

## Civil, Environmental and Sustainable Engineering

### Declining Car Use in a Megacity: Exploring the Drivers of Peak Car including Infrastructure Saturation

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## Abstract

There is increasing evidence that vehicle travel in developed countries may have peaked, contradicting many historical travel demand forecasts. The underlying causes of this peaking are still under debate and there has been a mobilization of research, largely focused at national scales, to study the explanatory drivers. There is, however, a dearth of research focused at the metropolitan scale where transportation policy and planning are frequently decided. Using Los Angeles County, California, as a case study, we investigate the Peak Car theory and whether social, economic, and technical factors, including roadways that have become saturated at times, may be contributing to changes in travel behavior. After peaking in 2002, vehicle travel in Los Angeles County declined by 3.4 billion (or 4.1%) by 2010. The effects of changing fuel prices, fuel economy, population growth, increased utilization of alternate transportation modes, changes in driver demographics, income, and freight are first assessed. It is possible, and likely, that these factors alone explain the reduction in travel. However, the growth in congestion raises questions of how a constricting supply of roadway network capacity may contribute to travel behavior changes. There have been no studies that have directly assessed how the maturing supply of infrastructure coupled with increasing demand affect travel behavior. We explore regional and urban factors in Los Angeles to provide insight into the drivers of Peak Car at city scales where the majority of travel occurs. The results show that a majority of the decline in VMT in Los Angeles can be attributed the rising fuel prices during the 2000s. While overall roadway network capacity is not yet a limiting factor for vehicle travel there is some evidence that suggests that congestion along certain corridors may be shifting some automobile travel to alternatives. The results also suggest that the relative impact of any factor on travel demand is likely to vary from one locale to another and Peak Car analysis across large geographic areas obscures the nuisances of travel behavior at a local scale.

## 1. Introduction

In many developed countries, there has been a plateau, and in some cases a decline, in automobile travel in the past decade (Millard-Ball and Schipper, 2011). Cumulative annual vehicle miles of travel (VMT) and annual VMT per capita steadily increased in most developed countries following the introduction of the personal automobile in the first half of the twentieth century but have not increased in many developed countries since the early 2000's. To date, the research seeking to unpack the underlying causes of this trend has focused primarily at the national level using aggregate data and trends. Yet transportation planning and policy making is largely decided at the regional and local levels where insight into the factors impacting peak car travel is relatively thin. While there is significant uncertainty as to whether travel in many countries and cities will remain flat or decline, if the trend holds there are significant implications for how transportation systems are planned to meet the demands of growing and changing urban populations.

The demand for automobile travel is the result of the physical network (both roads and parking), technologies, and the activity system (social and economic activities) (Manheim, 1979). Activities induce demand for travel and the design of the infrastructure enables modal options (auto, transit, bike, walk, etc.). The interaction between the two plus and other factors - such as the price of fuel and socio-cultural preferences such as licensure rates- produces flow patterns that, in many places, has been decreasing for automobiles. As such, the recent trend of plateauing VMT is either the result of, i) changes in the infrastructure system and technologies, ii) changes in the activity system, or iii) changes in traveler's preferences that could result from a multitude of factors. We explore the drivers of peak travel at an urban scale, using Los Angeles County, California (further referred to as Los Angeles) as a case study.

Much of the existing research on the Peak Car phenomenon has focused on socio-economic changes and rising costs associated with automobile travel. Yet there is increasing evidence that transportation infrastructure is becoming more and more saturated in many U.S. Cities (Schrank et al., 2012). Previous analysis of the roadway network in Los Angeles indicates that infrastructure deployment has slowed in recent decades while demand for vehicle travel steadily increased following a similar trajectory to the one seen at the national scale (Figure 1) (Caltrans, 1996-2011; FHWA, 1989-2012; Parrish and Chester, 2013). Increasing demand for transportation services without equivalent increases in the supply has resulted in roadway congestion that has been well

documented (Schrang et al., 2012). While Los Angeles still ranks at the top in the U.S. for congested travel, congestion has leveled off over the past decade (Schrang et al., 2012). Could roadway supply saturation be impacting vehicle travel and contributing to peak travel? This effect has not been studied and opportunity exists for evaluating how travel behavior has changed as demand has grown faster than supply.

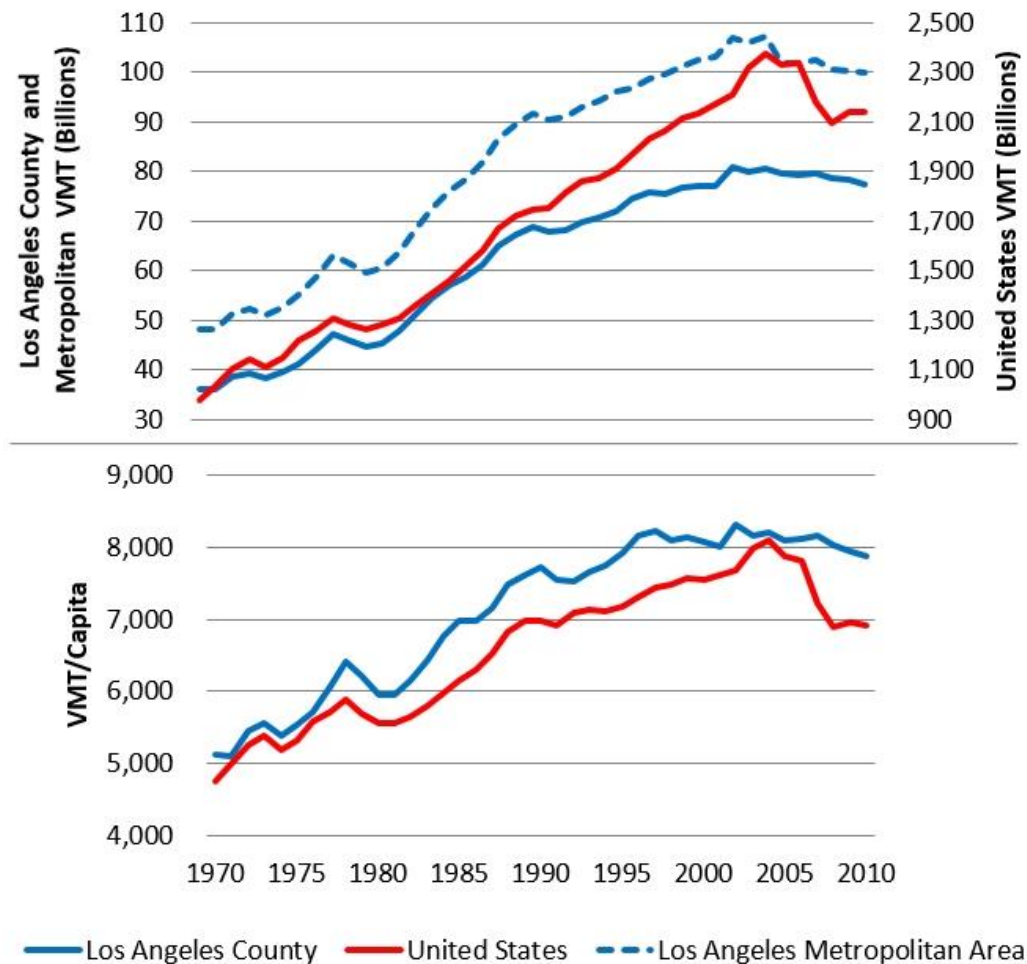


Figure 1: Annual and per Capita VMT for Los Angeles County, Los Angeles Metropolitan Statistical Area, and the United States from 1970-2010. The recent nationwide Peak Car trend (top chart) can be seen in Los Angeles County and the Metropolitan area. Supplemental Information Figure S1 shows the differing geographies. VMT per Capita (bottom chart) experienced a fairly continuous rise until peaking in 2002 followed by a decline through 2010.

