conservation and emission reduction policies,” by T. Litman, 2013, in *Transportation Research Part A: Policy and Practice*, 47, p. 160. Copyright 2012 Elsevier Ltd. Reproduced with permission.

Unfortunately, many of these policies only have minor effects on freight traffic.

Transportation demand management policies are mostly aimed at reducing personal

vehicle travel, but freight traffic would benefit from reduced congestion and a reduction of freight emissions would provide a significant benefit in terms of air quality.

Freight Transportation Planning to Reduce Emissions

The traditional freight transportation planning process can also be leveraged to reduce emissions. Freight transportation planning typically occurs on three levels: short-term or operational planning, medium-term or tactical planning, and long-term or strategic planning (Böse, 2011, p. 4). On the operational level, this typically concerns techniques to modify driver behavior; on the tactical level, this typically concerns techniques to optimize the utilization of existing resources, and on the strategic level, fleet renewal serves as the principal strategy.

Operational strategies for emissions reductions. Fuel economy can be drastically reduced by elements related to driver behavior. These reductions occur due to things like improper shifting, idling, speeding, aggressive acceleration or braking, inefficient routing, and speeding (U.S. Department of Energy, 2013m). Optimization of driving profiles can lead to a significant reduction in fuel consumption. Gonder, Earlywine, and Sparks (2011) found that a 30% to 60% boost to fuel economy is achievable if drivers behave ideally, though unrealistic in real world conditions due to the unpredictability of real-world road conditions (p. 1). More practical savings of 5% to 10% can be achieved through moderate driving styles, but drivers must be sufficiently motivated (Gonder et al., 2011, p. 1). If one-third of Americans adopted moderate driving techniques, 33 metric tons of CO₂ emissions and \$7.5-\$15 billion of fuel expenditures could be eliminated, dependent on the price of fuel (Barkenbus, 2010, p. 764).

Behavioral impact. Significant fuel consumption savings can be achieved through driver behavior modification. Because of the stop-and-go nature of city driving, most savings can be achieved in the urban environment. Gonder et al. (2011) found after examining 4,000 trips, that a correspondence exists between high levels of acceleration and trips with an average speed of 20 miles per hour, as shown in Figure 7 (p. 8).

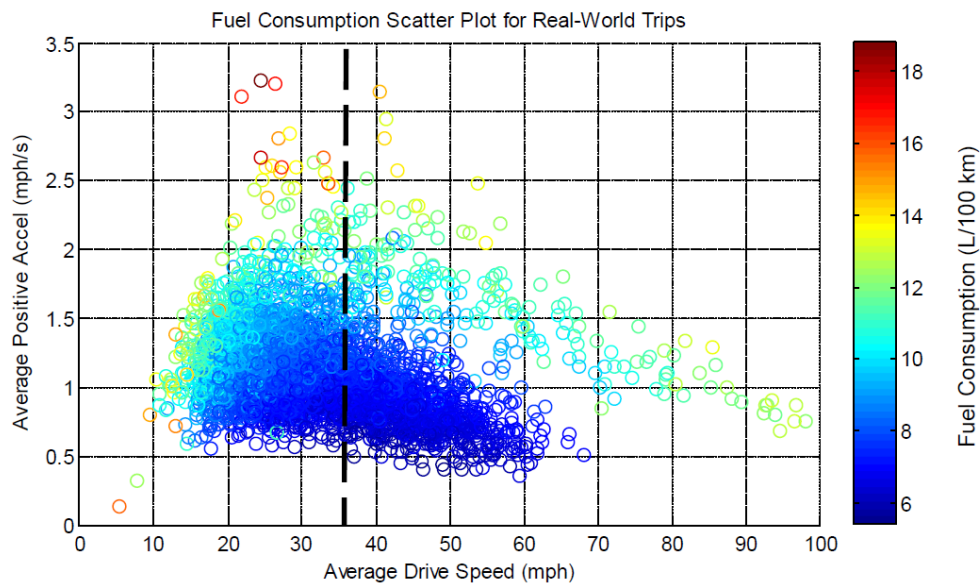


Figure 7. Fuel Consumption as a Function of Average Drive Speed and Average Acceleration. Adapted from Final Report on the Fuel Saving Effectiveness of Various Driver Feedback Approaches by J. Gonder, M. Earleywine, and W. Sparks, 2011, p. 8. Copyright 2011 by the U.S. Department of Energy. Public domain.

By paying attention to downstream traffic, speed manipulation can easily be used to avoid stopping in traffic or other bottlenecks (Gonder et al., 2011, p. 4). Simply by accelerating gently and being aware of when to brake, drivers can achieve savings up to 33% in the city and 5% on the highway (U.S. Department of Energy, 2012b).

Telemetric and driver feedback systems. Audi AG, a subsidiary of the Volkswagen Group, has been developing a vehicle feature called Traffic Light Assist that integrates in-car global positioning system navigation with information from municipal intelligent transportation systems (ITS) to provide drivers with information about upcoming traffic lights and their current signal phase (Barth, 2014). Such a system could allow for drivers to be aware of when they need to accelerate and break in order to achieve the 33% savings in the city and the 5% on the highways expected in ideal drivers by the Alternative Fuels Data Center (U.S. Department of Energy, 2012b). Audi's system, as shown in Figure 8, is indicating to the driver that the left-turn signal ahead is currently red and will change in nine seconds.



Figure 8. Audi Traffic Light Assist Demonstration. ©2014 by Consumers Union of U.S., Inc. Yonkers, NY 10703-1057, a nonprofit organization. Reprinted with permission from ConsumerReports.org for educational purposes only. No commercial use or reproduction permitted. www.ConsumerReports.org.

This technology could be utilized by drivers to fluctuate their speed in order to avoid red lights and save fuel. However, while Audi argues that the technology will improve safety through the elimination of Yellow-Red decision dilemmas, recent research has shown that knowledge about signal timing can increase the number of accidents (Barth, 2014). Kapoor and Magesan (2014) found that when drivers are able to see the countdown timer utilized for crosswalks, accidents may increase as some drivers will attempt to cross through the intersection, thinking that they can make it, while other drivers tend to brake.

Feedback devices providing information to drivers about how the vehicle is being operated can help reinforce efficient driving behavior. Telemetry systems for trucks can be utilized to calculate instantaneous or average fuel consumption in gallons per minute or miles per gallon by interfacing with the vehicle Engine Control Module, and this information can be provided to drivers to not only allow them to modify their driving behavior, but also to fleet managers who can determine which drivers may need some coaching (International Telematics, 2014; U.S. Department of Energy, 2013m). Additionally, these systems can be utilized to keep track of maintenance items that impact fuel consumption like engine hours, tire wear, and coolant levels (Lasso Technologies, LLC, 2014). Through the utilization of these instantaneous feedback systems, a 1% to 6% improvement in fuel economy is typical (U.S. Department of Energy, 2012b). A study of 167 drivers of various ages, economic backgrounds, levels of environmentalism, and driving styles conducted by Caulfield, Brazil, Fitzgerald, and Morton (2014) over 37 weeks in the Netherlands found that coaching drivers both in-vehicle and out-of-vehicle feedback regarding fuel consumption corresponded to a reduction of carbon dioxide emissions of 3% to 6% (p. 260).

Speed reduction. Despite the work of Gonder et al. (2011) illustrating that the highest levels of fuel consumption typically occur on trips with an average speed under 20 miles per hour, significant reductions to fuel economy also occur at highway speeds (p. 8). In Figure 9, typical city driving and highway driving are divided by the black weighted line, and fuel consumption is shown to increase as speeds increase to 100 miles per hour.

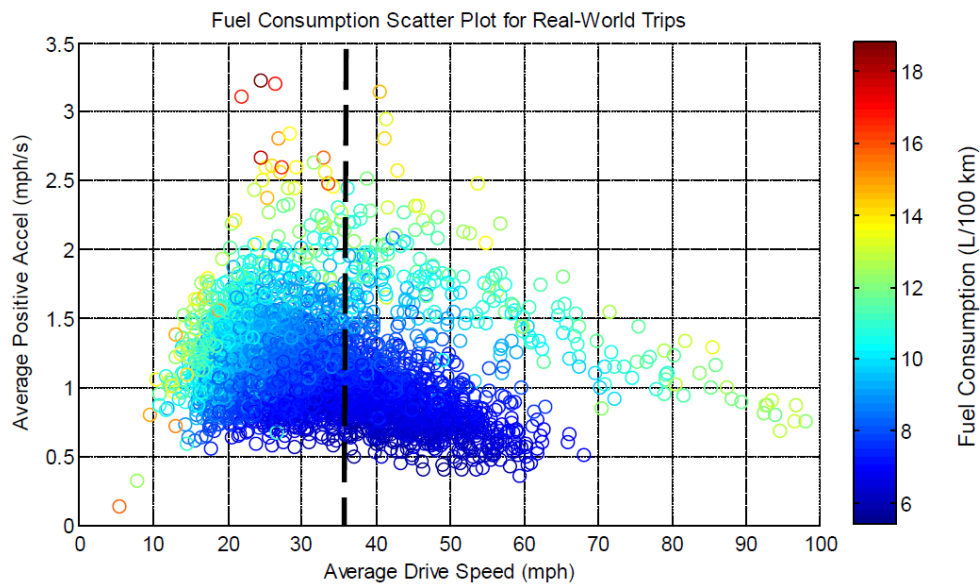


Figure 9. Fuel Consumption as a Function of Average Drive Speed and Average Acceleration. Adapted from *Final Report on the Fuel Saving Effectiveness of Various Driver Feedback Approaches* by J. Gonder, M. Earleywine, and W. Sparks, 2011, p. 8. Copyright 2011 by the U.S. Department of Energy. Public domain.

In trucks, research by the U.S. Department of Energy’s Alternative Fuels Data Center has shown that optimal fuel economy occurs around 50 miles per hour, with an increase of 5 miles per hour in speed equating to a \$0.26 increase in fuel costs per gallon, based on a \$3.75 per gallon fuel cost, due to higher consumption rates occurring as the engine works harder to overcome wind resistance (U.S. Department of Energy, 2012b).

Tactical strategies for emissions reductions. Where Operational Strategies to reduce fuel consumption and emissions focus on the in-vehicle activity of drivers, Tactical Strategies relate to external elements that can affect how fuel is consumed, such as dispatch, maintenance, and other incentive programs. As indicated by the typical planning levels of freight transportation, these elements are all at a higher than day-to-day operations and involve company-wide resource strategies (Böse, 2011, p. 4).

Incentive programs. Incentive programs have been adopted in order to encourage drivers to modify their behavior in order to conserve fuel by many public and private organizations. This type of behavior modification is tactical rather than operational planning as it involves decision-making that occurs outside of the vehicle. Typically, organizations will incentivize their drivers with privileges, recognition, or financial reward (U.S. Department of Energy, 2013m). Many of these programs score drivers on a variety of performance measures in order to prevent drivers from being significantly penalized for cargo and terrain variation (Lockridge, 2012). For example, Illinois-based Nussbaum Transportation utilizes a points-based system that incorporates safety and only compares similar trucks together in order to account for different engines and transmissions (Lockridge, 2012). Nussbaum Transportation pays drivers a monthly bonus based upon the number of accrued points (Lockridge, 2012). The municipality of Polk County, Florida, as part of a Florida Department of Transportation pilot program, incentivizes drivers with a 50/50 split of the dollar amount of their annual fuel savings, provided at least a 5% reduction in their fuel consumption is achieved (Stanton, 2011). By the end of the second year of the program, annual consumption had been reduced by 436,000 gallons, equating to a reduction of 3100 tons of carbon emissions (Stanton,

2011). North Little Rock, Arkansas-based Maverick Transportation operates a similar scheme that returns 80% to 90% of the cost savings to drivers (Lockridge, 2012). Safety is a key element in all of the incentive programs, and it is typically assumed that if a driver were involved in a preventable accident, they were engaging in aggressive behavior not conducive to efficient driving (Lockridge, 2012; Stanton, 2011). As Maverick Transportation Vice President of Maintenance Mike Jeffress indicated, “when we let someone go, they have other deficiencies, not just fuel mileage” (Lockridge, 2012).

Maintenance programs. Maintenance issues can have a significant impact on a vehicle’s fuel efficiency. A drop in tire pressure of only 1 pound per square inch in one tire can increase fuel consumption by 0.3% as more energy is required to overcome the increase in rolling resistance, or the force resisting the rotational motion of the wheels (U.S. Department of Energy, 2012c). This resistance is a result of elastic and inelastic tire deformation when the wheel assembly is rolling and the shear and compression forces between the tire and pavement (Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles, 2010, p. 111). In heavy-duty trucks, it is estimated that 15% to 30% of fuel consumption is utilized simply to overcome rolling resistance (U.S. Department of Energy, 2013o).

Motor oil viscosity is another important factor affecting efficiency. Motor oil is required in order to lubricate the moving parts of the engine in order to prevent wear, and its viscosity is a measure of its flow (Lockridge, 2014). Chris Guerrero, Shell Oil Company’s Global Marketing Manager simply explained the connection between efficiency and viscosity, saying “if you think about a swimming pool filled with water

and a swimming pool filled with honey, you'd find it easier to swim in water than honey, because the honey is more viscous" (Lockridge, 2009). Traditionally, heavy-duty vehicles have required higher viscosity oils to deal with higher levels of wear, but changing fuel economy standards have pushed engine manufacturers and oil refiners to test the utilization of low viscosity oils in heavy-duty vehicles (Lockridge, 2014). Despite the potential benefits of switching oils, engines are designed for specific viscosities and the utilization of incorrect motor oil during maintenance can affect fuel economy by up to 2% (U.S. Department of Energy, 2012c).

Finally, tune-ups occurring at the recommended interval by the engine manufacturer can also have a significant impact. According to the Alternative Fuels Data Center, performing regular maintenance to replace wear items like gaskets and engine belts typically results in a 4% improvement to fuel economy than if the maintenance had been deferred (U.S. Department of Energy, 2012c). As oxygen is consumed during the combustion phase of an engine, correcting problems with the air intake system could result in a 40% boost to fuel economy (U.S. Department of Energy, 2012c).

Replacement parts. Replacement of standard parts with more efficient ones can be an easy way to improve fuel economy. Rolling resistance is a result of elastic and inelastic tire deformation when the wheel assembly is rolling and the shear and compression forces between the tire and pavement (Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles, 2010, p. 111). In heavy-duty trucks, it is estimated that 15% to 30% of fuel consumption is utilized simply to overcome rolling resistance (U.S. Department of Energy, 2013o). Extensive tire testing of 51 different tire models conducted by Tan, Calwell, and Reeder (2003) utilizing the Society of

Automotive Engineers test SAE J1269, whereby the force required to roll a tire at 50 miles per hour is determined, found that low rolling resistance tires of similar size to standard models resulted in up to a 6% increase in fuel efficiency (p. 3). Research across a variety of drive cycles has shown improvements of 3.3% to 6% to be typical (Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles, 2010, p. 113). Additionally, according to the North American Council for Freight Efficiency, similar increases to fuel efficiency due to lower rolling resistance can be achieved through switching to wide base tires instead of dual truck tire assemblies, as shown in Figure 10 (North American Council for Freight Efficiency, 2010, p. 2).



*Figure 10. Dual Truck Tire Assembly (Left) and Wide Base Tire Assembly (Right). Adapted from *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles* by the Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles, 2010, p. 112. Copyright 2010 by National Academy of Sciences. Reproduced with permission.*

Switching to wide base tires does offer other benefits like easier maintenance, reduced wheel and tire management for fleets, an improved ride and handling, and longer brake life due to improved cooling (North American Council for Freight Efficiency, 2010, pp. 2-3). However, wide base tires also have disadvantages like higher wheel bearing wear

and increased costs due to breakdowns due to the inability to limp in the truck (North American Council for Freight Efficiency, 2010, p. 3).

In addition to rolling resistance, trucks have to overcome wind resistance at highway speeds. Aerodynamic treatments can reduce the impact of wind resistance, and several technologies have been tested by the U.S. Environmental Protection Agency SmartWay Technology program. The results are presented in Table 4.

Table 4

U.S. Environmental Protection Agency SmartWay Technology Program Verified Aerodynamic Technologies

Technology	Description	Impact on Fuel Economy
Trailer Gap Reducers	Panels that attach to the front of the trailer and limit the ability for air to flow between the cab and trailer	≥1%
Trailer Boat Tails	Panels that attach to the rear of the trailer decrease the area of negative air pressure directly behind the trailer	≥1%
Trailer Side Skirts	Panels that attach underneath the trailer to improve airflow around the trailer wheels	≥4%
Advanced Trailer End Fairing	Larger, more ridged version of the Trailer Boat Tails	5%
Advanced Trailer Skirt	Larger, more ridged version of the Trailer Side Skirts	5%

Note. Adapted from “Verified Aerodynamic Technologies” from SmartWay Technology, by the U.S. Environmental Protection Agency, September 26, 2014. Copyright 2014 by the U.S. Environmental Protection Agency. Public domain.

In addition to utilizing aerodynamic retrofitting to improve fuel economy at higher speeds, speed control modules can be installed. Speed control modules interface with the engine control module to limit a vehicle's maximum speed (U.S. Department of Energy, 2013o). Since 2006, through utilizing such devices, Staples has reduced fuel consumption by 3 million gallons (U.S. Department of Energy, 2013o).