## 2. Peak Travel Background

Evidence supporting the Peak Car theory is relatively recent but theories that a limit to vehicle travel exists have been around since the early 1960s in the United Kingdom. Published in

1963, the authors of *Traffic in Towns* hypothesize that following a rapid adoption of the automobile, vehicle ownership levels and use will ultimately reach a plateau by 2010 (Buchanan, 1963). Research on the stability of travel time budgets has found that the total expenditure of time used for daily travel remains relatively constant (Chen and Mokhtarian, 1999). Travel time budgets have been used to establish saturation in overall mobility. Schafer and Victor (2000) found a strong correlation between total distance traveled and income but suggest that distance traveled is ultimately constrained by a stable travel time budget and modal speeds. Metz (2010) also used travel time budgets in conjunction with decreasing marginal utility of more distant locations to conclude that a natural limit to personal mobility exists.

Vehicle travel trends supporting the peak car theory began appearing in the mid-2000s for developed countries and since 2008 the quantity of research and publications dedicated to the phenomenon have increased. Puentes and Tomer (2008) were the first to publish a report highlighting the peaking of vehicle travel in the United States. They showed that VMT peaked in 2004 before beginning to decline in 2007. The report also highlighted that VMT per capita had plateaued by 2000. At the time of publication the causes of the trend were not known but the authors hypothesized that vehicle ownership saturation may play a role in its occurrence. In a follow-up publication, Puentes (2013) also cited travel time budgets, increased public transit utilization, telecommunication and social networking, the economic recession, the decreasing trend of car ownership and use in Millennials, increased urban density, and a return to urban living as possible contributing factors to the trend. There is a growing body of literature which discusses the phenomenon of Peak Car in the United States and other developed countries in which possible explanations of peak car are explored including: increasing fuel prices, geography constraints, increases in urban living and density, aging populations, the decreasing trend of car ownership and use for Millennials, increased public transit utilization, and a saturation of destination alternatives. (Gargett, 2012; Goodwin, 2012; Goodwin and Van Dender, 2013; Grimal et al., 2013; Headicar, 2013; Kuhnimhof et al., 2013; Le Vine and Jones, 2012; Madre et al., 2012; Metz, 2010; Metz, 2012; Metz, 2013; Millard-Ball and Schipper, 2011; Newman and Kenworthy, 2011; van der Waard et al., 2013)

### 3. Peak Car Travel in Los Angeles

The explanations for Peak Car travel in Los Angeles have not been systematically developed. An analysis of individual driving characteristics using the 2001 and 2009 National Household Travel Surveys (NHTS) reveals changes in individual trip characteristics (Table 1) (FHWA, 2001, 2009). While mean trip distances appear to be relatively stable across trip types in the United States there have been significant reductions in mean trip distance in the Los Angeles area. These findings suggest that peak car phenomenon in the United States may result from travel changes that may vary from one region to another and are driven by vehicle travel reductions in highly populated urban environments.

While Los Angeles is a relatively young city by developed country standards, the growth of its roadway infrastructure has slowed to the point where no major capacity is being added (Fraser and Chester, 2015). The worsening congestion conditions (currently 94% of peak hour travelers experience congestion) suggest that there may be portions of the roadway network that have reached a saturation point for vehicle travel (Schrack et al., 2012).. We explore how this increasing congestion might be affecting travel behavior.

**Table 1 Changes in Automobile Trip Characteristics in the U.S. and the LA-MSA.** Mean trip distance for the U.S. and Los Angeles are provided in the top and bottom tables for 2001 and 2009 by trip purpose.

<b>United States</b>	All Day (7am-7pm)/Peak Periods (7-10 am & 3-7pm)			
	2001		2009	
	Mean Trip Distance	Std. Error of Mean	Mean Trip Distance	Std. Error of Mean
All	6.8/7.3	0.02/0.02	6.9/7.4	0.01/0.02
Home	7.4/8.0	0.03/0.04	7.6/8.2	0.02/0.03
Work	9.6/9.7	0.07/0.07	9.1/10.2	0.04/0.05
Medical/Dental Services	8.3/8.5	0.14/0.18	8.7/9.1	0.08/0.12
Shopping/Errands	5.0/5.2	0.04/0.06	4.9/5.1	0.02/0.03
Social/Recreational	7.6/7.6	0.08/0.10	7.2/7.3	0.05/0.06
Family Personal Business/Obligations	5.2/5.7	0.05/0.07	6.6/6.8	0.06/0.09
Transport Someone	5.6/5.5	0.05/0.06	6.0/5.9	0.04/0.04
Meals	4.8/5.3	0.06/0.10	4.9/5.4	0.04/0.06

<b>Los Angeles</b>	All Day (7am-7pm)/Peak Periods (7-10 am & 3-7pm)			
	2001		2009	
	Mean Trip Distance	Std. Error of Mean	Mean Trip Distance	Std. Error of Mean
All	7.5/8.3	0.16/0.22	6.6/7.2	0.06/0.09
Home	8.3/9.0	0.32/0.40	7.0/7.7	0.11/0.15
Work	11.3/11.1	0.56/0.59	9.9/10.9	0.21/0.25
Medical/Dental Services	9.1/9.1	1.09/1.41	7.9/8.1	0.36/0.52
Shopping/Errands	5.0/5.5	0.33/0.55	4.3/4.4	0.10/0.15
Social/Recreational	7.8/7.6	0.62/0.78	7.4/7.5	0.26/0.33
Family Personal Business/Obligations	5.4/5.8	0.41/ 0.59	6.4/6.4	0.31/0.39
Transport Someone	6.0/6.2	0.46/0.59	4.7/4.7	0.15/0.18
Meals	4.8/5.4	0.48/.72	4.5/5.1	0.19/0.29

#### 4. Methods

Explanatory variables for Peak Car in Los Angeles are evaluated by joining vehicle travel data and an assessment of socio-economic factors, fuel prices, alternative transportation modes, and freight travel which have been shown to impact automobile travel demand. The objective is to explore whether the recent plateau and subsequent decline in VMT in Los Angeles can be explained by these factors and to what extent. The analysis focuses on Los Angeles through 2010, a region that is part of the larger Los Angeles metropolitan area, largely due to data quality. Socio-economic and market data are widely available at the county level. While some data for the Los Angeles—Long Beach—Anaheim Metropolitan Statistical Area (LA-MSA) (which encompasses portions of 2 counties in the Los Angeles metropolitan area (SI Figure S1) are available, travel, and socio-economic and market data at this scale are not consistently available. Lastly, the peak car trend seen



at the county level is consistent with the trend at the metropolitan scale (Figure 1). As such, the county is used as the region of focus and includes 9.8 of the 12.8 million MSA residents in 2010 (USCB, 2012). We focus on a number of social, economic, and technological factors that have been identified in past research to comment on how significant each of these variables might be in explaining Peak Car.

Historical VMT estimates were developed from regional and state datasets. Data on annual VMT in Los Angeles are published by the California Highway Performance Monitoring System (CA-HPMS) between 1996-present and are based on average daily traffic counts. The data show that VMT in Los Angeles peaked in 2002 (Caltrans, 1996-2011). LA-MSA VMT estimates are available from 1989 to present (FHWA, 1989-2012). Prior to 1989, only statewide estimates were identified, beginning in 1967 (FHWA, 1967-1988). To capture a sufficiently long time period, a county-to-state population ratio was used to estimate Los Angeles VMT 1967-1988 from the statewide VMT estimates (USCB, 2014). Similarly, a county-to-MSA population ratio was used to estimate Los Angeles VMT from 1989-1995. The pre-1989 VMT analysis is used for contextualization of the rate of historical travel growth and the analysis of peak travel is focused on the post-2000 time period where high quality data exist. There is uncertainty associated with the method in which aggregate VMT estimates are derived, however, no other data sources were identified with sufficient time resolution to develop the analysis. CA-HMPS VMT estimates are found to be within 1-4% of vehicle travel estimates produced by the Southern California Association of Governments (SCAG) travel demand models for 2000, 2003, and 2008 (SCAG, 2000, 2003, 2008b).

A large body of research exists that explores the relationships between socio-economic factors and passenger and freight travel and we leverage these findings to assess the range of contribution to historical changes in travel. To isolate the drivers of peak and declining travel, it is necessary to evaluate the potential range of contribution for all factors included in the analysis. A literature review was developed to identify changes in population, transit use, driver demographics, licensure rates, vehicle availability, trips, trip lengths, income, employment opportunities, fuel price, fuel economy, and freight activity as key elements that are expected to impact vehicle travel. These factors are either used directly or joined with travel elasticity estimates to calculate the significance of the variable in Los Angeles' changing travel. The primary data used to determine changes in these factors are provided in Table S1 of the Supplemental Information (SI). A range of elasticities is developed by evaluating studies that focus on the U.S., and at times include estimates from other

developed countries, due to a lack of comprehensive studies across relevant socio-economic and other factors specific to Los Angeles or Southern California. These data are summarized in SI Table S2. The causal factor analysis is focused on changes that occurred following the peak in vehicle travel in Los Angeles and the extent to which these individual factors may have resulted in the recent decline in county wide VMT (2002—2010).

Increases in population have been shown to have a positive impact on VMT with elasticities measured between 0.4 – 0.6 (Hansen and Huang, 1997). Los Angeles experienced little growth in population between 2002-2010 only gaining 108,900 new residents, an increase of  $\approx 1\%$  (USCB, 2014). Expected increases in VMT as a result of population growth could be limited if not matched with equivalent growth in licensed drivers and available vehicles. A review of DMV records reveals that there was an overall increase in the number of licensed drivers, 5,850,223 — 5,946,629, while drivers licenses per capita remained relatively constant, 0.602 — 0.605, from 2002 – 2010 (CADMV, 2014; Los Angeles Almanac, 2014a; USCB, 2014). Similarly, there was an increase in total registered vehicles as well as vehicles per licensed driver between 2002-2008 (data unavailable for 2009 and 2010) (Los Angeles Almanac, 2014b). These increases indicate that licensure rates and vehicle availability would not have limited VMT increases attributed to population growth over the assessed time period. The impact of changes to driver demographics was found to be inconclusive and is discussed in the SI.

The peak and subsequent decline in annual VMT in Los Angeles occurred before the beginning of the economic recession in 2007 yet changes in income and countywide employment should be assessed. The extent to which economic and employment activity influences travel demand is evaluated by analyzing changes in income per capita and total countywide employment. Between 2002-2010 income per capita increased by 8% (inflation adjusted) in Los Angeles (USBEA, 2014a). VMT elasticities with respect to income range between 0.18 — 1.53 (SI Table S2). Despite an increase in per capita income, the total number of jobs in Los Angeles decreased by approximately 250,000 (USBEA, 2014b). VMT reductions from a decrease in the workforce is calculated by comparing worker and non-worker automobile travel characteristics derived from the 2001 and 2009 NHTS (FHWA, 2001, 2009).

Real term fuel price has increased by 70% in Los Angeles between 2002 and 2010 and has the potential to affect travel demand (Goodwin et al., 2004; USEIA, 2014). Long run elasticities for

changes in fuel prices range from (-0.67) – (-0.08) (SI Table S2). Gillingham (2013) found elasticities in California to be (-0.22) during the assessed time period. Increases in vehicle fuel economy can offset a portion of the increased costs associated with rising fuel prices. The California Air Resources Board’s (CARB) Emissions Factors model (EMFAC) is used to estimate changes in fleet wide fuel economy for passenger vehicles in Los Angeles between 2002-2010 (CARB, 2011). Elasticities associated with fuel economy have been estimated to range from 0.1 – 0.3 (SI Table S2).

Los Angeles has invested heavily in public transit in the past two decades and its growing transit ridership may be shifting travelers from automobiles. Public transit ridership is determined from the National Transit Database for all reporting agencies in Los Angeles (FTA, 1997-2010). There is a limited understanding of the effects of transit usage on VMT with very few published studies (Salon et al., 2012). However, at the outside, if we consider average automobile trip occupancy derived from the 2001 & 2009 NHTS, 1.63 and 1.67 respectively, the relationship between passenger miles traveled (PMT) on transit and VMT based purely on occupancy is 1:0.59-0.61 (FHWA, 2001, 2009). For trip distance shifts, some previous research has assumed a 1:1 relationship between transit PMT and avoided auto VMT (Chester et al., 2013a; Choo et al., 2005). Other research asserts that additional transit PMT can result in VMT reductions greater than one due to trip chaining, changes in route choice and destination, and transit use in combination with walking/biking. Existing research has found that transit leverages can range from 1.4-9 avoided auto VMT for every transit PMT and are dependent on density and land use characteristics. (Holtzclaw, Undated; Litman, 2004). Accounting for occupancy, increased transit utilization is evaluated with a range of leverages from 0.59-5.6.