Dispatch programs. Dispatch techniques, whereby the routing and scheduling of trucks are controlled, can be an effective method for reducing fuel consumption, either through the elimination of superfluous driving or unnecessary idling. Route optimization is one strategy to eliminate such factors. Route optimization utilizes vehicle telematics, the global positioning system, roadway conditions, and the location of nodes along the roadway network to determine the best way for vehicles to be routed across the roadway network in order to achieve some goal, typically quickest travel time or cheapest travel time (U.S. Department of Energy, 2013m). Through the utilization of their proprietary On-Road Integrated Optimization and Navigation (ORION) system, for 2014 UPS estimated that it eliminated the consumption of 1.5 million gallons of fuel, equating to 14,000 metric tons of greenhouse gasses (United Parcel Service of America, Inc., 2014, p. 51). When ORION is fully deployed in 2017, UPS expects that the reduction of just one mile traveled on each route will result in \$50 million of savings in fuel costs (United Parcel Service of America, Inc., 2014, p. 51). Although UPS has developed ORION internally, several smaller transportation and logistics providers have utilized similar dispatch systems to achieve similar results through external providers. Associated Food Stores, a grocery distributor in the Midwestern United States, utilized optimization software developed by Roadnet Technologies to reduce annual mileage by 400,000 miles

by eliminating 2-3 routes per day through routing and loading optimization, and additionally increased on-time performance by 96% (Roadnet Technologies, Inc., 2014).

Idle reduction through gate strategies. One challenge to meeting on-time performance goals are trucking laws that limit the number of hours truck drivers can be behind the wheel due to safety concerns (Gaines, Vyas, & Anderson, 2006, p. 94). While route optimization strategies can reduce the number of hours a driver is on the road by eliminating unnecessary driving, long-haul truck drivers will typically pull off the road and rest (p. 94). While resting, drivers usually idle their trucks in order to generate electricity, as well as provide heating and cooling, consuming fuel in the process unless the location the truck is parked is equipped with electrical hookups (p. 94). This type of idling, called overnight idling due to the time of day it typically occurs, is estimated to consume 685 million gallons of fuel per year in heavy-duty vehicles (p. 95). Another type of idling, workday idling, typically occurs during the middle of the day when heavy-duty vehicle drivers idle their engines while processing paperwork, eating lunch, or waiting for access to a facility, accounts for the consumption of 2.49 billion gallons of fuel per year across the 18 million commercial vehicles in the United States (pp. 95-97). A study of 391 drivers in Taichung City, Taiwan by Jou, Wu, and Liu (2014) to determine the minimum acceptable time to turn off idling engines found that drivers would only consider turning off their engines for potential idling periods longer than 293 seconds, having utilized a partially adaptive estimation technique to improve the level of significance of the inputs (p. 67).

Several strategies have been developed to help combat workday idling for vehicles waiting at freight terminals: drop-and-hook techniques allow drivers to avoid delays

associated with loading and unloading the trailers; gate scheduling and take-a-number systems allow vehicles to be routed so that they arrive when they are able to be served, eliminating the wait; and the extension of gate operating hours, potentially to a 24-hour system, allows drivers to be routed to arrive during off-peak periods when the demand at the facility has decreased (Gaines, Vyas, & Anderson, 2006, p. 96). Walmart has successfully utilized drop-and-hook techniques to reduce delays at its terminal facilities, though this requires more trailers than tractors and does not work for less-than-truckload (LTL) freight (p. 96).

Unfortunately, an emissions analysis of the gate scheduling appointment system adopted by the ports of Los Angeles and Long Beach by Giuliano and O'Brien (2007) proved inconclusive, as terminal operators were not required to participate, those that did participate did not always provide dedicated appointment lanes, and only an estimated 30% of terminal transactions utilized appointments over the year and a half long study (Giuliano & O'Brien, 2007, p. 465). Additionally, usage varied at terminals over the course of study, as shown in Figure 11.

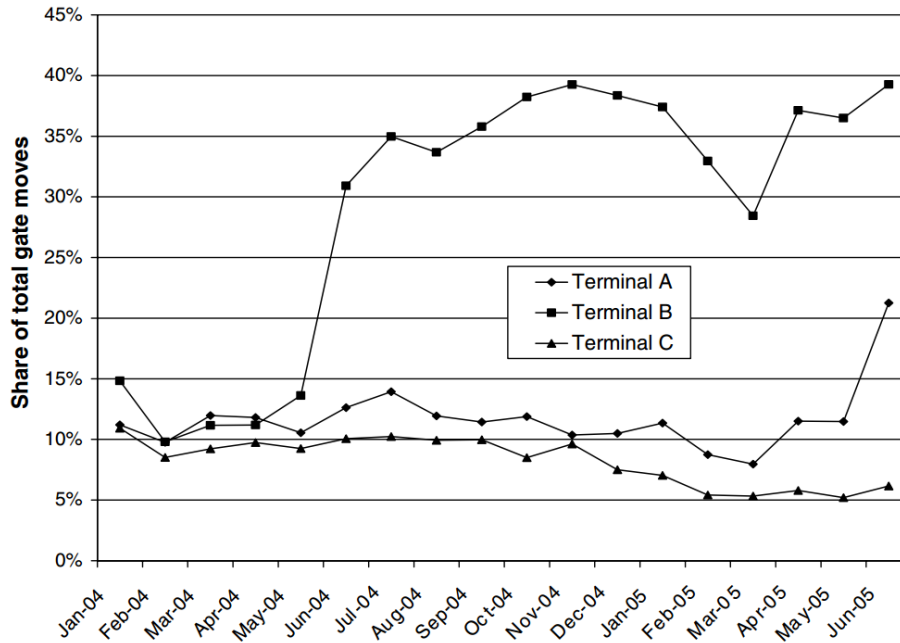


Figure 11. Share of Terminal Transactions utilizing the Los Angeles-Long Beach Appointment System. Adapted from “Reducing port-related truck emissions: The terminal gate appointment system at the Ports of Los Angeles and Long Beach,” by G. Giuliano and T. O’Brien, October 2007, in *Transportation Research Part D: Transport and Environment*, 12(7), p. 462. Copyright 2007 by Elsevier Ltd. Reproduced with permission.

Finally, due to terminal expansion projects and technology improvements at the terminals over the course of study, terminal operators were unsure of the source of any perceived efficiencies (Giuliano & O'Brien, 2007, p. 466). It should be noted that while Transport Canada was able to identify efficiency improvements due to use of an appointment system, the emissions study is incomplete (Morais & Lord, 2006, pp. 44-45). The U.S. Environmental Protection Agency, however, did find success in reducing emissions through an appointment system in the Port of New Orleans (U.S. Environmental Protection Agency, 2006, p. 1). Additional research in Canada concluded that such a system can only be effective when all participants (the port authority, trucking companies, drivers, labor organizations) buy into the benefits such a system has to offer,

and the acceptance issues faced in the Ports of Los Angeles and Long Beach were most likely due to the appointment system being imposed externally through the Lowenthal Bill (Morais & Lord, 2006, pp. 89-90). In the Port of New York and New Jersey, concerns about data-sharing amongst stakeholders also proved to be an additional barrier (Spasovic, Dimitrijevic, & Rowinski, 2009, pp. 47-48).

Extensive study of the Port of Newark/Elizabeth's intermodal marine container terminals by Karafa (2012) through utilizing Quadstone Paramics traffic microsimulation software, found extended hours to be most effective at reducing the congestion of trucks waiting to enter the terminals, and therefore emissions, as demand on the facility increased (pp. 75-78). Once demand reached an increase of 20% over base conditions, the implementation of an appointment system was found to be a detriment as delays increased (p. 78). Despite a trial of extended hours at two of the Port of Newark/Elizabeth's three terminals, buy-in issues again arose and only 7% of trucks serving the facilities took advantage of the extended hours (Spasovic et al., 2009, p. 50). Willingness of stakeholders to participate in any gate strategy remains the key to its success or failure. Despite the challenges faced at the Ports of Los Angeles and Long Beach in implementing a gate appointment system, the utilization of extended gate hours has been well received. The PierPASS Off-Peak program, created by marine terminal operators at these ports, charges drivers a \$50 fee per TEU for daytime pickups to encourage the use of off-peak hour arrivals, and to date, 50% of all truck arrivals have been shifted to off-peak hours (Federal Highway Administrations, 2013; Mongelluzzo, 2014b). At Port Metro Vancouver, long wait times prompted a truck driver strike in March 2014 and the port has successfully implemented a program where terminals are

assessed penalties based upon how long it takes to serve a truck, encouraging terminals to work with truckers to encourage off-peak arrivals (Mongelluzzo, 2014b). Many ports in the United States are examining strategies to improve efficiencies in anticipation of serving larger ships while ports on the east coast are examining strategies to improve efficiencies in anticipation of serving more ships due to expanded capacity through the Panama Canal (Mongelluzzo, 2014a). This focus on increased efficiency has caused extended gate hours to become a common strategy (Mongelluzzo, 2014a).

Strategic strategies for emissions reductions. Where Operational Strategies to reduce fuel consumption and emissions focus on the in-vehicle activity of drivers and Tactical Strategies relate to external elements that can affect how fuel is consumed, such as dispatch, maintenance, and other incentive programs, Strategic Strategies for emissions reductions focus on fleet renewal. Fleet renewal is a strategic level freight transportation planning strategy due to the level of investment required and that these choices may impact the types of services a transportation company may be able to offer.

Newer traditionally fueled vehicles. One strategy for fleet renewal is to replace older, inefficient vehicles with newer models that have benefited from fuel economy increases as technology has evolved. In 2010, through the National Clean Fleets Partnership, the Department of Energy partnered with medium- and heavy-duty vehicle manufacturers and transportation providers to develop and implement efficient technologies in anticipation of the first ever CAFE fuel economy regulations for medium- and heavy-duty vehicles in the 2014 model year (The White House, 2014, p. 6). Previously, medium- and heavy-duty vehicles were subject to soot and smog pollution regulations that could often be addressed in older vehicles though aftermarket parts like particulate

filters (The White House, 2014, pp. 3-5). Fuel efficiency gains were ancillary benefits in new vehicles due to technological improvements made for vehicles subject to CAFE standards in addition to competition among manufacturers for business (The White House, 2014, pp. 3-5). Unfortunately, as vehicles are strategic level purchases and as such, remain in service for a long period of time, older vehicles may still emit significant quantities of pollution despite any aftermarket solutions. In order to help address pollution issues around the Ports of Los Angeles and Long Beach, the Ports of Los Angeles and Long Beach implemented the Clean Truck Program whereby in 2008, trucks older than 1989 were banned from accessing the port; in 2010, trucks older than 1993 and any truck made between 1993 and 2003 that did not have emissions-reduction retrofits were banned from accessing the port; and in 2012, all trucks that did not run on ultra-low sulfur diesel fuel meeting 2007 standards were banned from the accessing the port (The Port of Los Angeles, 2014). Since the implementation of the Clean Truck Program, truck emissions have been reduced in the port by 80% (The Port of Los Angeles, 2014).

Alternatively fueled vehicles. One tactic to reduce emissions and fuel costs is to switch to alternatively fueled vehicles (Windecker & Ruder, 2013, p. 34). Since 1988, the United States Government has promoted the use and development of alternatively fueled vehicles by providing manufacturers with CAFE credits through the Alternative Motor Fuels Act (U.S. Department of Energy, 2014j). Per the Energy Policy Act of 1992, in the United States, when used to power vehicles, the following are considered alternative fuels: electricity, coal-derived liquid fuels, alcohols including methanol and ethanol, propane, biodiesel, other non-alcohol biologically-derived liquids, blends of alcohols and either gasoline or diesel where the alcohol content is at least 85%, natural gas, hydrogen,

and blends of natural gas and alcohol commonly known as P-Series fuels (U.S. Department of Energy, 2013g). Additionally, hybrid vehicles combining an electric powertrain to supplement a combustion engine also exist.

According to the U.S. Department of Energy's Alternative Fuel Data Center, the medium- and heavy-duty vehicles that are available for sale in the United States direct from the manufacturer (as opposed to being retrofitted) run on electricity, propane, compressed natural gas (CNG), liquefied natural gas (LNG), an ethanol-gasoline mix meeting the 85% threshold marketed as E85, and hydrogen (U.S. Department of Energy, 2013b, pp. 10-12). Additionally, hybrid systems are available direct from the manufacturer that combine an electric drivetrain with a traditional diesel engine, a CNG engine, and a hydrogen fuel cell (U.S. Department of Energy, 2013b, p. 15). Per the U.S. Department of Energy, the quantities of vehicle models available directly from the manufacturer and application by fuel type are presented in Table 5.

Table 5

Quantities of Alternatively Fueled Vehicle Models Available Direct from the Manufacturer and Application by Fuel Type

Fuel Type	Terminal Tractor	Long-Haul Tractor	Large Van	Vocational Truck	School Bus	Shuttle Bus	Transit Bus	Refuse Truck
Electricity	3	-	4	4	1	-	3	-
Propane	1	-	3	4	5	6	-	-
CNG	2	11	2	8	2	9	10	11
LNG	2	12	-	5	-	-	6	3
E85	-	-	-	1	-	-	-	-
Hydrogen Fuel Cell	-	-	-	-	-	-	2	-
Hydrogen Fuel Cell Hybrid	1	1	-	-	-	1	1	-
CNG Electric Hybrid	-	-	-	-	-	-	1	-
Gasoline Electric Hybrid	-	-	-	-	-	2	-	-
Diesel Electric Hybrid	-	4	-	6	1	2	13	2
TOTAL	9	28	9	28	9	20	36	16

Note. Adapted from *Clean Cities Guide to Alternative Fuel and Advanced Medium- and Heavy-Duty Vehicles*, by the U.S. Department of Energy, 2013, pp. 17-37. Copyright 2013 by the National Renewable Energy Laboratory. Public domain.

Electricity as a fuel. Electric vehicles utilize electricity stored in batteries to drive an electric powertrain that unlike an internal combustion powertrain, offers better efficiency as less energy is wasted. An internal combustion powertrain loses about 70% of its energy to heat, vibration, and friction, while about 90% of an electric vehicle's energy gets applied to the wheels, offering much better torque at low speeds (Dye, 2013). Traditionally, the batteries of electric vehicles are charged by plugging them into the existing electrical power grid at a charging station (U.S. Department of Energy, 2013c). Additionally, plug-in hybrid electric vehicles utilize an internal combustion engine to supplement the electric powertrain, serving as an on-board generator for the batteries to extend range through the electrical powertrain, distinguishing them from traditional hybrid vehicles where both an internal combustion powertrain and an electrical powertrain both drive the vehicle in cooperation (U.S. Department of Energy, 2013a). Both electric vehicles and plug-in hybrid electric vehicles generate zero emissions when operating in electric mode, and there is currently enough capacity in the United States electrical system whereby no additional emissions are created; only 5% of the time is the demand on the electrical grid over 90% of capacity, with average demand around 50% of capacity (U.S. Department of Energy, 2013d). Unfortunately, after examining electrical vehicle adoption projections from the University of California-Berkeley, the U.S. Energy Information Administration, the Electric Power Research Institute, the U.S. National Renewable Energy Laboratory, and the Argonne National Laboratory, a 30% market penetration of electric vehicles and plug-in electric vehicles (cars) can be expected by 2030 (van Vliet, Brouwer, Kuramochi, van den Broek, & Faaij, 2011, pp. 2298, 2301). However, at this market penetration uncoordinated charging, charging whenever needed,

during peak periods is unsustainable; though overall demand on the electrical power would only increase by 35%, uncoordinated charging would increase demand by 54% during peak periods, exceeding capacity (van Vliet et al., 2011, pp. 2298, 2305). It is important to note that these estimates do not include any medium- or heavy-duty electrical vehicles.

Propane as a fuel. Propane is a byproduct of both the crude oil refining process and a natural gas processing that is commonly used as an energy source for heavy industry, heating, agriculture, refrigeration, cooking, and as a transportation fuel (U.S. Department of Energy, 2013k). While propane's use as an energy source only accounts for 2% of energy usage in the United States, its use as a transportation fuel only accounts for 0.04% of all energy usage in the United States despite being the third most common engine fuel in the world (U.S. Department of Energy, 2013k). For use as a vehicle fuel, propane is compressed to 150 psi to liquefy the gas, as the energy intensity of propane as a liquid is about 270 times higher than in its gaseous form (U.S. Department of Energy, 2013k). Propane has a higher octane rating than gasoline, ensuring higher compression during the combustion stroke of an internal combustion engine, resulting in more power to be extracted per engine stroke (U.S. Department of Energy, 2014m). However, gasoline has a higher British Thermal Unit rating, meaning gasoline has more energy than propane for the same quantity of fuel (U.S. Department of Energy, 2014m). As a result, propane vehicles are typically not as fuel efficient. It is possible to convert gasoline engines to combust propane, and typically some of the benefits that will be realized are lower emissions as propane has a lower carbon content and reduced engine wear due to less interaction with the lubricating oil (U.S. Department of Energy, 2014m).

Natural gas as a fuel. As a fuel, natural gas is either sold as CNG or LNG. Natural gas is pressurized between 3000 psi and 3600 psi for use as CNG fuel, and as CNG powertrains are completely sealed to ensure pressure throughout, there are no evaporative emissions (U.S. Department of Energy, 2013i; U.S. Department of Energy, 2014l). Natural gas is cooled down to -260° F to liquefy it for use as LNG fuel, which is typically used in longer range vehicles when compared to CNG as the energy density is much higher (U.S. Department of Energy, 2013i). As with propane, natural gas, having a lower carbon content, emits less than gasoline, though only on a magnitude of 6% to 11% when lifecycle emissions are considered (U.S. Department of Energy, 2013j).

Ethanol as a fuel. Prior to the emergence of gasoline as the dominant fuel, several vehicle manufacturers expected ethanol, a type of alcohol, would become the prevailing energy source for vehicular travel (U.S. Department of Energy, 2014g). Currently, 95% of the gasoline sold in the United States is an ethanol blend, either E10 or E15, containing 10% or 15% ethanol respectively (U.S. Department of Energy, 2014g) (U.S. Department of Energy, 2013e). However, neither E10 nor E15 meet the 85% alcohol content threshold set by the Energy Policy Act of 1992 for being classified as an alternative fuel. Ethanol is most commonly sold as an alternative fuel in a 15% gasoline – 85% ethanol blend, E85 (U.S. Department of Energy, 2014f). In addition to vehicles designed to run exclusively on E85, there are flexible fuel vehicles, commonly “FlexFuel” vehicles, that can run on ethanol and gasoline blended in any ratio (U.S. Department of Energy, 2014f). In the United States, ethanol is primarily derived from corn starch (U.S. Department of Energy, 2014f). Ethanol reduces life-cycle emissions by 52% compared to traditional gasoline, however, cellulose is currently being investigated as it would reduce life-cycle

emissions by another 34% and eliminate food security concerns (U.S. Department of Energy, 2014f). Similar to propane, ethanol is higher in octane than gasoline, but less efficient by 27% due to lower Btu per gallon of fuel (U.S. Department of Energy, 2014f).

Hydrogen as a fuel. Similar in that they utilize an electric powertrain, hydrogen-fueled vehicles generate electricity from a fuel cell instead of storing it in a battery (U.S. Department of Energy, 2014h). In a fuel cell, hydrogen molecules are split, releasing electrons that are captured to drive an electric motor. The negatively charged hydrogen atoms then bind with oxygen which produce the only emission: water vapor (U.S. Department of Energy, 2010, p. 1). Currently, fuel cells are about 60% efficient in their conversion of hydrogen to electricity (U.S. Department of Energy, 2010, p. 1). Additionally, as hydrogen gas has low energy density, it has to be compressed significantly, up to 10,000 psi, liquefied, or bonded with another molecule (U.S. Department of Energy, 2013h).

Biodiesel as a fuel. Biodiesel is a type of diesel fuel that is produced from reprocessed grease from restaurants, animal fat, or vegetable oil and that can either be utilized on its own or as a blend with traditional diesel fuel (U.S. Department of Energy, 2014d). Biodiesel can be substituted for traditional diesel fuel and provide significant emissions benefits as shown in Figure 12.

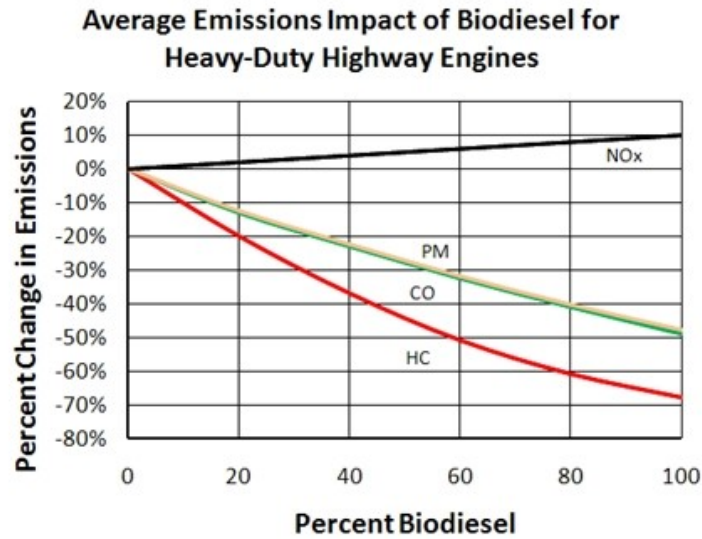


Figure 12. Changes in Heavy-Duty Diesel Emissions with Various Biodiesel Blends. NOx – Nitrogen Oxide, PM – Particulate Matter, CO – Carbon Monoxide, HC – Hydrocarbons. Adapted from *Biodiesel Benefits and Considerations*, by the U.S. Department of Energy, 2014. Public domain.

In addition to the emissions improvements switching to biodiesel offers, biodiesel can improve engine lubrication and raise the Cetane rating, indicating that in a diesel engine, it will combust easier (U.S. Department of Energy, 2014c). In addition to these qualities, more information about biodiesel and other alternative fuels can be found in Table 6 for easy comparison.

Table 6

Comparison of Alternative Fuels

	Gasoline/E10	Diesel	Biodiesel	Propane	CNG	LNG	E85	Hydrogen	Electricity
Fuel Source	Crude Oil	Crude Oil	Animal Fat, Vegetable Oil, Recycled Grease	Petroleum or Natural Gas Processing Byproduct	Underground Reserves	Underground Reserves	Agriculture Byproduct	Natural Gas, Methanol, Electrolysis of Water	Combustion of Fossil Fuels or Renewable Sources
Gasoline Gallon Equivalent (Energy)	100%/96.7%	113%	B100: 103% B20: 109%	73%	5.66 lb: 100%	5.38 lb: 100%	73%-83%	2.198 lb: 100%	33.70 kWh: 100%
Physical State	Liquid	Liquid	Liquid	Pressurized Liquid	Compressed Gas	Cryogenic Liquid	Liquid	Compressed Gas or Liquid	Electricity
Cetane Rating	-	40-55	48-65	-	-	-	0-54	-	-
Octane Rating	84-93	-	-	105	≥120	≥120	110	130	-
Maintenance Concerns	-	-	Hose Wear	-	High-Pressure Tank Inspections	Tank Pressure Must Be Periodically Relieved	Special Lubricants May Be Required	High-Pressure Tank Inspections	Battery Replacement

Note. Adapted from *Alternative Fuels Data Center – Fuel Properties Comparison*, by the U.S. Department of Energy, 2014. Copyright 2014 by the U.S. Department of Energy. Public domain.

Alternative fuel pricing. A common way of comparing the various types of alternative fuels is the Gasoline Gallon Equivalent, which quantifies the amount of a fuel required to contain the same amount of energy as one gallon of gasoline. Since 2000, the U.S. Department of Energy has tracked the price of alternative fuels by quarter, and the average national prices are shown in Figure 13.

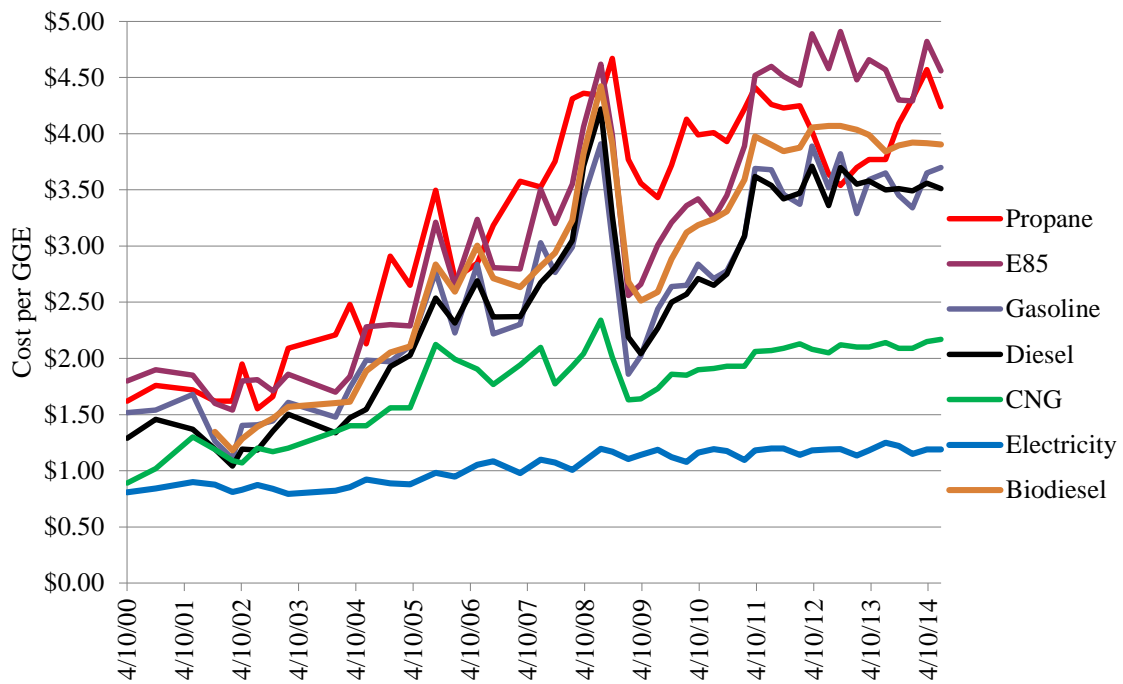


Figure 13. Average National Cost per Gasoline Gallon Equivalent of Vehicle Fuels by Quarter. Adapted from *Fuel Prices* by the U.S. Department of Energy, 2014. Public domain.

The U.S. Department of Energy has not included information about LNG or hydrogen in their fuel price reporting as not enough stations of those types participate in the reporting program (U.S. Department of Energy, 2014e). While roughly 500 stations of

each other fuel type participate, only 5 hydrogen stations and 30 LNG stations participate (U.S. Department of Energy, 2014e, pp. 3, 6). The average price reported in July 2014 for hydrogen was \$5.88 and the average price reported for LNG was \$2.65 per gasoline gallon equivalent (U.S. Department of Energy, 2014e, pp. 3, 6). It should be noted that the prices of alternative fuels are not always less than that of either gasoline or diesel, and fluctuate with market forces like gasoline and diesel do.

The current low-cost of natural gas due to hydraulic fracturing within the United States is pushing an expansion of the use of the fuel in the transportation sector (Cardwell & Krauss, 2013). The United States Energy Information Administration expects under ideal market conditions, natural gas vehicles could potentially account for 32% of heavy-duty vehicles by 2035, up from 0.2% in 2010 (U.S. Department of Energy, 2012a, p. 40). Citigroup more aggressively forecasts that 30% of heavy-duty vehicles would run on natural gas by 2020 (Cardwell & Krauss, 2013). The comparative low-cost of alternative fuels has not only lead to customers pressuring transportation providers to investigate its usage, notably by Walmart and Nike, but providers have begun to recognize the benefits as well (Cardwell & Krauss, 2013). UPS, after extensive study, has announced plans to shift 1 billion vehicle miles to alternatively fueled vehicles by 2017, and to do so, it is purchasing natural gas long-haul vehicles, partnering with fuel providers to help build-out the natural gas infrastructure, and purchasing electric short-haul vehicles (Goossens, 2013). UPS' chief sustainability officer indicated that the company expects to achieve a 40% cost reduction within its trucking fleet through these changes (Goossens, 2013).

Barriers to alternative fuels. Sierzchula (2014) conducted a survey of American and Dutch fleet managers whom had purchased electrical vehicles for public, commercial,

and industrial usage to determine factors that influenced their initial purchase and factors that encouraged or discouraged expansion of their electrical fleet. Factors for the initial purchase and/or expansion of an existing fleet included: government grants or subsidies, government regulations, the advantage of being an early adopter of new technology, trial experience for potential future use, lower fuel and maintenance costs, fixed routing to allow for a centralized charging point, ownership of the charging infrastructure, lower environmental impact, and public relations (Sierzchula, 2014, p. 131). Factors that fleet managers felt discouraged any fleet expansion included: vehicle capabilities did not meet expectations, low vehicle range, time lost due to charging vehicles, and the lower operational costs not justifying the high purchase price (Sierzchula, 2014, p. 132).

Petsching, Heidenreich, and Spieth (2014) attempted to utilize two established social psychological theories, the theory of reasoned action and the theory of innovation adoption, to develop an alternative fuel vehicle adoption model (p. 69). Factors identified as influencing attitude formation included: relative advantage or extent to which the new technology is perceived as being superior over existing technology, compatibility with previous experiences, ease-of-use, observability of innovation compared to existing technology, trial experiences, perceptions of the environment, perception of prestige among others, product design, profitability, physical risk, and functional risk of adopting a technology that fails (pp. 71-73). Additionally, perceptions personal and social norms are included (pp. 73-74). One-thousand and eighty Germans responded to a questionnaire that was developed to measure perceptions of each factor through rankings, and structural equation modeling using partial least squares regression was employed to determine relationships between each factor and their respective levels of significance in the

decision making process (pp. 75-76). Petsching et al. (2014) found that the most important decision elements were traditional vehicle purchase decisions (reliability, design, safety, etc.) and compatibility, suggesting that vehicle manufacturers should stress accessibility to the refueling infrastructure when attempting to sell alternatively fueled vehicles (p. 80).

The results from Sierzchula's (2014) and Petsching, Heidenreich, and Spieth's (2014) studies highlighted a common issue among adoption of any alternative fuel vehicle: the refueling process (Petsching et al., p. 80; Sierzchula, p. 131). Sperling and Kurani (1987) studied diesel vehicle adoption in the 1980s and suggested that the threshold for consumer adoption of an alternative fuel would be a 10% to 15% level of market saturation of traditional fuel stations (as cited in Melania, Bremson, & Solo, 2013, p. 1). Further examination of CNG vehicle adoption in New Zealand by Kurani (1992) and diesel stations in California by Nicholas, Handy, and Sperling (2004) revised this threshold down to 10% (as cited in Melania, Bremson, & Solo, 2013, p. 1). Melania, Bremson, and Solo (2013) attempted to look at the time cost penalty, in terms of a cost against a new vehicle, for taking longer trips due to the lack of market penetration that drivers of alternatively fueled vehicles faced. Their studies of drivers in the Los Angeles, Atlanta, Seattle, and Minneapolis-St. Paul metropolitan areas, exposed that drivers faced a \$750 to \$4,000 cost penalty for trips within the Metropolitan area, and cost penalties between \$3,500 to \$12,000 for medium- and long-range trips (Melania, Bremson, & Solo, 2013, p. 18). Medium-range trips were defined as those under 150 miles in order to allow for a 300 mile typical vehicle range (Melania, Bremson, & Solo, 2013, p. 18).

Kang and Recker (2014), assuming traditional fueled vehicle trips represented the ideal, utilized 392 trips selected from the California Household Travel Survey, inserted a stop for refueling a hydrogen fuel cell vehicle or electrical vehicle and ran the Household Activity Pattern Problem to determine the cost penalty for having to refuel those vehicles on a per trip basis (p. 31). Southern California trips were selected as three out of the five “early adopter” alternative fuel vehicle clusters in California were located in the region, as well as limited hydrogen and electrical infrastructure (p. 32). The Household Activity Pattern Problem, derived by Recker (1995), predicts the optimal path through space and time as a series of tasks are completed by a household member (p. 61). Considering a value of time of \$30 per hour, a \$22 to \$38 additional time value cost can be expected on the day that the owner of a hydrogen fuel cell vehicle has to refuel (Kang & Recker, 2014, p. 40). Depending on the charging infrastructure utilized, for 5.6-hour fast-charge stations, drivers can expect an additional cost of \$6 to \$10; however, drivers utilizing 15-hour standard charge stations could expect an additional cost of \$47 to \$50 due to the extended charge time (Kang & Recker, 2014, pp. 36, 40).

Comparison of freight transportation planning strategies to reduce emissions.

Despite significant research being done on the effectiveness of various emission reduction strategies, not much work has been done of a comparative nature between the different planning transportation levels. Alam and Hatzopoulou (2014) attempted to quantify the potential emissions reductions along a corridor in Montreal that were achievable in buses through traffic operations (tactical planning level) and alternative fuels (strategic planning level), employing the traffic microsimulation software package VISSIM in conjunction with the U.S. Environmental Protection Agency’s Motor Vehicle

Emissions Simulator (MOVES) (pp. 129, 131). Their study focused only on CNG as an alternative fuel, and found that CNG use reduced greenhouse gas emissions by 8% to 16%, while traffic operations like signal priority and dedicated lanes reduced emissions by 14% (Alam & Hatzopoulou, 2014, p. 129).

Comparing the strategic level and tactical level of freight transportation planning is possible to an extent in a manner similar to how Alam and Hatzopoulou (2014) studied bus emissions. Through traffic microsimulation Karafa (2012) studied freight terminal operations and different strategies for minimizing delay at the gate, concluding that utilizing extended hours is the most efficient way to minimize delay and allow for future capacity growth, with a reduction of emissions as an ancillary benefit (pp. 75-78).

Through studying an area with high levels of freight traffic, the adoption of gate strategies, a tactical decision about freight operations, and the utilization of alternative fueled vehicles, a strategic decision about freight operations, may be compared as strategies for reducing emissions in the area. Where public transportation and traffic operations are both typically the domain of a municipal government, freight terminal operations and the vehicles serving the terminals are not always controlled by the same entity, making the potential levels of adoption less clear.

Gonder et al. (2011) found that a 30% to 60% boost to fuel economy is achievable if drivers behave ideally, though unrealistic in real world conditions due to the unpredictability of real-world road conditions (p. 1). More practical savings of 5% to 10% can be achieved through moderate driving styles, but drivers must be sufficiently motivated (p. 1). Unfortunately, the same unpredictability cited by Gonder et al. (2011) remains a challenge in microsimulation, where the interaction of individual vehicles are

simulated on a roadway network (p. 1). Where ideal driving behavior is unachievable in the real-world due to the unpredictability of real-world conditions, in computer simulations where everything is controllable, every attempt is made to mimic real-world conditions instead of applying an ideal. As such, attempting to calibrate driver/vehicle behavior to real world conditions, rather than ideal conditions, is desired in microsimulation.