The 2007 recession and load consolidation trends may have impacted freight-related travel. There is a dearth of high quality data at the county level, but several regional government sources provide insight into trends from 2002-2010. SCAG, a Metropolitan Planning Organization (MPO) which includes Los Angeles, provides estimates of passenger VMT and heavy duty truck (HDT) VMT in the 2004, 2008, and 2012 Regional Transportation Plans (RTPs) (SCAG, 2004, 2008a, 2012). The estimates are developed by SCAG’s travel demand model and produced at the regional level and for individual air basins. The urbanized portion of Los Angeles is part of the South Coast Air Basin and the high desert area is part of the Mojave Desert Air Basin (SI Figure 1). Linear interpolation is used to estimate 2002 and 2010 HDT VMT from the 2000, 2003, 2008, and 2012 RTPs. CARB’s EMFAC model provides HDT VMT estimates at the MPO and county level for

every year and are based on a separate HDT travel demand model (CARB, 2011). The Annual Average Daily Truck Traffic (AADTT) report details average estimates for truck travel on various links in the state highway network (Caltrans, 2004b, 2010). Los Angeles highway segments that appear in both the 2002 and 2010 reports are analyzed to identify potential changes in HDT VMT.

To assess road network capacity and traffic volumes across the network, several sources are consulted to establish the distribution of VMT across time and space. Overall network capacity is derived from a historical inventory of the Los Angeles roadway system that captures highway, arterial, collector, and local line miles (Fraser and Chester, 2015). The proportional distribution of VMT for each type of roadway facility is derived from the FHWA statistics for the LA-MSA (FHWA, 1989-2012). The 2001 and 2009 NHTS are used to determine time-of-day distributions for VMT using both trip totals and reported mileage for all vehicle based trips (transit excluded) (FHWA, 2001, 2009). Linear interpolation estimations were used for time-of-day distributions for other years evaluated in the analysis. The distributions are combined with lane mile estimates to establish average network flow rates in vehicles per lane per hour (veh/ln/hr). Average flow rates are compared to standard level of service (LOS) criteria as a basis for which to assess an overall capacity constraint (Transportation Research Board, 2010). Average flow rates for arterial and highway facilities are compared to specific link flow rates and evaluated using LOS criteria (Caltrans, 2004a, 2011).

## 5. Peak Car and Potential Underlying Causes

Los Angeles experienced a continuous rise in annual VMT and VMT per capita until 2002 when vehicle travel peaked and then declined (Figure 1). The peak in VMT occurred approximately 10 years after the network had been fully deployed and at a time when 85% of travel during daily peak periods experienced congestion (Schrank et al., 2012a). In 2002, VMT and VMT per capita peaked at 81 Billion and 8,300 respectively. By 2010, annual VMT declined by 3.4 billion, a 4.1% drop, and VMT per capita declined to 7,900, a 5.2% decrease (Figure 1). VMT in Los Angeles in 2010 fell short of all previous Motor Vehicle Stock Travel and Fuel Forecast (MVSTAFF) projections, the travel demand forecasts developed by the state (Caltrans, 2013).

### *5.1 Generation of Passenger Travel*

Population growth, increasing income per capita, and improving fuel economy since 2002 have likely contributed to more demand for personal vehicle travel. The population increase

between 2002-2010 should have resulted in an overall increase of 360 – 540 million annual VMT, or 3,300 – 5,000 annual VMT per new resident, when VMT elasticities with respect to population growth are applied (Hansen and Huang, 1997). To a certain level, rising income increases discretionary spending and the consumption of goods and services, which manifests with increased vehicle travel (Millard-Ball and Schipper, 2011). There was a slight dip in income per capita in Los Angeles between the onset of the recent recession (2007) and 2010 but there was an overall increase since 2002 from \$38,880-\$41,030 (USBEA, 2014a). Increasing individual income should have created demand for an additional 1 – 6.1 billion annual VMT, an increase of 100 – 620 annual VMT per capita. Furthermore, increases in vehicle fuel economy should reduce the costs of driving thereby creating demand for additional vehicle travel. Average fuel economy for passenger vehicles in Los Angeles increased from 19.4 – 20.1 mpg between 2002-2010 (CARB, 2011). Using VMT elasticities with respect to changes in fuel economy, the increasing fuel economy should have increased annual VMT by 274 – 714 million, an increase of 28 – 72 annual VMT per capita. In total, increases in population, income, and fuel economy should have resulted in an additional 1.6 – 7.4 billion annual VMT between 2002 and 2010, dominated by income increases.

### *5.2 Suppression of Passenger Travel*

The increasing cost of fuel, public transportation access, and decreases in employment opportunities may have contributed to the recent plateau and decline in annual VMT. Increasing fuel prices are found to have the greatest potential influence on VMT reductions. Over the last decade, the increase in the average price per gallon of gasoline (from \$1.47/gal in 2000 to \$3.11/gal in 2010) may have suppressed 4.8 – 23 billion VMT. Use of the public transportation system (which includes bus, subway, light rail, and commuter rail) increased from 2.41 to 2.51 billion annual PMT between 2002-2010 (FTA, 1997-2010). Using auto VMT to transit PMT shift ratios, the increase in public transit usage may have displaced 54 – 533 million VMT. For the LA-MSA, self-identified non-workers drove an average of 7,780 and 6,600 annual VMT less than workers (FHWA, 2001, 2009). The recent economic recession has resulted in the loss of 250,000 jobs in LA and could have decreased annual VMT by 1.7 – 1.9 billion (USBEA, 2014b). The combination of these factors is estimated to have suppressed 6.5 – 25.8 billion annual VMT in 2010.