The Lamar Corridor in Memphis, Tennessee. In 2009, the U.S. Department of Transportation, the U.S. Environmental Protection Agency, and the U.S. Department of Housing and Urban Development entered into an interagency “Partnership for Sustainable Communities” at the direction of President Barack Obama in order to cooperatively increase transportation mode choices while reducing transportation costs, protect the environment, and provide greater access to affordable housing through the incorporation of six principals of livability (U.S. Department of Transportation, 2014a). These six principals include: providing more transportation choices; promoting equitable, affordable housing; enhancing economic competitiveness; supporting existing communities; coordinating and leveraging federal policies and investment; and valuing communities and neighborhoods (U.S. Department of Transportation, 2014a).

The city of Memphis, Tennessee is a major freight transportation hub due to its geographic location near the center of the United States, access to five Class I railroads, the second largest cargo airport in the world, and the fourth largest inland port in the United States (Airports Council International, 2014, p. 4; Intermodal Freight Transportation Institute, 2012; Port of Memphis, 2014). The Lamar Corridor is a 6.5 mile section of U.S. Highway 78 in Memphis that travels from I-240 south toward the

Tennessee-Mississippi border. The area is home to the Memphis International Airport, the FedEx World Hub, the BNSF Railway Memphis Intermodal Facility, as well as other manufacturing, warehouse, and commercial land uses that generate high levels of freight traffic (Cambridge Systematics, Inc., 2011). The Lamar Corridor is highlighted in red in Figure 14.

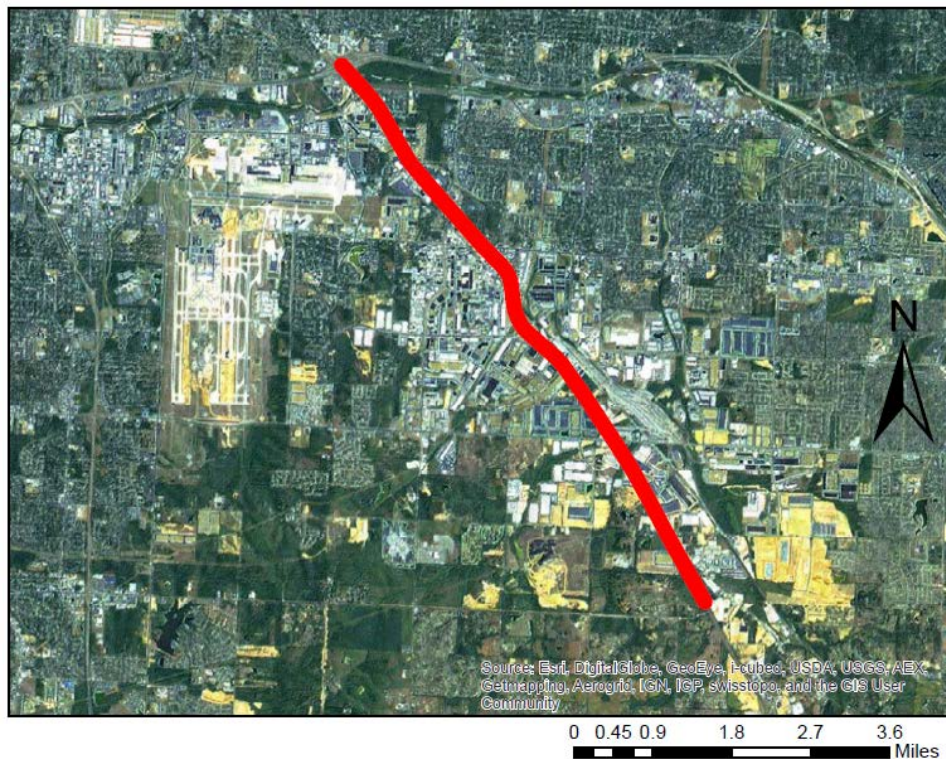


Figure 14. Lamar Corridor in Memphis, Tennessee

The area has been recognized by the Partnership for Sustainable Communities (a consortium consisting of the U.S. Department of Transportation, the U.S. Environmental Protection Agency, and the U.S. Department of Housing and Urban Development focused on livability) as a target area for livability improvements due to “blight, concentrated poverty and crime, and poor esthetics and connectivity” due to poor land

use planning in the area resulting with neighborhoods being juxtaposed with the previously mentioned industrial and commercial activities (U.S. Department of Transportation, 2014b). This identification resulted in funding the Aerotropolis/Lamar Corridor Initiative at a level of \$1,260,905 through the U.S. Housing and Urban Development and the U.S. Department of Transportation grants in 2010 to study methods to improve livability in the area (Daniels & Meeks, 2010).

The University of Memphis' Intermodal Freight Transportation Institute on behalf of the Memphis Urban Area Metropolitan Planning Organization surveyed 114 transportation industry professionals and found that a majority employed some operational strategy in order to minimize delay due to congestion, with gate strategies being the most common response and extended hours being the most common gate strategy (Mersereau, 2014, p. 19). As Morais and Lord (2006) discussed, buy-in from players in the transportation industry is a key factor to the success of any gate strategy, and having this buy-in already existent supports the decision to study the impact of extended hours. Additionally, in Mersereau's (2014) study (p. 39), when asked about the potential use of alternative fuels, transportation professionals were receptive of the idea for reasons similar to those found by Sierzchula's (2014) study of American and Dutch fleet managers (p. 131). This indicates that an alternative fuel strategy may also be viable in the Lamar Corridor.

Methodology

According to the Federal Highway Administration, "livability in transportation is about leveraging the quality, location, and type of transportation facilities and services available to help achieve broader community goals such as... enhancing the natural

environment through... enhanced air quality, and decreased green house [*sic*] gasses” (Rue et al., 2011, p. 6). Considering this definition of livability that includes air quality, the large number of transportation-related businesses in the vicinity of the Larmar Corridor and that the Lamar Corridor has already been selected by the U.S. Government as an area to be targeted for livability improvements, the Lamar Corridor is an ideal location to study the implications of extended gate hours versus alternative fuels as strategies for emissions reductions. This process can be accomplished through a combination of traffic microsimulation and emissions modeling. A flowchart of the methodology followed for comparing these strategies is in Figure 15.

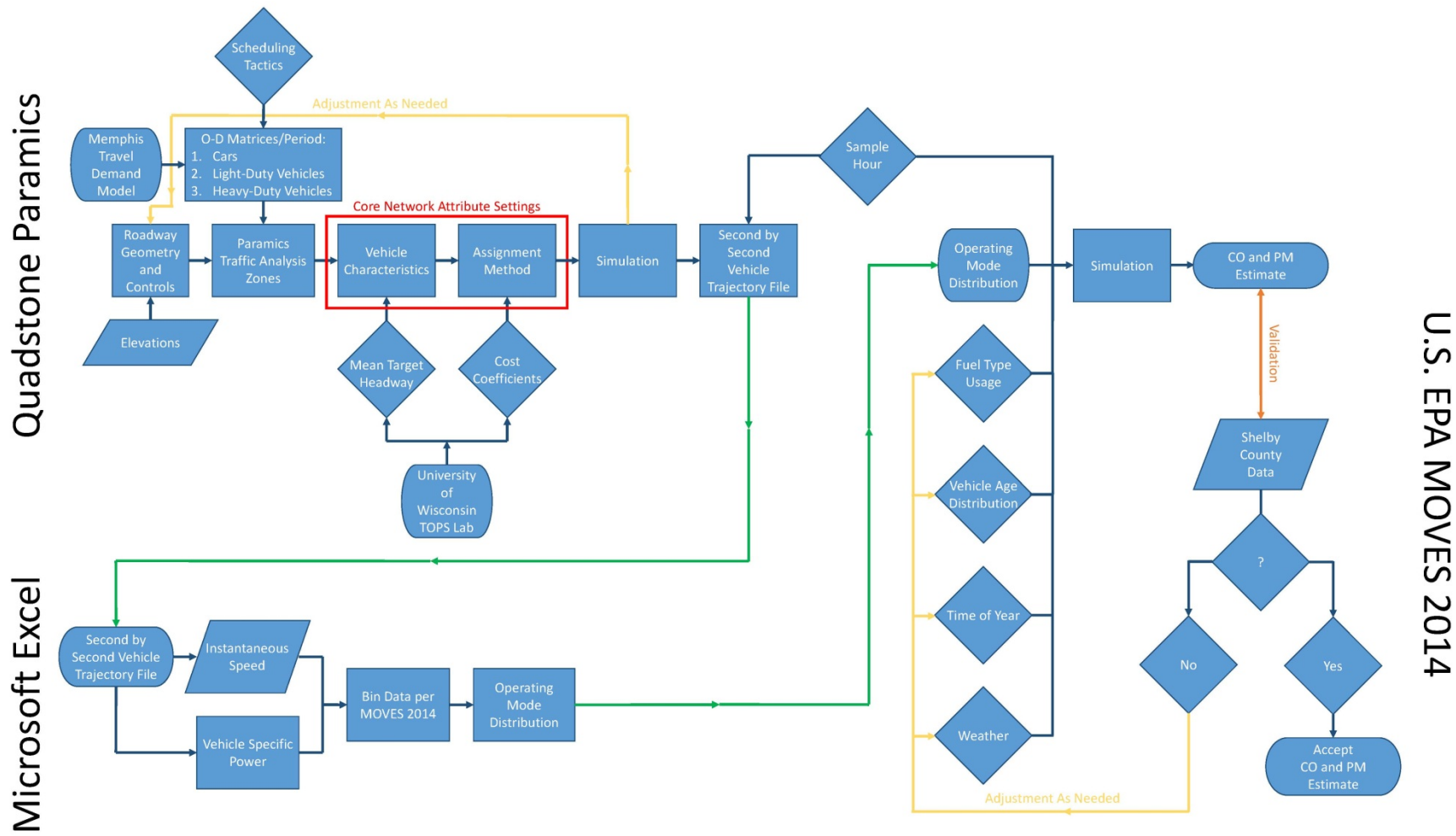


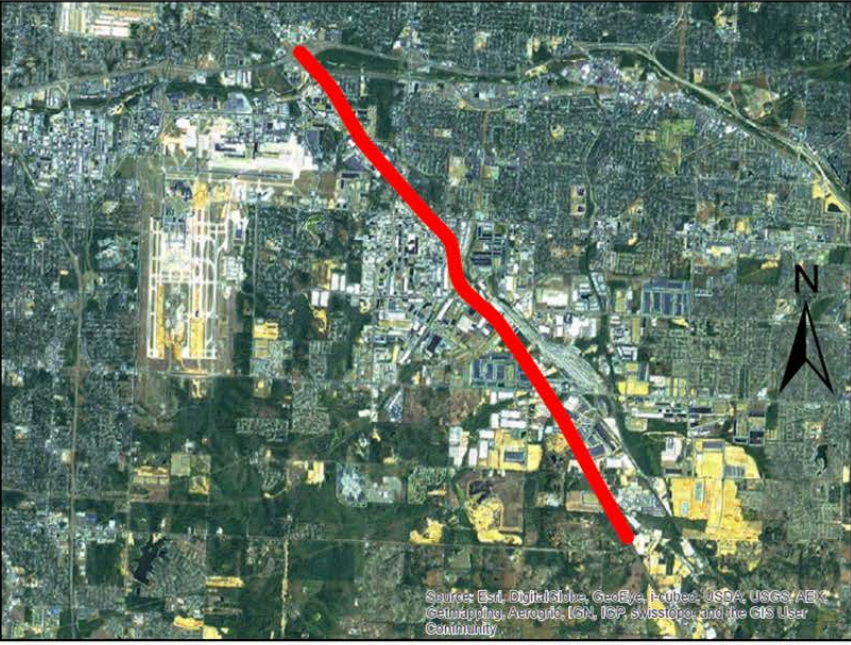
Figure 15. Methodology Flow Chart

Microsimulation of the Lamar Corridor

Traffic microsimulation allows the creation of a computer model of a selected element of transportation infrastructure and the simulation of roadway traffic at the microscopic level of detail, revealing the interactions of individual vehicles with one another and how they respond to the roadway network instead of an aggregated simulation of vehicle flows (PitneyBowes Software, 2014). Several types of traffic microscopic simulation software suites are available, including Quadstone Paramics, AIMSUN, INTEGRATION, VISSIM, TRANSIMS, CORSIM, and Synchro, many of which are able to integrate with some form of emissions modeling (Chamberlin & Talbot, 2013). Ratrouf and Rahman (2009) conducted an extensive comparison of various traffic microsimulation models in different applications and concluded that despite their differences, their variability did not prove substantial (as cited in Karafa, 2012, p. 13).

An existing Quadstone Paramics model of the Lamar Corridor area was selected for use as the basis for this research. This model, developed by and used with permission from Dr. Mihalis M. Golais and Alireza Naimi from the University of Memphis, was developed between 2010 and 2012 utilizing 2010 data from the Memphis Urban Area Metropolitan Planning Organization. The model utilizes three Origin-Destination (O-D) matrices derived from the Memphis Travel Demand Model for each vehicle class (cars, light-duty trucks, heavy-duty trucks) for the morning peak period (6:00 AM to 9:00 AM), the midday period (9:00 AM to 2:00 PM), the evening period (2:00 PM to 6:00 PM), and the overnight period (6:00 PM to 6:00 AM). These demands represent a typical weekday and there is no demand heterogeneity by income class, value of time, or trip purpose. It should be noted that two types of heavy-duty vehicles utilize the heavy-duty O-D matrix:

Single Unit Long-Haul Trucks (OGV1 in Paramics), and Combination Long-Haul Trucks (OGV2 in Paramics). Roadway geometry elements, traffic analysis zones corresponding to the O-D matrices, and traffic control elements (speed limits, traffic signals and their timings) all were entered into Quadstone Paramics and calibrated to ensure smooth operation. An aerial comparison of the model and the Lamar Corridor, showing the model's roadway network and the traffic analysis zones, is shown in Figure 16 with the Lamar Corridor highlighted in red in each case.



Source: Esri, DigitalGlobe, GeoEye, Earthstar (USA), USGS/AEX, GeoEye, AeroGRID, IGN, IGP, swisstopo, and the GIS User Community

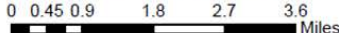


Figure 16. Aerial Views of the Quadstone Paramics Lamar Corridor Model (Left) and the Lamar Corridor (Right)

It should be noted that while the location, geometry, and data of the Traffic Analysis Zones in the model do correspond with those of the U.S. Census Bureau, they are numbered sequentially instead of utilizing the U.S. Census Bureau numbering scheme.

Several changes were incorporated into the model prior to running the simulations for this project. First, as the data used in the generation of the model was from 2010, a growth factor was applied to ensure a valid representation of 2014 conditions. The growth factor was obtained from the Memphis Travel Demand Model documentation, which indicates expected growth in travel along the Lamar Corridor to occur at a rate of 2.2% per year (Memphis Urban Area Metropolitan Planning Organization, 2012, p. G7). However, as data was unavailable to validate the model for future years, only the 2010 scenario was completed, as the O-D matrices were known to be correct. Second, the initial model did not incorporate any elevation changes. Elevation can have a significant impact on emissions: Boriboonsomsin and Barth (2009) found that passenger car fuel consumption can increase by 15% to 20% over level travel rates when subjected to rolling terrain while Zhang and Frey (2006) found that emissions can increase by over 40% on roads with a fractional grade greater than +5% (as cited in Wyatt, Li, & Tate, 2014, p. 161). Wyatt, Li, and Tate (2014) utilized Light Detection And Ranging (LiDAR) with a Geographic Information System (GIS) to incorporate road grade into their traffic microsimulation and found that the Technical University of Graz's Passenger car and Heavy duty Emissions Model (PHEM) estimates of carbon dioxide emissions were improved to be between 80% and 110% of actual recorded emissions over the same roadway segment, leading them to stress the importance of including elevations in the microsimulation process (Wyatt et al., 2014, pp. 160-161, 169). Elevations for the

Quadstone Paramics model of the Lamar Corridor were obtained through Google Earth, which utilizes the NASA Shuttle Radar Topography Mission dataset, obtained through the utilization of high-resolution radar scanning of the earth during NASA Space Shuttle mission STS-99 (Ramirez, 2009). Finally, the Mean Target Headway and Generalized Cost Coefficients were modified in accordance with Quadstone Paramics guidelines developed by the University of Wisconsin Traffic Operations and Safety Laboratory for the Wisconsin Department of Transportation (Wisconsin Department of Transportation, 2014). The default Mean Target Headway is calibrated to British drivers and was adjusted to 0.90 seconds; the default Generalized Cost Coefficients only include a time coefficient of 1 and were set to 0.667 for time and 0.333 for distance (Wisconsin Department of Transportation, 2014). With these changes incorporated, the simulations were run for each period, and a separate Vehicle Trajectory File was generated for every second of simulation time, revealing each vehicle's position, grade, instantaneous velocity, and instantaneous acceleration on the network. As only the Lamar Corridor is being studied, the Vehicle Trajectory Files were filtered to only include data from the links along the corridor.

U.S. Environmental Protection Agency MOVES

There has been a recent trend to couple emissions models with microscopic transportation models due to the much more detailed level of analysis allowed by examining dynamic vehicle operations over a given series of timestamps (Malone & Chamberlin, 2011). While Quadstone Paramics does include an emissions modeling plugin component and can easily interface with several other emissions models, the decision was made to utilize the U.S. Environmental Protection Agency's Motor Vehicle

Emissions Simulator (MOVES) despite interaction between the two not currently being supported by either software development groups. MOVES analyses can be conducted at three different scales: the national-level; the count- level, used for emission inventory analysis for transportation conformity under the Clean Air Act; and the project-level, used for detailed carbon monoxide (CO) and particulate matter (PM) analysis of specific segments of a roadway network. Each level of analysis requires increasingly detailed inputs regarding vehicle activity. The use of MOVES has been mandated for CO and PM analysis at the project-level since December 2012 for any project that receives federal funding, any project that impacts or increases the travel of a significant number of diesel vehicles, any project that affects intersections operating at Level-of-Service D or worse, any project that includes a bus or rail terminal due to the congregation of diesel vehicles, or any project that includes a previously identified problematic area (Malone & Chamberlin, 2011; U.S. Environmental Protection Agency, 2012b, pp. 2-3).

There are several elements regarding the Lamar Corridor that would indicate that the utilization of MOVES is appropriate. A study of the Lamar Corridor by the University of Memphis in 2009 found that many of the intersections were already operating at Level-of-Service D or worse at various times of day, as shown by Figure 17 (Cambridge Systematics, Inc., 2011, p. 3-2).

Intersection	a.m. (7:30-8:30)	Lunch (11:30-12:30)	Midday (2:30-3:30)	p.m. (4:30-5:30)	Average
Lamar at American Way	C	C	D	F	D
Lamar at Pearson	B	D	B	B	C
Lamar at Democrat	C	E	B	B	C
Lamar at Knight Arnold	B	C	B	C	C
Lamar at Winchester	F	F	F	F	F
Lamar at Concorde	E	B	A	B	C
Lamar at Shelby	F	F	F	F	F
Lamar at Tuggle	E	F	A	B	D
Lamar at Holmes	F	E	E	F	F
Average	D	D	C	D	D

Figure 17. Average Level-of-Service at Lamar Corridor Intersections in 2009. Adapted from *Lamar Avenue Corridor Study*, by Cambridge Systematics, Inc., 2011, p. 3-2. Copyright 2011 Tennessee Department of Transportation. Public domain.

Additionally, the BNSF Railway Memphis Intermodal Facility is located northwest of the intersection of Lamar Avenue and Shelby Drive. The presence of this facility and many other smaller freight and logistics facilities in the area attract a high level of diesel truck traffic along the Lamar Corridor. Finally, the Lamar Corridor was previously identified as a problematic area regarding livability with the U.S. Housing and Urban Development and the U.S. Department of Transportation funding the Aerotropolis/Lamar Corridor Initiative in 2010, though not specifically due to emissions (Daniels & Meeks, 2010). Despite conducting a study for the Tennessee Department of Transportation regarding capacity along Lamar Avenue, Cambridge Systematics, Inc. (2011) did not utilize MOVES for an emissions estimate, but applied the Federal Highway Administration's Highway Economic Requirement System's pollution impact estimates, which are based upon data from the U.S. Environmental Protection Agency's superseded MOBILE6

model (Cambridge Systematics, Inc., 2011, p. 8-6; Federal Highway Administration, 2005, p. F-4). Additionally, no project-level analysis of the Lamar Corridor has been completed subsequent to the Cambridge Systematics, Inc. report in anticipation of construction of any of the Tennessee Department of Transportation's proposed capacity improvements (Christopher Boyd, personal communication, October 23, 2014). These factors indicate that the utilization of MOVES is an appropriate choice for modeling the Lamar Corridor. In order to ensure compliance with the future conformity targets, the recently released MOVES2014 was selected over MOVES2010b.

On the project-level, a MOVES analysis can only be conducted for a single hour of activity. As four time periods are being modeled in Quadstone Paramics, a single hour was selected for modeling in MOVES in the middle of each period. This allowed traffic flows to be fully formed and as the O-D matrices were the same for each hour within the period, the data collected would be consistent. There are three methods whereby the Vehicle Trajectory Files could be incorporated into MOVES for analysis: Average Speed, Link Drive Schedule, and Operating Mode Distribution (Chamberlin & Talbot, 2013, p. 8). The Average Speed method aggregates the calculated average speed of each vehicle over a given roadway link and MOVES utilizes assumptions regarding vehicle activity (deceleration, acceleration, etc.) to generate an emissions output (Chamberlin & Talbot, 2013, p. 9). However, this methodology would not provide accurate emissions estimates as vehicle activity can vary greatly from vehicle to vehicle over the same link, yet the vehicles can still have the same average speed (Barth et al., 2000, p. 259). Additionally, idling is underrepresented as the average speed will never equal zero unless all vehicles on the same link are idling (Zhao & Sadek, 2013, p. 883). The Link Drive Schedule

method utilizes a *k*-means clustering algorithm to cluster similar vehicle trajectories together (Chamberlin & Talbot, 2013, pp. 10-11). The generated aggregation of similar trajectories is then simulated in MOVES across each link for each cluster, a potentially computationally intensive process if a large number of vehicle clusters are obtained (Zhao & Sadek, 2013, p. 883). With both the Average Speed and Link Drive Schedule methods, MOVES internally determines an Operating Mode Distribution, or percentage of time that each vehicle is operating in various modes (idling, accelerating, etc.) (Chamberlin & Talbot, 2013, p. 13). However, the Operating Mode Distribution method allows a user-defined Operating Mode Distribution to be entered. Through the utilization of second-by-second vehicle trajectories, this may be done accurately. When comparing the three methods, Chamberlin and Talbot (2013) found that the Operating Mode Distribution method to be similar to direct measurements, while the Link Drive Schedule method underestimated emissions by 5% and the Average Speed method over estimated emissions by 10% to 20% (p. 22).

Data pre-processing. The information in the Vehicle Trajectory Files must be pre-processed prior to utilization in MOVES as the data is not in a format that is usable. Quadstone Paramics outputs the Vehicle Trajectory Files in Comma Separated Value format, so Microsoft Excel was selected for manipulating the data. First, as 3,600 Vehicle Trajectory Files were generated for each hour of simulation time, these were merged to allow for manipulation of all the data at once. The two components needed to generate an Operating Mode Distribution for MOVES were Instantaneous Speed in mph and Vehicle Specific Power. Instantaneous Speed could be obtained directly from the Vehicle Trajectory Files. Vehicle Specific Power, *VSP*, was calculated using

$$VSP = \left(\frac{A}{M}\right)v + \left(\frac{B}{M}\right)v^2 + \left(\frac{C}{M}\right)v^3 + (a + g \times \sin \theta)v \quad (3)$$

where A is a factor for rolling resistance with units of $\frac{\text{kW} \times \text{s}}{\text{m}}$, B is a factor for rotating resistance with units of $\frac{\text{kW} \times \text{s}^2}{\text{m}^2}$, C is a factor for aerodynamic resistance with units of $\frac{\text{kW} \times \text{s}^3}{\text{m}^3}$, M is a fixed mass factor in metric tons. v is the Instantaneous Speed in $\frac{\text{m}}{\text{s}}$, a is the instantaneous acceleration in $\frac{\text{m}}{\text{s}^2}$, g is the acceleration due to gravity – taken as $9.81 \frac{\text{m}}{\text{s}^2}$, and θ is the fractional road grade at the vehicle’s given position (U.S. Environmental Protection Agency, 2010b, p. 67). The values that were utilized for A , B , C , and M , as determined by the U.S. Environmental Protection Agency (2010b), are provided in Table 7.

Table 7

Coefficients Used to Determine Vehicle Specific Power

Common Name	Paramics Vehicle Type	MOVES Vehicle Type	A	B	C	M
Passenger Car	Car	21	0.156461	0.002002	0.000493	1.4788
Light Commercial Truck	LGV	32	0.235008	0.003039	0.000748	2.05979
Single Unit Long-Haul Truck	OGV1	53	0.498699	0	0.001474	17.1
Combination Long-Haul Truck	OGV2	62	2.08126	0	0.004188	17.1

Note. Adapted from *MOVES2010 Highway Vehicle Population and Activity Data*, by the U.S. Environmental Protection Agency, 2010, p. 71. Copyright 2010 by the U.S. Environmental Protection Agency. Public domain.

Based upon the Vehicle Specific Power and Instantaneous Speed, the Operating Mode could be determined. Each of the 23 Operating Modes, called Bins, are shown in Figure 18.

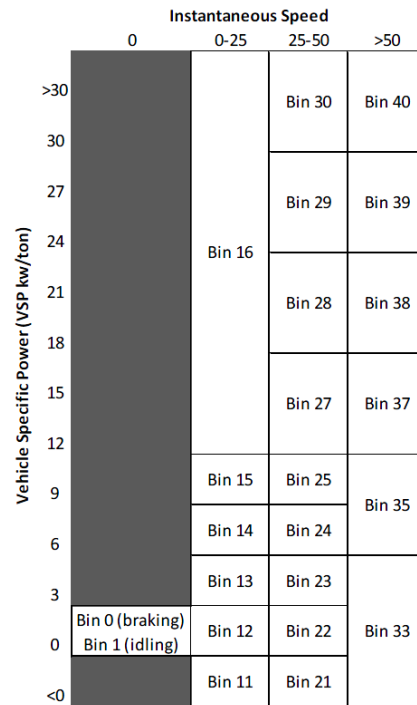


Figure 18. MOVES Operating Modes. Adapted from *MOVES and Transportation Microsimulation Model Integration*, by R. Chamberlin and E. Talbot, 2013, p. 13. Copyright 2013 Resource Systems Group, Inc. Reproduced with permission.

By determining the Operating Mode of each vehicle at each second, an Operating Mode Distribution could be derived for the simulated hour, whereby the fraction of the entire distribution that occurs in each Bin was determined. Thus, a spreadsheet for importing into MOVES was derived including each sourceType (vehicle type), the opModeID (the Operating Modes observed for that type of vehicle), and the opModeFraction (the fraction of the simulation time that was observed in each Operating Mode).

Other MOVES variables. In addition to the Operating Mode Distribution, other variables needed to be entered into MOVES. From the simulation results, the number of vehicles on Lamar and the fraction of each type of vehicle present were entered into the Links and Link Source Type files. The Links file includes information about the roadway segments being modeled, including their length, number of vehicles present, grade, and average speed. As the Operating Mode Distribution incorporates the effect of the roadway grade and actual vehicle speeds, these elements can be ignored. As such, the system can be treated as a single link. Other user-definable variables include temperature, humidity, month and year, time of day, vehicle age distribution, and fuel information. Choi, Beardsley, Brzezinski, Koupal, and Warila (2010) utilized MOVES to study the impact of temperature and humidity on vehicle emissions and found that temperature had the greater effect on both gasoline and diesel emissions, while humidity only tended to significantly impact gasoline fueled vehicles (pp. 4-8). Decreasing temperature tends to increase emissions, while increasing humidity tends to increase emissions (Choi, Beardsley, Brzezinski, Koupal, & Warila, 2010, pp. 4-8). As a result of these relationships, the MOVES guidance for a project-level analysis recommends utilizing January averages for temperature and humidity, in this case: 41.2 F and 57% (National Weather Service, 2014; U.S. Environmental Protection Agency, 2012b, p. 21). The Fuel Supply, Fuel Formulation, Fuel Usage Fraction (the fraction of bi-fuel capable vehicles that operate on each alternate fuel), Fuel/Engine Technology, and Age Distribution were set to default values. These default values are based upon national data regarding gasoline and diesel vehicles.

Model validation. In order to validate the modeling process, model results should be compared with data obtained from the Memphis and Shelby County Health Department's Pollution Control Section as it is the responsible party for emissions modeling and monitoring within the Memphis Urban Area Metropolitan Planning Organization jurisdiction. However, the Memphis and Shelby County Health Department's Pollution Control Section has neither completed a project-level analysis of the Lamar Corridor nor obtained any field data by which such a model could be validated (Christopher Boyd, personal communication, October 23, 2014).

Scenarios modeled. In addition to the existing conditions scenario, two other scenarios were modeled for comparison: the adoption of extended hours and the adoption of alternative fueled vehicles. Multiple estimates peg the adoption of alternative fuels between 15% and 30% by 2035 (BP p.l.c., 2014, p. 25; Cardwell & Krauss, 2013; U.S. Department of Energy, 2012a, p. 40; U.S. Department of Energy, 2014f). The variation is due to uncertainty regarding fuel pricing and future public policy incentives to encourage adoption, and many of the higher adoption rates are resultant of models that see aggressive adoption rates while the lower adoption rates result from oil-industry projections (Plumer, 2013). As a result, a 20% market adoption of alternative fueled vehicles was selected, with the composition of the fleet being derived from the 2011 alternative fueled vehicle population, eliminating hydrogen vehicles as there is no hydrogen infrastructure in the Memphis region (U.S. Department of Energy, 2014a; U.S. Energy Information Administration, 2013). The fuel usage by vehicle type for the alternative fueled vehicle scenario is presented in Table 8. Biodiesel was not included as

is there is insufficient data regarding the number of diesel vehicles that exclusively utilize biodiesel as a fuel.

Table 8

Alternative Fuel Scenario

Fuel	Passenger Car	Light Commercial Truck	Single Unit Long-Haul Truck	Combination Long-Haul Truck
E85 (%)	15.931	15.931	9.251	0.092
Propane (%)	1.491	1.491	5.726	10.412
CNG (%)	1.283	1.283	4.977	8.362
LNG (%)	0.003	0.003	0.028	0.909
Electricity (%)	1.292	1.292	0.019	0.225

Note. Adapted from *How many alternative fuel and hybrid vehicles are there in the U.S.?*, by the U.S. Energy Information Agency, 2013. Copyright 2013 by the U.S. Energy Information Agency. Public domain.

Unfortunately, MOVES does not incorporate many of these vehicle/fuel combinations due to insufficient data. In order to address this, instead of running a single MOVES simulation with 20% of the vehicles running on alternative fuels, two separate simulations were run: one composing of 80% of the vehicles being run on gasoline and diesel in their normal conditions, and another composing of 20% being run on either gasoline or diesel, where each vehicle type is only run on one type of fuel. This allows for shares of the resultant emissions by vehicle type, corresponding to the alternative fuel fleet shares by vehicle type, to be converted to alternative fuel emissions utilizing the conversion rates contained within the Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool developed by the Argonne National Laboratory and the U.S. Department of Energy. AFLEET is intended for fleet managers and stakeholders in the U.S. Department of Energy’s Clean Cities program to compare

lifetime costs, well-to-wheel and on-road emissions, and fuel use by light-, medium-, and heavy-duty vehicles powered by both traditional and alternative fuels (Argonne National Laboratory, 2013). To estimate on-road emissions, AFLEET incorporates MOVES data for traditionally fueled vehicles and U.S. Environmental Protection Agency engine certification data for alternatively fueled vehicles (Argonne National Laboratory, 2013).

The implementation of extended gate hours was based upon expectations of the Ports of Los Angeles and Long Beach's PierPASS extended hours program. Though exceeded, the initial measurement for success of the PierPASS program was if 15% to 20% of truck traffic shifted to night or weekend hours during the first year of the program's implementation (Federal Highway Administrations, 2013). Based upon this level of acceptable first-year usage, 17.5% of truck traffic was shifted to the daytime periods by manipulating the truck O-D matrices. It should be noted that the types of trucks shifted were the Single Unit Long-Haul Trucks and Combination Long-Haul Trucks, as Light Commercial Trucks are smaller and utilized for last-mile services that typically occur during the daytime.

Results and Discussion

The simulations of the existing conditions and extended hours scenarios in Quadstone Paramics generated a cumulative 28,800 separate vehicle trajectory files for that had to be filtered in order to only include data for the Lamar Corridor. These vehicle trajectory files included information about each vehicle traveling on the network at each second, including instantaneous speed, acceleration, and grade. Based upon the simulation outputs, the statistics about each representative hour from each simulated period presented in Table 9 were obtained.

Table 9

Quadstone Paramics Lamar Corridor Representative Hour Simulation Statistics

Period	Scenario	Number of Vehicles	Average Speed (mph)	Data Points
AM Peak	Existing Condition	14,082	21.16	2,617,334
Midday	Existing Condition	10,929	30.62	1,269,259
PM Peak	Existing Condition	14,104	15.66	2,617,056
Overnight	Existing Condition	3,990	34.86	425,363
AM Peak	Extended Gates	13,766	25.79	2,150,995
Midday	Extended Gates	11,284	30.50	1,364,141
PM Peak	Extended Gates	13,975	15.90	2,266,514
Overnight	Extended Gates	4,068	35.23	439,783

Despite modifying the O-D matrices to reduce the number of trucks on the network during the daytime periods in the extended gates scenario, the number of vehicles traveling the Lamar Corridor increased during the midday period. This possibly occurred due to vehicles being routed over the Lamar Corridor that had not been during the existing condition scenario. Despite the increase of 335 vehicles, the average speed only dropped 0.39% - representing the largest change in number of vehicles traveling the Lamar Corridor and the smallest change in average speed. When examining the change in types of vehicles utilizing the corridor during this period, the new vehicles traveling the corridor are all either Passenger Cars or Light Commercial Trucks, vehicles types that retained their original O-D matrices in the Extended Gates scenario, indicating the increase is due to new routings.

The MOVES analysis of the Existing Condition scenario could be utilized to validate the modeling process. For the Existing Condition Scenario, the results for emissions of carbon monoxide (CO), particulate matter smaller than 10 μm in diameter (PM₁₀), and

particulate matter smaller than 2.5 μm in diameter ($\text{PM}_{2.5}$) are given in Figure 19 and Figure 20.