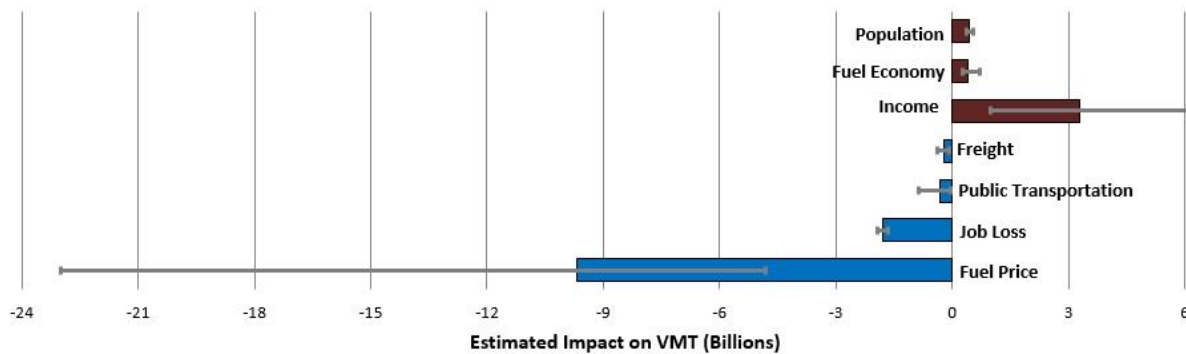
### *5.3 Changes in Freight Travel*

The extent to which HDT VMT may have changed is difficult to ascertain, but all three factors indicate that a decrease in freight traffic between 2002 and 2010 likely occurred. A dearth of data and geographic discrepancies make it difficult to assess changes accurately but because HDT VMT estimates range between 5-7% of total regional VMT, even dramatic reductions in freight traffic are expected to have a relatively small impact and not fully explain the 3.4 billion VMT reduction. SCAG's regional transportation plan estimates that HDT VMT in the South Coast Air Basin and Mojave Desert Air Basin decreased by 430 million from 2002-2010, a 4.3% decrease (SCAG, 2004, 2008a, 2012). The asynchronous geographies make it difficult to estimate changes specific to Los Angeles, and the periodic estimates developed by SCAG (once every 4 years) does not allow for specific estimates to be developed around the economic recession which began in 2007. EMFAC estimates of HDT VMT in Los Angeles also decreased from 2002-2010 by 91 million, a 2.3% reduction (CARB, 2011). A comparison of MPO level estimates reveals that the EMFAC model predicts 10-24% fewer HDT VMT than SCAG's model (Figure S2 SI). Analysis of the AADTT reports finds 173 highway links listed in both the 2002 and 2010 report of which 57% experienced a reduction in AADTT from 2002-2010. In total HDT VMT fell by 6.5%, a greater reduction than those estimated by either travel demand model (Caltrans, 2004b, 2010). Using the reduction estimated by EMFAC as a lower bound and combining the overall AADTT reduction (6.5%) with the maximum ratio of HDT VMT to total VMT (7%) to define the upper bound, it is estimated that HDT VMT in Los Angeles County decreased between 91-370 million between 2002 and 2010.

## **8. Explaining Peak Car in Los Angeles**

Peak Car is likely the result of an interaction between a number of the underlying variables and the univariate analyses can help identify those factors that likely played a larger role. Figure 2 shows the potential contribution of each variable to VMT changes. A comparison across the factors suggests that the increase in fuel prices is likely the greatest contributor to the decline in VMT. However, suppression estimates of 4.8—23 billion VMT resulting from rising fuel costs are larger than the experienced decline suggesting that the response to rising fuel costs in Los Angeles tends to be more inelastic than the literature suggests. This inelastic response may result from urban form characteristics that result in an automobile dependency and interregional travel that is not captured by the analysis. The impact of rising fuel prices is likely correlated with the increased usage of public

transportation and would have been lessened by rising income levels and fuel economies. However, it should be noted that the increased usage in public transportation would have only had a significant impact on VMT reductions at the upper bounds which is unlikely given the homogenous medium density and separated land uses found in most of Los Angeles (Sorensen et al., 2008). Despite the increase in public transit use and reduction in automobile travel there is still only 1 PMT for every 31 VMT in Los Angeles. Job loss resulting from the recession may have had a significant impact on VMT. However, as the economy improves and unemployment falls it should be expected that VMT reductions attributable to job loss will dissipate. While logistic improvements may be contributing to greater reductions in interregional travel, the results show that reductions in freight travel even at the upper bounds of what is estimated, have played a small role (3—11%) in the recent decline in aggregate VMT. The suppressive impact on VMT of these factors is buoyed by increases in income, improving fuel economy, and population growth. Of the three, income is the only factor found to have a significant generation effect. The relatively small improvement in vehicle fuel economy and minimal population growth are likely to have had, even at the upper bounds, a small generational impact on VMT. The significance of interaction effects cannot be determined with the available data and disaggregate modeling is needed to identify how these variables interact.



**Figure 2 Estimated Impact on VMT in Los Angeles (2002-2010).** The figure shows the average impact for each explanatory factor uncertainty based on the range in underlying factors. Red factors are estimated to induce automobile travel while blue suppress travel.

## 7. Travel Behavior Changes from Increasing Congestion

The Los Angeles roadway network, one of the most extensive in the country, was deployed largely between 1940 and 1970 and since 1980 this growth has significantly slowed. There are approximately 68,400 lane miles of combined highway, arterial, collector and local roads in the county and over half of the network's lane miles were constructed between 1935-1960 coinciding

with Federal Housing Administration policies that encouraged low-density development of residential property, the widespread dismantling of the interurban rail lines, and the rise of the personal automobile as the dominant mode of travel (Nelson, 1983; Wachs, 1984, 1993; Whittlemore, 2012). By 1990, 99% of the current roadway network had been deployed. Due to spatial limitations the overall roadway network in Los Angeles is unlikely to experience significant expansion (Brookings Institution, 2001).

Since 2002, along with an aggregate reduction in annual VMT, there have also been changes to how VMT are distributed across the network in time and physical space and the recent reduction can be attributed to specific roadway classifications. Proportionally, VMT on local roads decreased by 2% from 2002 to 2010 and was offset by an increase in the proportion of travel on county highways along with a modest increase in travel on collectors (FHWA, 1989-2012). The proportion of travel on arterial roads has remained relatively constant. As a result, annual VMT on local and arterial roads have fallen by 1.8 and 1.5 billion respectively and represent approximately 97% of the overall decline in annual VMT since peaking in 2002. Annual VMT on collectors and highways have remained relatively constant.

Analyzing the distribution of VMT on each facility type by time of day indicates that overall network capacity is not likely a constraining factor to vehicle travel in Los Angeles. There have been minor shifts in the distribution of vehicle trips and VMT based on trip start times between 2001 and 2009 (Figure S3 in SI). In addition to typical AM and PM peak travel periods, there is a relatively consistent level of vehicle travel from 7am to 7pm. Average vehicle flow rates across the system for each of the roadway classifications are shown in Figure 3. Even during peak periods, average flow rates for all facility types are consistent with LOS A indicating that there is an adequate supply of lane miles. This finding shows that if infrastructure saturation is playing a role in Peak Car it is a function of supply distribution and not an inadequacy of supply.