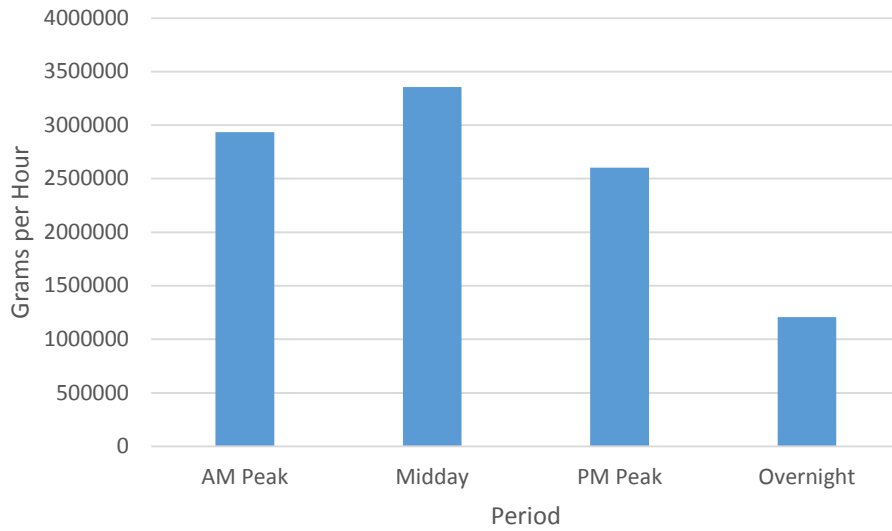


Figure 19. Carbon Monoxide Emissions Produced during the Existing Condition Scenario

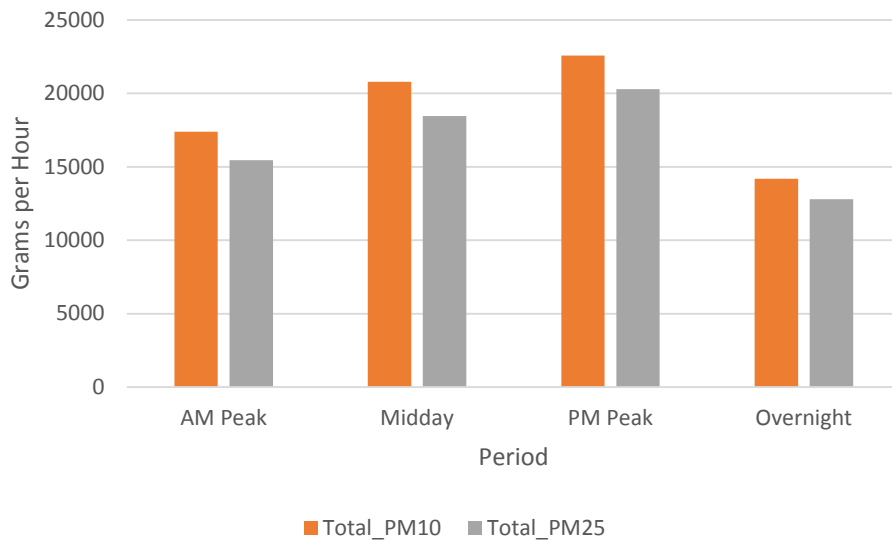


Figure 20. Particulate Matter Emissions Produced during the Existing Condition Scenario

Unfortunately, the Memphis and Shelby County Health Department’s Pollution Control Section, responsible for emissions monitoring and modeling for the Memphis Urban Area Metropolitan Planning Organization, has neither conducted emissions monitoring along the Lamar Corridor, nor conducted a MOVES analysis of the Lamar Corridor in order to compare the results to for validation (Christopher Boyd, personal communication, October 23, 2014). However, 2010 emissions data exists for heavy-duty trucks serving the Ports of Los Angeles and Long Beach, and by comparing the Existing Condition scenario truck traffic to that data, the order of magnitude of the Lamar Corridor emissions may be validated. A comparison of the 2010 Ports of Los Angeles and Long Beach and Lamar Corridor heavy-duty truck traffic is presented in Table 10.

Table 10

Comparison of Heavy-Duty Truck Emissions at the Ports of Los Angeles and Long Beach with the Lamar Corridor

Pollutant	Ports of Los Angeles and Long Beach	Lamar Corridor
CO	352 short tons/year	219 short tons/year
PM ₁₀	30 short tons/year	19 short tons/year
PM _{2.5}	27 short tons/year	18 short tons/year

Note. Adapted from “Reducing truck emissions at container terminals in a low carbon economy: Proposal of a queueing-based bi-objective model for optimizing truck arrival pattern,” by G. Chen, K. Govindan, and M. M. Goliias, August 2013, in *Transportation Research Part E: Logistics and Transportation Review*, 55, p. 4. Copyright 2013 by Elsevier Ltd. Adapted with permission.

Table 10 indicates that the Lamar Corridor emissions are on the correct magnitude, and as expected due to the comparative volumes, less than those produced at the Ports of Los Angeles and Long Beach.

Through comparing the MOVES outputs from the Existing Condition and Extended Gates scenarios, the effect on emissions along the Lamar Corridor of implementing extended hours at the gates may be determined. The results are presented in Figure 21, Figure 22, Figure 23, and Table 11 comparing CO emissions, PM₁₀ emissions, and PM_{2.5} emissions.

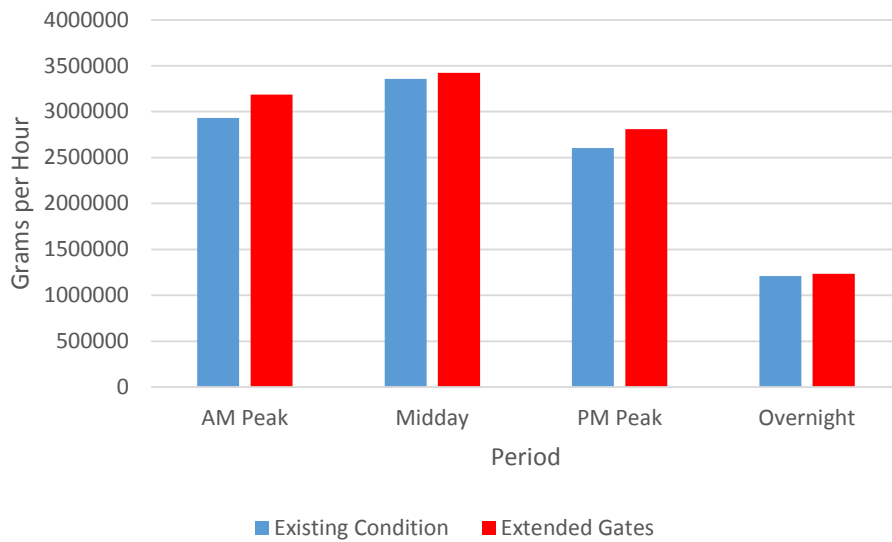


Figure 21. Carbon Monoxide Emissions along the Lamar Corridor in the Existing Condition and Extended Gates Scenarios

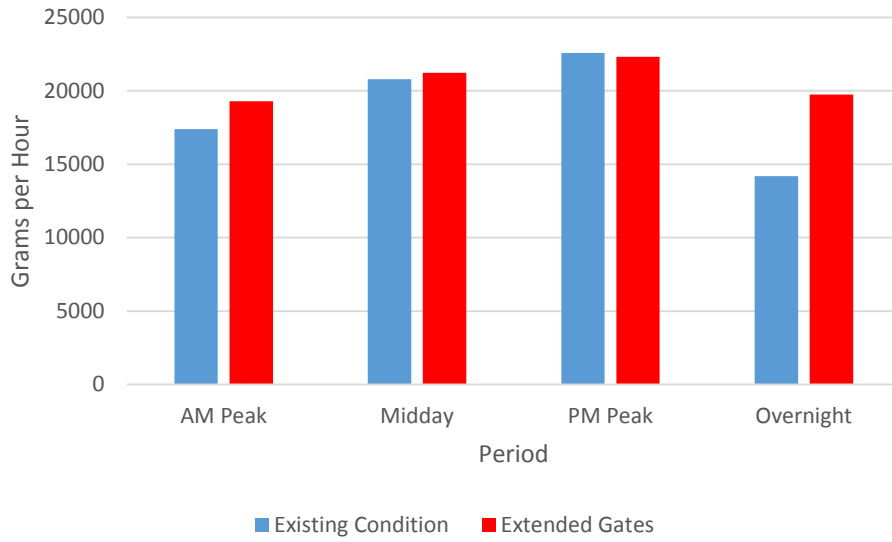


Figure 22. PM₁₀ Emissions along the Lamar Corridor in the Existing Condition and Extended Gates Scenarios

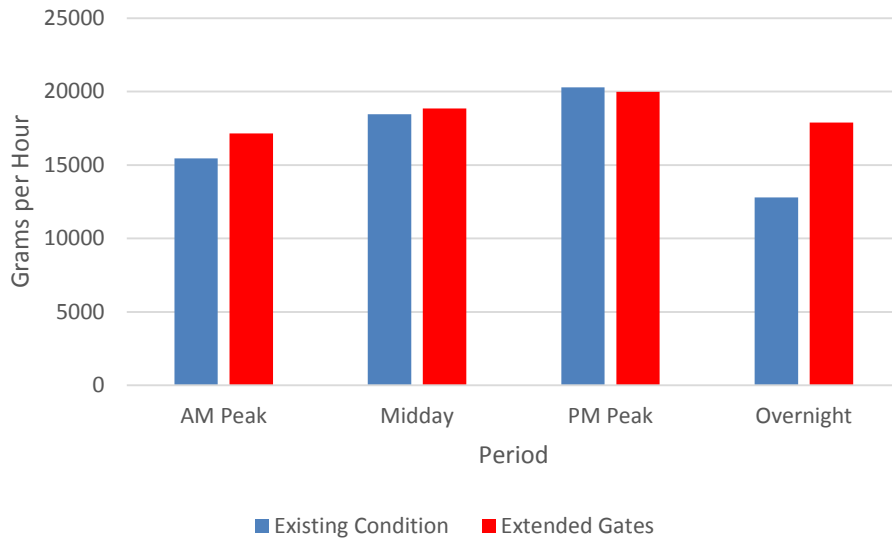


Figure 23. PM_{2.5} Emissions along the Lamar Corridor in the Existing Condition and Extended Gates Scenarios

Table 11

Percent Change per Period between the Existing Condition and Extended Gates Scenarios

Period	CO	PM ₁₀	PM _{2.5}
AM Peak	8.59%	10.93%	10.92%
Midday	1.99%	2.09%	2.12%
PM Peak	7.90%	-1.16%	-1.42%
Overnight	2.18%	39.12%	39.94%

PM emissions increased during every period except during the PM peak period. As the number of trucks on the network increases during each daytime period and as truck traffic, especially diesel truck traffic as it is the greatest contributor to PM emissions, shifting trucks to the overnight period would have the greatest effect on the PM peak period. This effect is represented in Figure 22 and Figure 23. CO emissions increased during every period as well. This can be explained by comparing the Operating Mode Distributions. In 57% of the bins where the engine is applying power, activity increased in the Extended Gates scenario. Reexamining the equation for Vehicle Specific Power, *VSP*, where

$$VSP = \left(\frac{A}{M}\right)v + \left(\frac{B}{M}\right)v^2 + \left(\frac{C}{M}\right)v^3 + (a + g \times \sin \theta)v \quad (4)$$

the first term accounts for rolling resistance and increases linearly with speed, the second term accounts rotating resistance and increases exponentially with speed, the third term accounts for aerodynamic resistance and increases exponentially with speed, and the fourth term accounts for acceleration and road grade and increases linear with speed. As such, it is intuitive that as speeds increase on the network, the power being applied by each vehicle would also increase, thereby producing more emissions. This indicates that shifting 17.5% of truck traffic to the overnight period did not reduce traffic enough on the

Lamar Corridor whereby the increases may be offset. The Ports of Los Angeles and Long Beach sought to shift 15% to 20% of daytime truck traffic during the first year of the PierPASS program, and in the case of the Lamar Corridor, it appears that the shift of this amount of truck traffic may have been too low to reduce emissions (Federal Highway Administrations, 2013). While Karafa (2012) showed that emissions at freight terminals themselves can be reduced through gate strategies that reduce the number of vehicles waiting for service at the facilities, it appears that implementing such strategies may have an adverse effect on emissions along the corridor serving said facilities, especially if the corridor serves a mix of traffic types. It is important to note that the Quadstone Paramics model did not incorporate the facilities themselves, so any emissions benefit or drawback at the facility gates are not included.

While the implementation of extended gate hours and shifting 17.5% of truck traffic to overnight operations was unsuccessful at reducing emission along the Lamar Corridor, the utilization of alternative fuels by 20% of the vehicle fleet was able to lower emissions. These reductions are shown in Figure 24, Figure 25, Figure 26, and Table 12 for CO emissions, PM₁₀ emissions, and PM_{2.5} emissions.

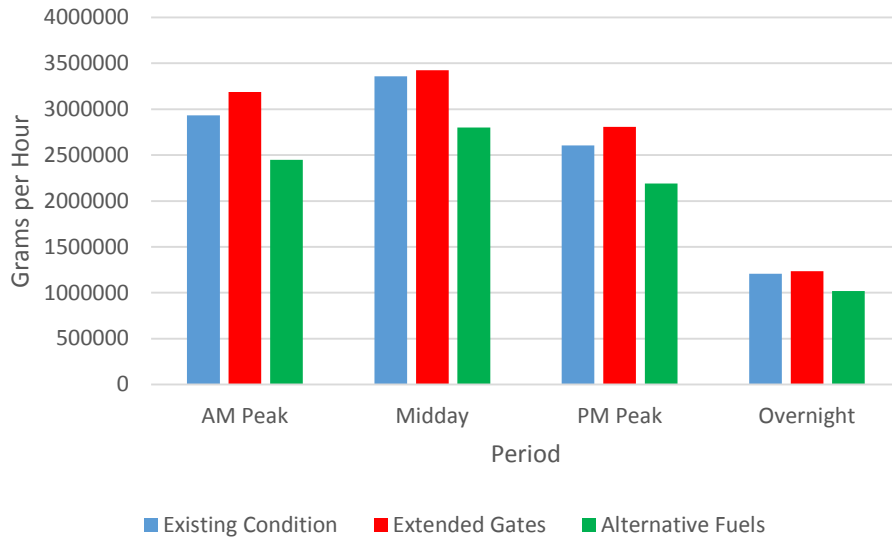


Figure 24. Carbon Monoxide Emissions along the Lamar Corridor in All Scenarios

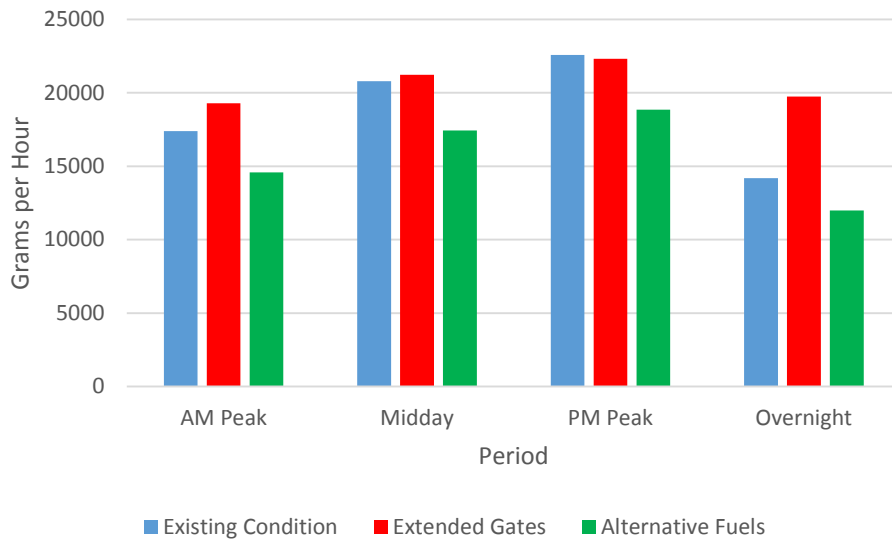


Figure 25. PM₁₀ Emissions along the Lamar Corridor in All Scenarios

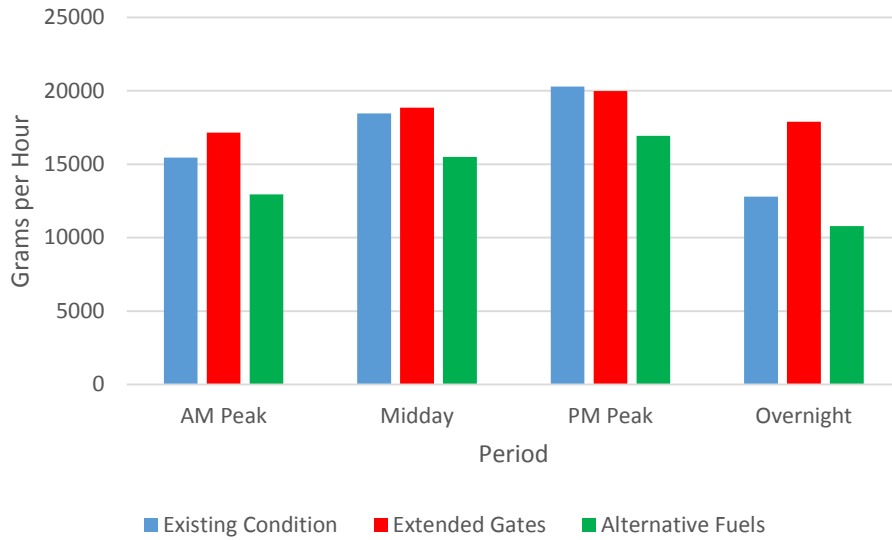


Figure 26. PM_{2.5} Emissions along the Lamar Corridor in All Scenarios

Table 12

Percent Change per Period between the Existing Condition and Alternative Fuels Scenarios

Period	CO	PM ₁₀	PM _{2.5}
AM Peak	-16.57%	-16.20%	-16.17%
Midday	-16.56%	-16.11%	-16.07%
PM Peak	-15.89%	-16.55%	-16.54%
Overnight	-15.57%	-15.56%	-15.62%

All figures indicate a reduction of each type of emissions in each period. When strictly comparing heavy-duty truck emissions, heavy-duty trucks produce 9.90% more CO emissions, but 17.17% fewer PM₁₀ emissions and 17.18% fewer PM_{2.5} emissions. The increases in CO emissions result primarily from E85, Propane, and CNG applications. In the case of E85, the entire well-to-wheel process must be considered in order for an emissions reduction to be evident, as the carbon emission is balanced by the carbon absorption during photosynthesis when the feedstock crops are grown (U.S. Department

of Energy, 2014f). Propane primarily also only offers benefits when considering life cycle emissions, typically on the magnitude of 10% (U.S. Department of Energy, 2013l). In the case of CNG, CO is indicated by the U.S. Department of Energy to be an emission of primary concern (2013j).