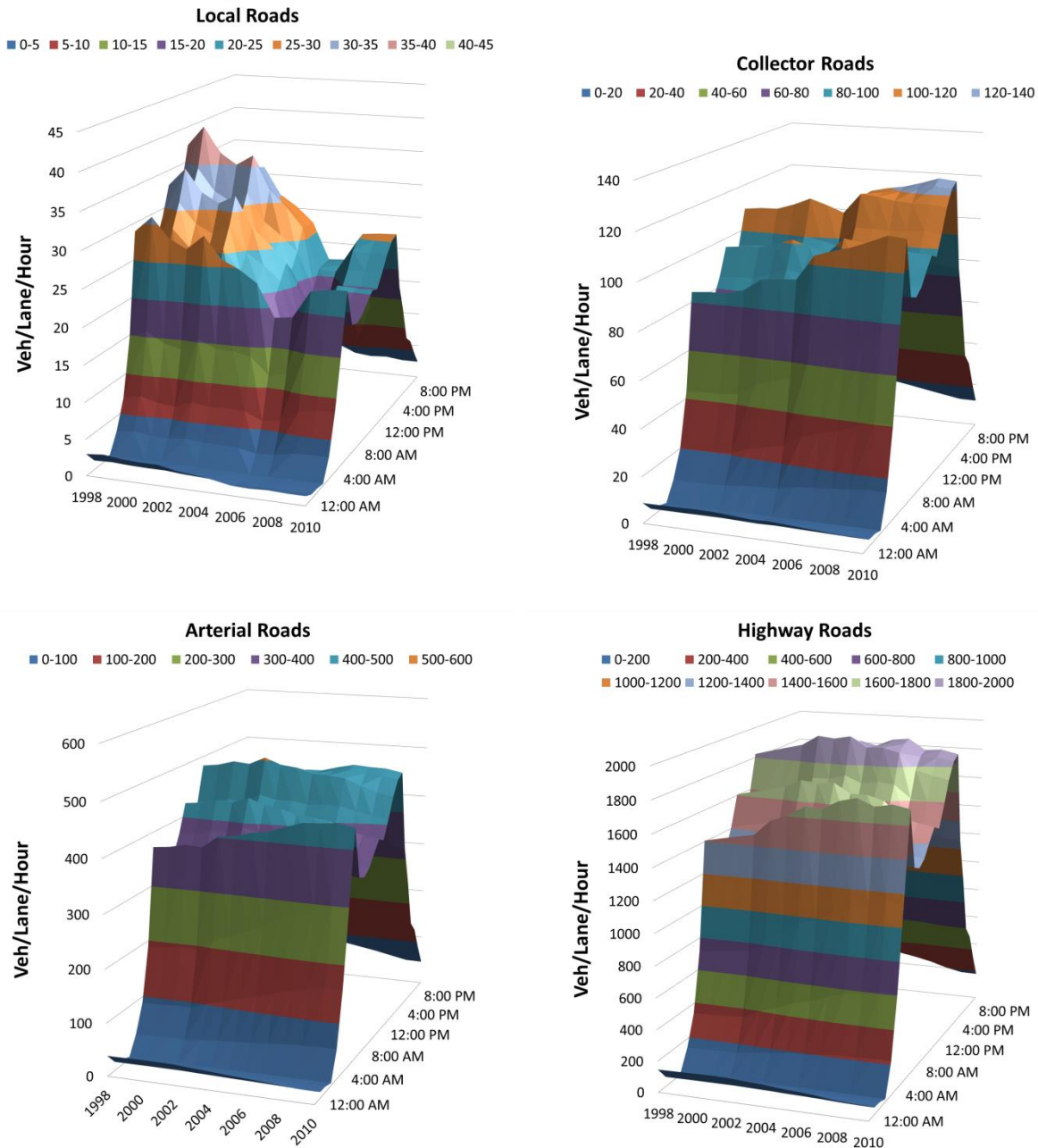


Figure 3 Average Vehicle Flow Changes (vehicles/lane/hour) from 1998-2010 by Facility Type and Time-of-Day. The figure indicates that there is sufficient network capacity for current travel demand across facility type and time of day. Level-of-service A (free flow) conditions for collectors are 600 vehicles/lane/hour, arterials 740, and highways 2,000 (Transportation Research Board 2010).

Overall network capacity is not a limiting factor to vehicle travel in Los Angeles but the well-documented issues with congestion indicate that demand is not evenly distributed across the network. Previous research has shown that even a single bottleneck can degrade the performance of a complex network so an understanding of how vehicle flows are distributed is important. (Xia and

Hill, 2010). Traffic counts for individual highway links indicate that there are significant network bottlenecks throughout the peak periods where localized demand exceeds link capacity. While the average vehicle flow on highway lanes never exceeds 2,000 veh/ln/hr, approximately 57% of links in the 2002 and 2010 Annual Average Daily Traffic Report (AADT) exceeded 2,000 veh/ln/hr during peak periods. Of the 1,280 links in common between the 2002 and 2010 AADT, 68% experienced a decrease in peak period travel. On average, links with greater than 2,000 veh/ln/hour in 2002 experienced a decrease in peak period VMT of 4.4% while peak period VMT on links with less than 2,000 veh/ln/hour in 2002 increased by 4.4%. Los Angeles' most congested corridors (> 20,000 vehicles during the peak hour) experienced an average decline of 5.4% VMT during peak periods. This suggests that levels of congestion along highly utilized corridors may have reached levels that are no longer acceptable and some portion of drivers may be using alternative routes, changing destinations, selecting alternate departure times, or foregoing the trip altogether.

## 9. Discussion

The estimated impact on VMT varies among individual factors suggesting that the Peak Car phenomenon in developed countries over the last decade may result from differing localized responses to a variety of factors. Ultimately, those assessing Peak Car should consider the scale of the region. By analyzing automobile transportation patterns at the national scale (especially in the United States), the nuisances of local and regional activities and infrastructure systems are neglected. National level statistics show there have been significant increases in public transit utilization over the past decade. However, this is misleading because these increases can be attributed to several markets and are not indicative of what is going on throughout the country. Public transportation clearly has some role in reducing VMT but its ability to serve as an alternative to the automobile is largely dependent on urban form. Equal improvements in transit quality and quantity may have significant impacts on VMT in high-density mixed use environments but may lead to insignificant reductions in VMT elsewhere. It is clear, however, that rising prices in global petroleum markets are likely a significant contributor to the recent decline in automobile travel in developed countries. Recent petroleum market events make projecting vehicle travel trends difficult. At the least, we should expect some increases in automobile travel given the recent collapse of crude oil prices (2014) and corresponding decline in fuel prices in the short term. The factors analyzed here do not represent an exhaustive list of those which may impact automobile travel demand and other factors

which may also be altering demand, including parking availability and emerging digital lifestyles, are left for future research.

While the results did not show that capacity constraints are currently limiting vehicle travel, the future of mobility created by large scale road infrastructure investment and automobile ownership is uncertain. Los Angeles has struggled with managing the demand for auto-mobility and current levels of demand have exceeded the capacity of some network components resulting in high levels of congestion and increased travel times for some origin-destination pairs. It is possible that this may be shifting a portion of would-be auto travelers to alternative routes, destinations, modes, or resulting in fewer trips. Despite Los Angeles' historical commitment to the automobile through infrastructure financing and off-street parking policies, the infrastructure is maturing and expectations of a consistent or increasing level of auto-related mobility may not be realistic as a result of a leveling off of roadway supply, an established mature building infrastructure, and projected population growth. (Reyna and Chester, 2014).

Historic land use and zoning policies, which discouraged density and encouraged the separation of land use, have led to travel issues relating in the distribution of transportation infrastructure supply and the distribution of travel inducing nodes (Whittemore, 2012). The results suggest that these policies have resulted in the inefficient and unbalanced use of existing roadway infrastructure. Recent shifts in land-use planning in Los Angeles have created the potential for smart growth, and a focus on accessibility rather than mobility through mixed-use zoning. The integration of transportation and land use planning, may help alleviate future challenges created by a physical limit to vehicle travel (Nahlik and Chester, 2014). Along with accommodating projected population growth in close proximity to high quality transit options, which has been shown to decrease individual travel demand, zoning policies which enable the redistribution of automobile travel demand to underutilized portions of the transportation network could lead to the more efficient use of the overall network, as well as unintended impacts (Clower et al., 2011; Rodgers, 2014). There are potentially significant upfront public and private costs associated with these strategies which produce long term benefits increasing the temptation to improve mobility through traditional regional development and roadway link expansion (Camagni et al., 2002; Chester et al., 2013b). However, improvements to individual mobility through capacity expansion may only be temporary. (Downs, 2004; Duranton and Turner, 2011). The limitations of auto-centric infrastructure should be considered when evaluating infrastructure investment alternatives.

## 10. Conclusion

Peak Car is the result of a suite of social, economic, and technological changes. By focusing at the national scale, the Peak Car discussion has not yet considered the variability of the factors impacting localized travel demand. Because passenger vehicle flows largely result from the interaction of the local activity and transportation systems, analysis of Peak Car at the national scale, especially in the United States, results in a focus on factors which may dominate travel behavior in a few highly populated areas, are related to inter-city passenger, and long-distance freight travel. The results indicate that the distribution of the supply of transportation infrastructure and roadway link capacity may not yet be a contributing factor in changing travel behavior in Los Angeles. However, transportation planners in Los Angeles, and other regions that struggle with congestion, should consider the impact of infrastructure supply constraints along with changing social, economic, and technological norms when predicting future travel behavior.

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# Supporting Information

## S1. Socio-Economic Data Sources

The following data sources were used to estimate changes in social, economic, and technical factors, which have been previously found to impact auto travel demand.

**Table S1: Data Sources for Los Angeles County Population, Travel, Socio-economic, and Fuel Factors**

<b>Factor</b>	<b>Source</b>
Population	U.S. Census Bureau
Transit Use	National Transit Database TTI – Urban Mobility Report
Driver Demographics	Federal Highway Administration Highway Statistics Series Table DL-22 National Household Travel Survey 2001 & 2009 $\Delta$
Licensure Rates	Federal Highway Administration Highway Statistics Series Table DL-22 California DMV
Vehicle Availability	California DMV $\pm$
Automobile Trip Characteristics	National Household Travel Survey 2001 & 2009 $\Delta$
Income & Employment	U.S Bureau of Economic Analysis
Fuel Prices	U.S. Energy Information Administration
Fuel Economy	California Emissions Factors Model (EMFAC)
Freight Activity	Southern California Association of Governments – Regional Transportation Plans EMFAC California Department of Transportation – Average Daily Truck Traffic Counts

$\pm$  Available only until 2008

$\Delta$  2001 & 2009 NHTS are used to estimate travel characteristics in 2002 & 2010

## S2. Dataset Geographies

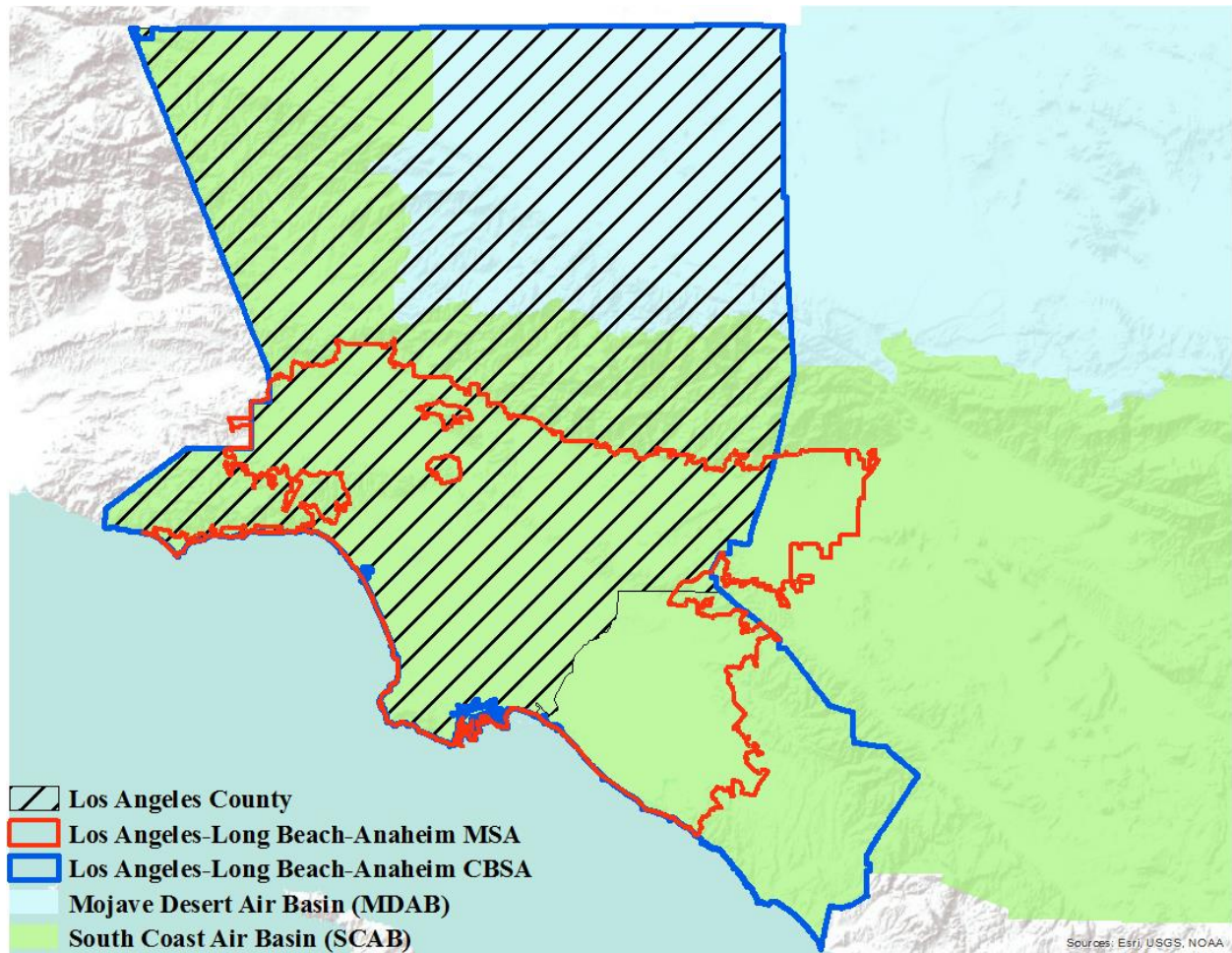


Figure S2 Los Angeles Area Administrative Boundaries: The map above depicts the varying geographies of the datasets used in the analysis.