Although benefits are observed when alternative fuels are utilized, as a strategic-level freight planning decision, the ability for these fuels to be utilized must also be considered. The lack of hydrogen infrastructure in the Memphis region excluded it as a viable alternative fuel, and as such, it was not included in the modeling process. While a limited refueling infrastructure does exist for the other alternative fuels, not all trips are possible. Utilizing an assumed maximum one-way vehicle range of 150 miles to allow for a return trip on a single tank, similar to Melania, et al. (2013), the range of trips possible with one refueling stop were plotted in Esri ArcGIS utilizing known station locations and the buffer tool, and propane was found to allow for the greatest range of trips and have the greatest station density, as shown in Figure 27. However, it should be noted that E85 capable vehicles can typically also run on gasoline and biodiesel and traditional diesel may also be interchanged. Major metropolitan areas that are accessible in a propane-fueled vehicle with one refueling stop include Jackson, Mississippi, Monroe, Louisiana, Little Rock, Arkansas, Nashville, Tennessee, Chattanooga, Tennessee, Huntsville, Alabama, and Birmingham, Alabama. Similar maps are provided in the Appendix, though for electric vehicles, the one-way vehicle range has been shortened to 50 miles as this is more typical.

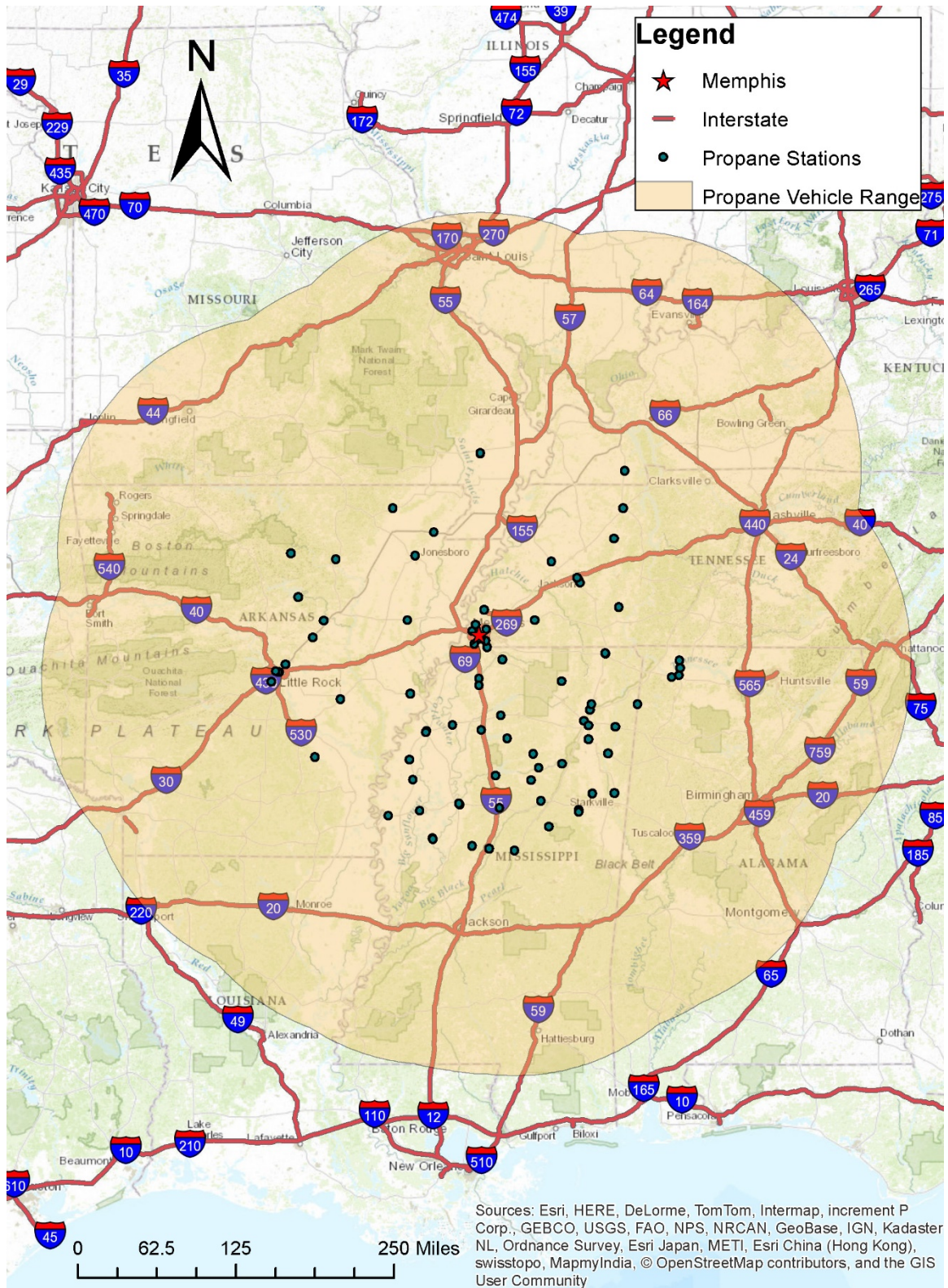


Figure 27. Range of Possible Propane-Fueled Trips from Memphis, Tennessee with One Refueling Stop

Conclusions and Future Research

The modeling process accomplished three major tasks: completing the first project-level MOVES analysis of the Lamar Corridor, an important task that will need to be accomplished prior to the planned capacity improvements; examining the effect of implementing extended gate hours on corridor emissions where previous studies had focused on the effects at the terminals served by the corridor; and studying the effect of the use of alternative fuels at a level of adoption probable by 2030 (BP p.l.c., 2014, p. 25; Cardwell & Krauss, 2013; U.S. Department of Energy, 2012a, p. 40; U.S. Department of Energy, 2014f). Generally, emissions along the Lamar Corridor were found to increase under the implementation of extended gate hours and decrease with the utilization of alternative fuels. In order to quantify each scenario’s impact on livability in the area, the externalized healthcare costs of the emissions studied are presented in Table 13 utilizing costs developed by Piecyk, McKinnon, and Allen with the Chartered Institute of Logistics and Transport (UK) (2012, p. 86).

Table 13

External Healthcare Costs of Emissions Modeled Along the Lamar Corridor

Pollutant	Existing Condition Scenario (\$/year)	Extended Hours Scenario (\$/year)	Alternative Fuel Scenario (\$/year)
CO	\$722,136.31	\$753,991.66	\$605,604.94
PM ₁₀	\$21,959,413.35	\$25,830,312.74	\$18,447,353.17
PM _{2.5}	\$19,673,180.19	\$23,212,798.74	\$16,525,507.30
Total	\$42,354,729.85	\$49,797,103.15	\$35,578,465.41

The costs to the healthcare system in every scenario are significant, and equate to roughly the costs associated with 12 to 17 deaths from respiratory disease per year. Despite these

costs being developed in the United Kingdom, the impact of particulate matter is significant and it is clear why the U.S. Environmental Protection Agency (2011) considers particulate matter to be one of the two most harmful pollutants to human health (p. 3).

Future use of the data produced must take into account the assumptions that were made in the methodology, namely: no projections for fluctuation in demand on the network were made beyond shifting 17.5% of truck activity to the overnight period; it is assumed that facilities in the area would be able to operate extended hours; and national datasets from the U.S. Environmental Protection Agency were utilized for fuel chemistry, ratio of diesel to gasoline usage for each vehicle type, and vehicle age where local data would be desirable for more accurate results. However, given these assumptions, it is possible that refinement of the results is possible by incorporating more data.

Future Research

The Ports of Los Angeles and Long Beach sought to shift 15% to 20% of daytime truck traffic during the first year of the PierPASS program, and in the case of the Lamar Corridor, it appears that the shift of this amount of truck traffic may have been too low to reduce emissions (Federal Highway Administrations, 2013). While Karafa (2012) showed that emissions at freight terminals themselves can be reduced through gate strategies that reduce the number of vehicles waiting for service at the facilities, it appears that implementing such strategies may have an adverse effect on emissions along the corridor serving said facilities, especially if the corridor serves a mix of traffic types. However, the Quadstone Paramics model utilized does not incorporate activity occurring at any terminals, so the increase in emissions along the Lamar Corridor may be balanced

by the reduction of trucks idling while waiting to enter. Completing the same modeling process with the terminals included could be insightful. Additionally, shifting more trucks to overnight arrivals may reduce emissions along the corridor as the average speed along the corridor approaches the speed limit. Establishing a target for the quantity of trucks that needs to be shifted is a much-needed area of future research.

As the Memphis and Shelby County Health Department's Pollution Control Section, responsible for emissions monitoring and modeling for the Memphis Urban Area Metropolitan Planning Organization, has neither conducted emissions monitoring along the Lamar Corridor, nor conducted a MOVES analysis of the Lamar Corridor in order to compare the results for validation, obtaining real-world emissions data for comparing the model outputs would be desirable (Christopher Boyd, personal communication, October 23, 2014). One possible solution to validate the model is to collect emissions data through the utilization of a portable emissions monitoring system in a single vehicle, where enough trips along the Lamar Corridor are recorded so an average may be determined for that vehicle type. This data could then be compared to the simulation results for similar vehicle models, and the model adjusted as needed until the outputs match the recorded data, a process similar to that utilized by Wyatt et al. (2014) in calibrating the effect of elevation into their model.

Finally, though Chamberlin and Talbot (2013) showed that the Operating Mode Distribution method produces the most accuracy out of the three methods of conducting a project-level MOVES analysis, the method is computationally intensive at the corridor level. While Chamberlain and Talbot (2013) only focused on a single intersection in their study and Alam and Hatzopoulou (2014) focused only on bus traffic in their corridor

study, neither incorporated the volume of data utilized here. The vehicle trajectory files output by Quadstone Paramics measured 11.9 GB of data that needed to be processed prior to entry into MOVES. The development of a more efficient method for study at the corridor level would also be desirable.

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Appendix – Alternative Fuel Stations and Trips Possible with One Refueling Stop

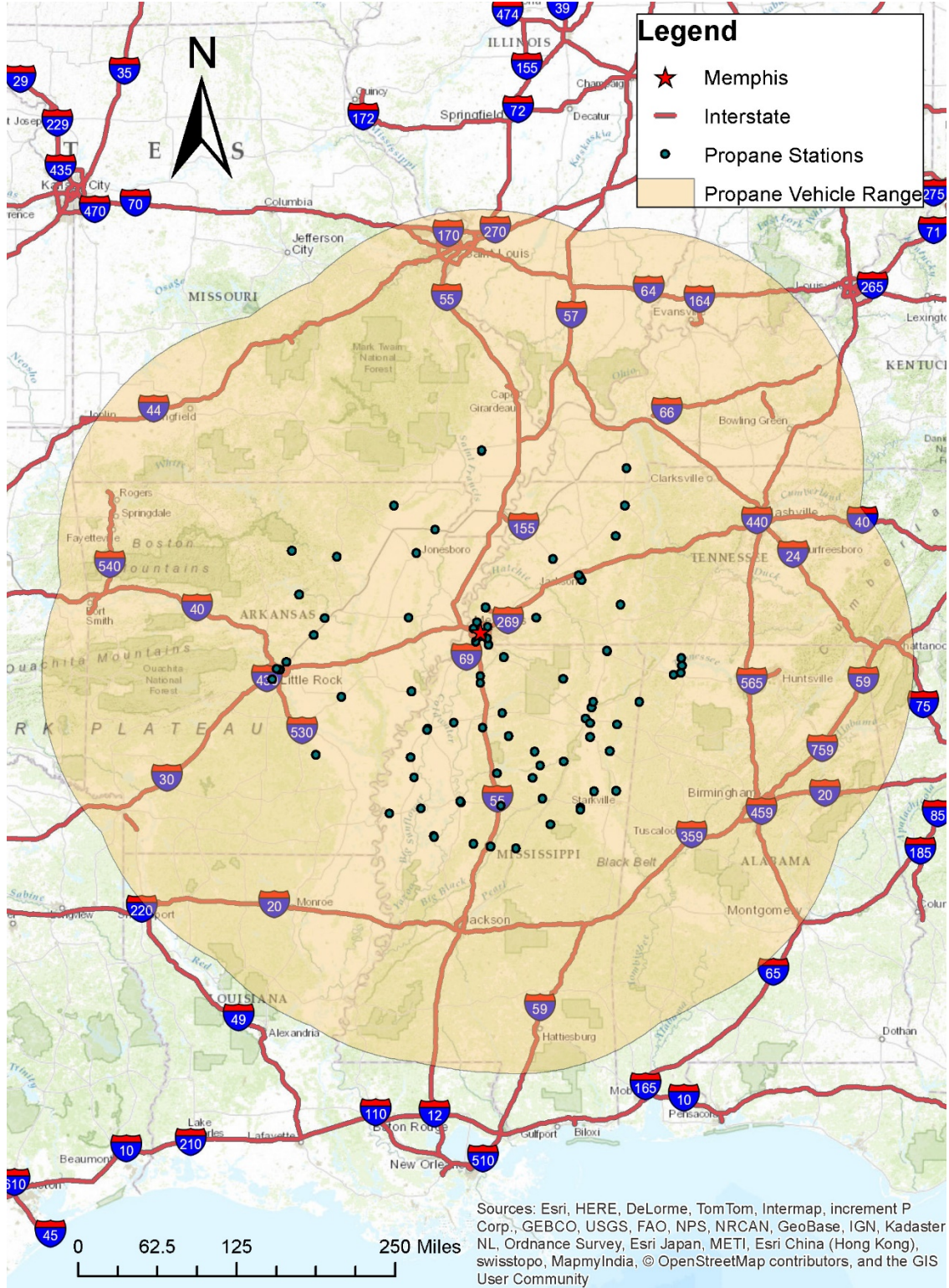


Figure 28. Range of Possible Propane-Fueled Trips from Memphis, Tennessee with One Refueling Stop



Figure 29. Range of Possible LNG-Fueled Trips from Memphis, Tennessee with One Refueling Stop

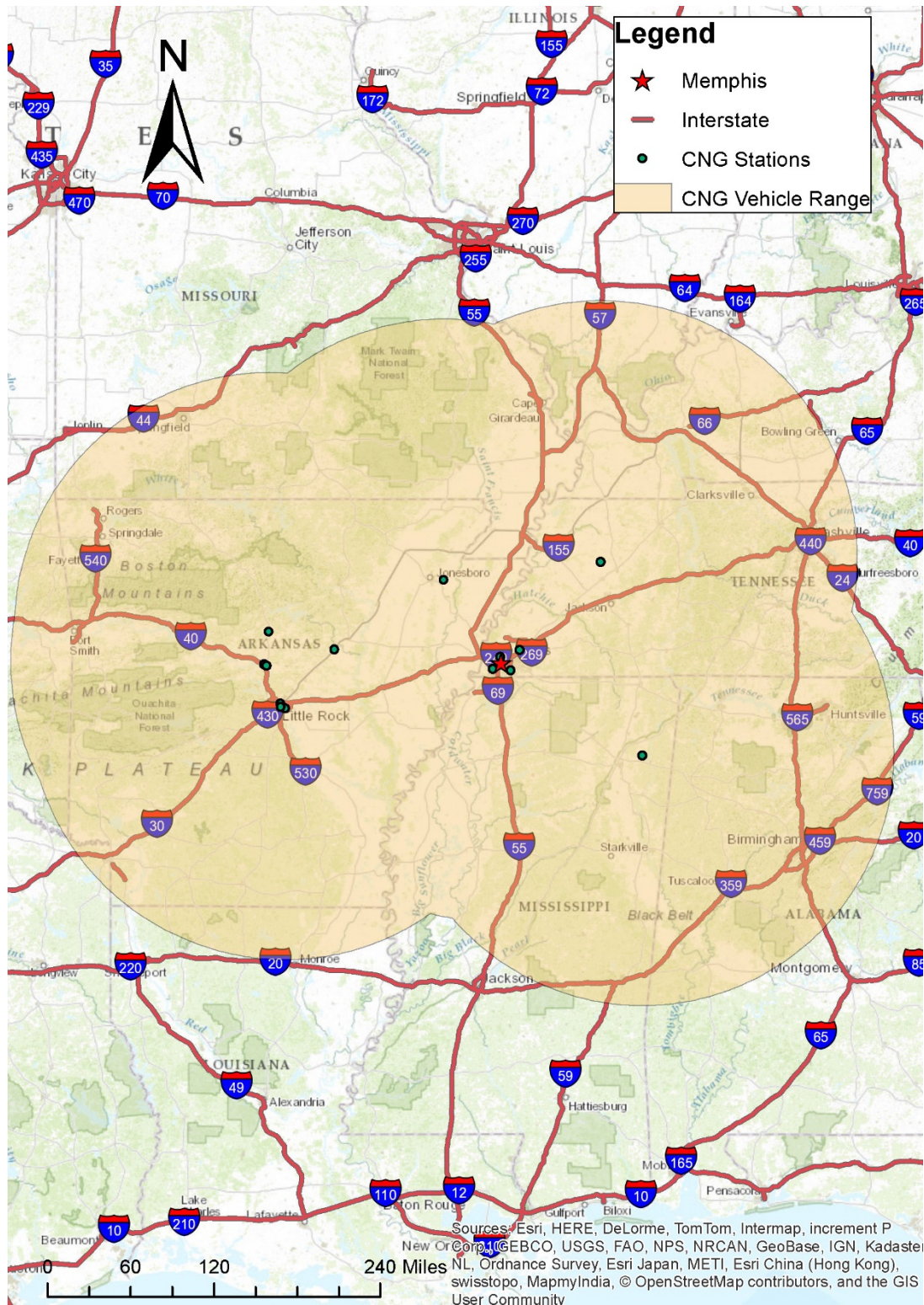


Figure 30. Range of Possible CNG-Fueled Trips from Memphis, Tennessee with One Refueling Stop

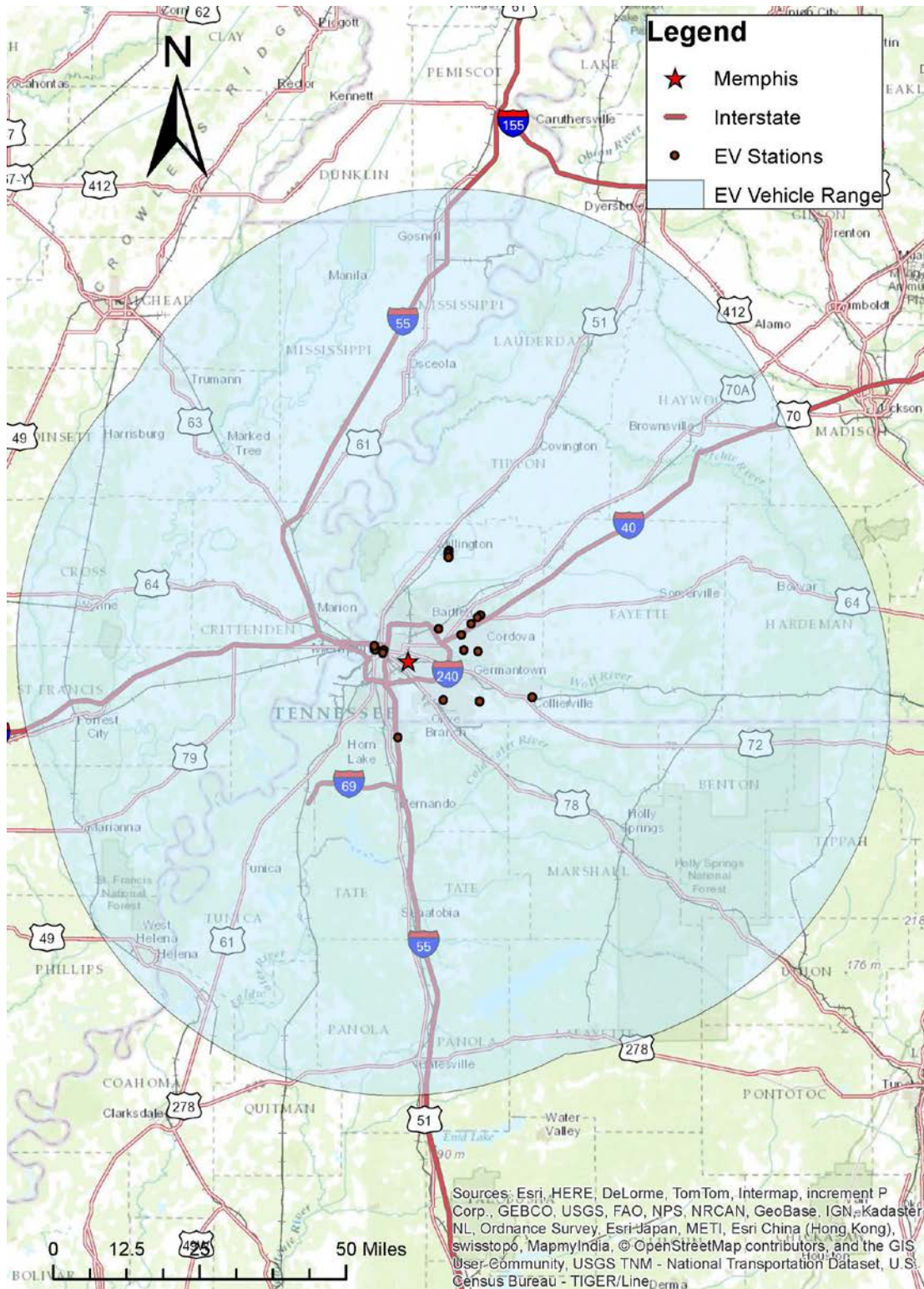


Figure 31. Range of Possible Electricity-Powered Trips from Memphis, Tennessee with One Refueling Stop

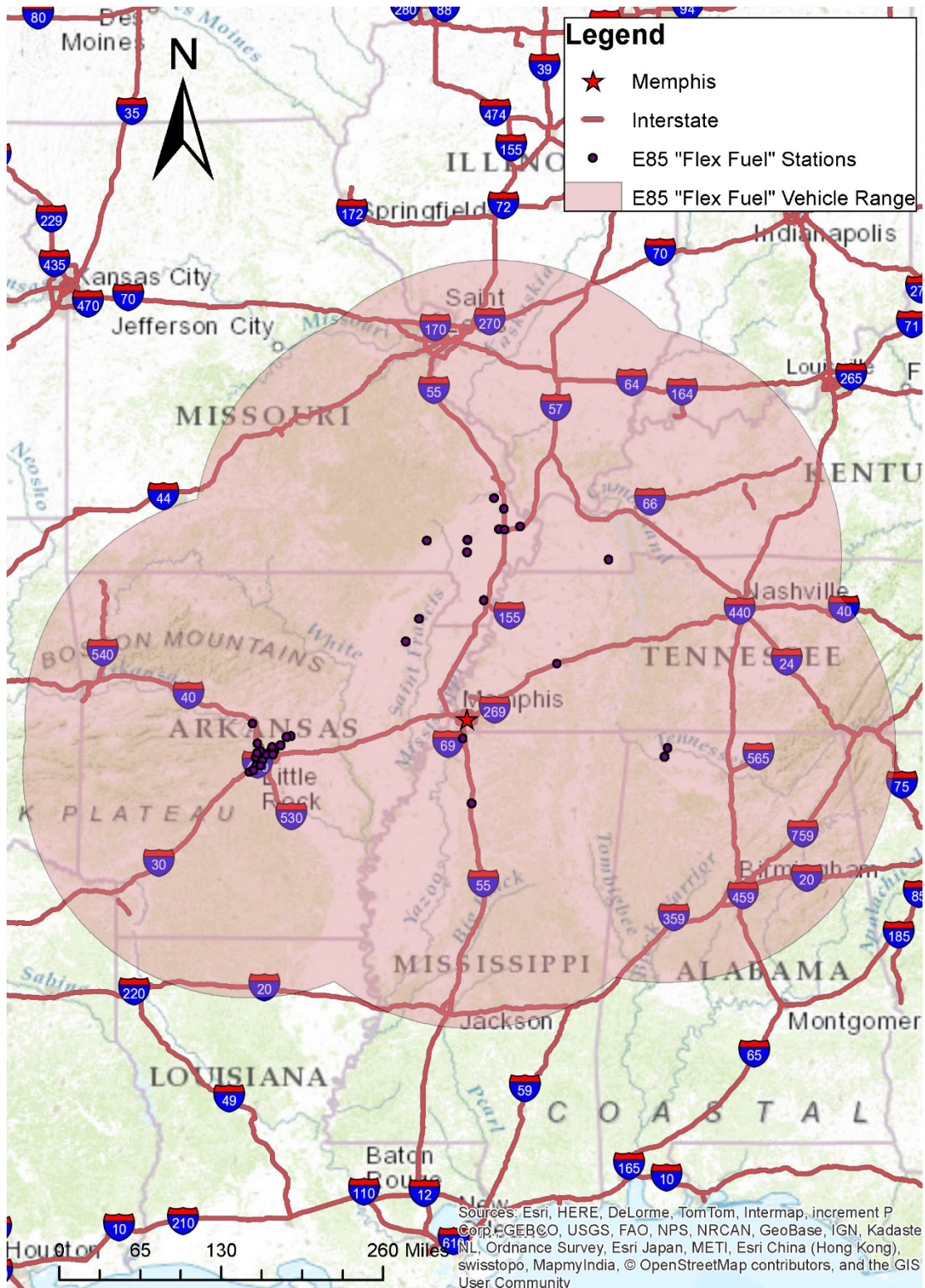


Figure 32. Range of Possible E85-Fueled Trips from Memphis, Tennessee with One Refueling Stop

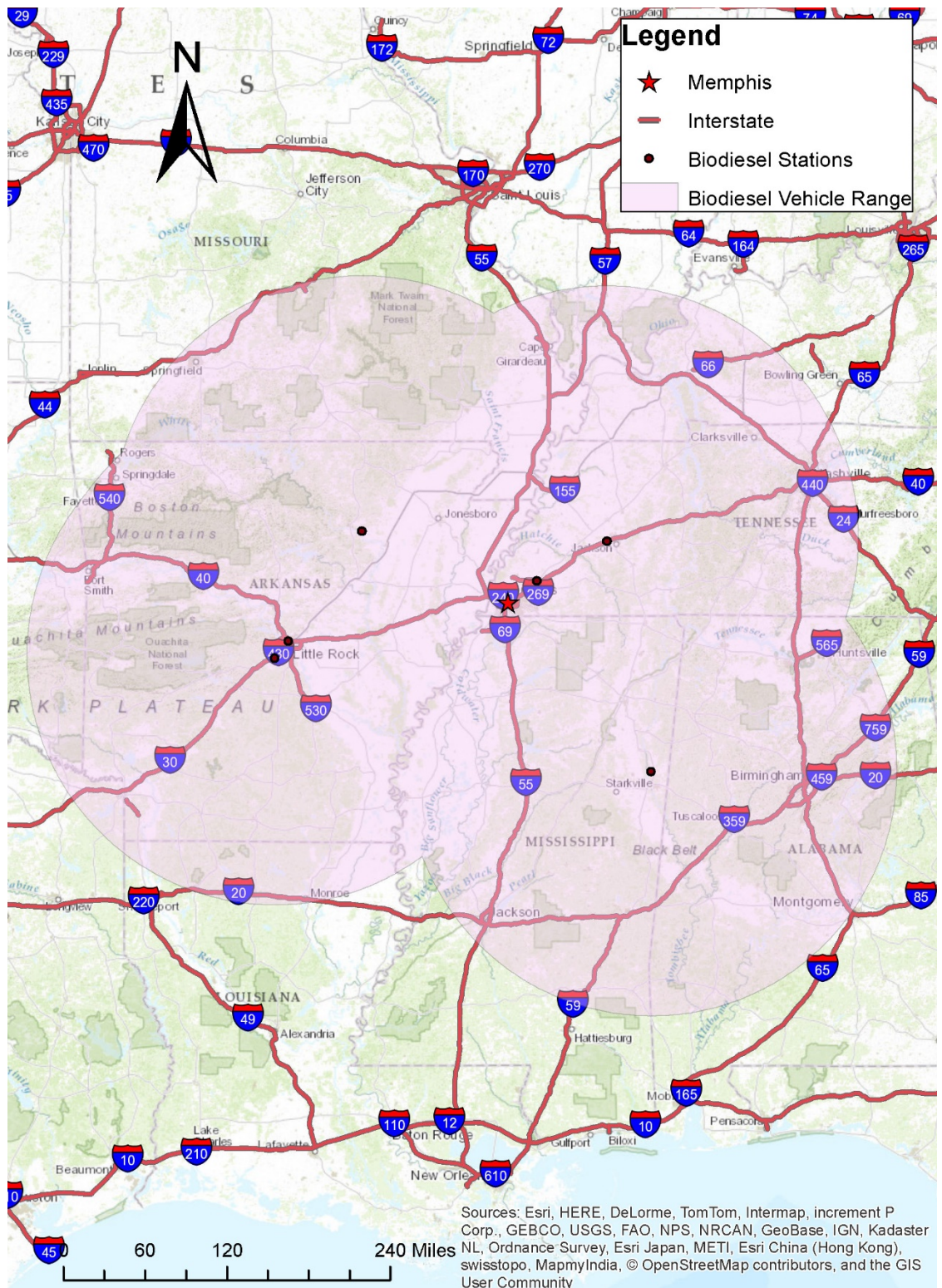


Figure 33. Range of Possible Biodiesel-Fueled Trips from Memphis, Tennessee with One Refueling Stop

From: [Robert Chamberlin](#)
To: [Jim Mersereau \(jlmrsrau\)](#)
Subject: RE: Permission Request
Date: Tuesday, October 28, 2014 5:32:58 AM

Hi Jim,

no problem, feel free to use the figure.

Bob Chamberlin

Robert Chamberlin, PE/PTOE
Senior Director, RSG
180 Battery Street, Suite 350
Burlington, VT. 05401
802-383-0118, ext 317, office
802-356-9161, mobile

From: Jim Mersereau (jlmrsrau) [jlmrsrau@memphis.edu]
Sent: Monday, October 27, 2014 6:37 PM
To: Robert Chamberlin
Subject: Permission Request

Mr. Chamberlin,

I am currently working on my Master of Science in Civil Engineering degree at the University of Memphis. As a component of the program, I am currently writing a thesis entitled *A Comparison of Emissions-Reduction Strategies to Improve Livability in Freight-Centric Communities through Modeling*, and I am utilizing the guidance provided by you on the integration of Quadstone Paramics and MOVES through your [November 2011 Paramics Webinar](#) and [your presentation to the MOVES Model User Group](#). I am writing to ask permission to use the figure included on slide 13 of your presentation, the chart explaining the relationship between Instantaneous Speed and Vehicle Specific Power, in my methodology section as a way to help explain the binning process. For your consideration, I have included a PDF file that indicates the tentative use of your figure, pending your consent.

Thank you,

Jim Mersereau, E. I.

Department of Civil Engineering
Intermodal Freight Transportation Institute
The University of Memphis
Memphis, TN 38152

E: jlmrsrau@memphis.edu
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Jim Mersereau (jlmrsrau)

From: Wendy Wintman <wwintman@consumer.org>
Sent: Friday, October 31, 2014 11:32 AM
To: Jim Mersereau (jlmrsrau)
Cc: Wendy Wintman
Subject: File #P4103: Permission Request for engineering program paper
Attachments: Consumer_Reports_Usage_Request_Mersereau.pdf

Jim Mersereau, E. I.

Department of Civil Engineering

Intermodal Freight Transportation Institute

The University of Memphis

Memphis, TN 38152

Dear Mr. Mersereau:

Thank you for your request for permission to reprint the image of the Audi dashboard that was posted in our article "[Audi's Traffic Light Assist tells how long until the signal goes green](#)", posted on ConsumerReports.org in January 2014 for inclusion in your thesis at the University of Memphis' Department of Civil Engineering Master of Science in Civil Engineering program.

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Sincerely,

Wendy

ACKNOWLEDGED AND AGREED:

Jim Mersereau

By: 
Name: James Lewis Mersereau
Title: Graduate Assistant
Date: 11/12/14

Wendy J. Wintman

Manager, Records Management and Legal Services
Consumer Reports
101 Truman Avenue | Yonkers, NY 10703
Voice: 914 378-2448
Fax: 914 378-2946
wwintman@consumer.org



On Sun, Oct 26, 2014 at 11:16 PM, Jim Mersereau (jlmrsrau) <jlmrsrau@memphis.edu> wrote:

Dear Sir or Madam,

I would like to display the image included in Liza Barth's article "[Audi's Traffic Light Assist tells how long until the signal goes green](#)", published online on January 10, 2014 at 04:15 PM in my thesis being completed as part of my degree requirements as part of the University of Memphis' Department of Civil Engineering's Master of Science in Civil Engineering program. My thesis is entitled *A Comparison of Emissions-Reduction Strategies to Improve Livability in Freight-Centric Communities through Modeling*. The figure will appear exactly once in a section on driver-feedback tools, and I have included a draft of the surrounding text and tentative use of the image to illustrate how it will be used.

Thank you,

Jim Mersereau, E. I.

Department of Civil Engineering
Intermodal Freight Transportation Institute
The University of Memphis
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