## S3. VMT Elasticities

VMT elasticities distributions are developed through a literature review of studies. These studies are summarized in Table S2 with their geographic focus.

Table S2: VMT Elasticity Review

Study	Factor	Geographic Scope	Elasticity Estimates
Gillingham (2013)	Fuel Price	U.S. (California)	-0.22
TRACE (1999)	Fuel Price	Europe	-0.35 – -0.19
Johansson and Schipper (1997)	Fuel Price	OECD Countries	-0.3
Goodwin (1992)	Fuel Price	United Kingdom	-0.33
Mayeres (2000)	Fuel Price	Belgium	-0.43 – -0.16
Jong and Gunn (2001)	Fuel Price	Europe	-0.26
Goodwin et al. (2004)	Fuel Price	U.K.	-0.29
Spiller and Stephens (2012)	Fuel Price	U.S.	-0.67

McMullen and Eckstein (2011)	Fuel Price	U.S.	-0.1542
Hymel et al. (2010)	Fuel Price	U.S.	-0.293
Muchlegger et al. (2012)	Fuel Price	U.S.	-0.24
Knittel and Sandler (2013)	Fuel Price	U.S.	-0.26 – -0.14
Mannering (1986)	Fuel Price	U.S.	-0.28 – -0.15
Barla et al. (2009)	Fuel Price	Canada	-0.30 – -0.26
Boilard (2010)	Fuel Price	Canada	-0.256 – -0.085
Haughton and Sarkar (1996)	Fuel Price	U.S.	-0.35 – -0.23
Johansson and Schipper (1997)	Income	OECD Countries	1.2
Mayeres (2000)	Income	Belgium	0.7 – 1.53
McMullen and Eckstein (2011)	Income	U.S.	0.263
Hymel et al. (2010)	Income	U.S.	0.5
Hughes et al. (2008)	Income	U.S.	0.39
Barla et al. (2009)	Income	Canada	0.18 – 0.21
Boilard (2010)	Income	Canada	0.423 – 0.699
Mannering (1986)	Fuel Economy	U.S.	0.13 – 0.26
Greening et al. (2000)	Fuel Economy	U.S.	0.1 – 0.3
Small and Van Dender (2007)	Fuel Economy	U.S.	0.22
Green et al. (1999)	Fuel Economy	U.S.	0.23
Goldberg (1998)	Fuel Economy	U.S.	0.2
Hansen and Huang (1997)	Population	U.S. (California)	0.4 – 0.6

The following figure shows the ranges of VMT elasticities with respect to fuel price, income, fuel economy, and population identified in the literature. The impact associated with changes to each of these four factors are evaluated along with the entire range of elasticity estimates.

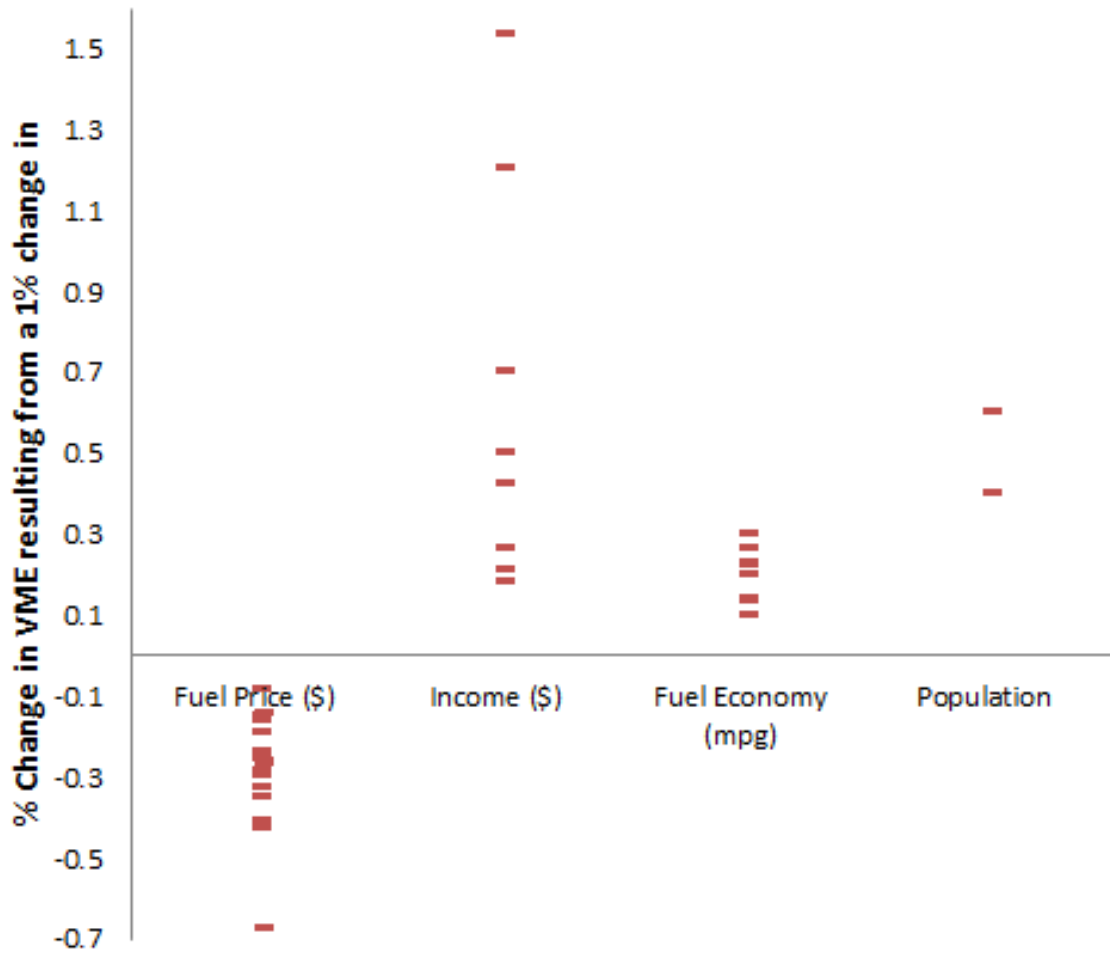


Figure S3: Elasticities with Respect to Fuel Price, Income, Fuel Economy, and Population

## S4. Heavy Duty Truck VMT in Los Angeles

Figure S3 shows estimates of heavy duty truck travel in Los Angeles Region from 2002 – 2012. There are discrepancies between SCAG’s RTP model and EMFAC which can be observed by comparing the purple triangles and green diamonds. Additionally, there is a lack of data between 2008 and 2012 in SCAG’s RTP and extrapolation may not capture the impact of the economic recession that is seemingly captured by EMFAC’s model (CARB, 2011; SCAG, 2004, 2008a, 2012).

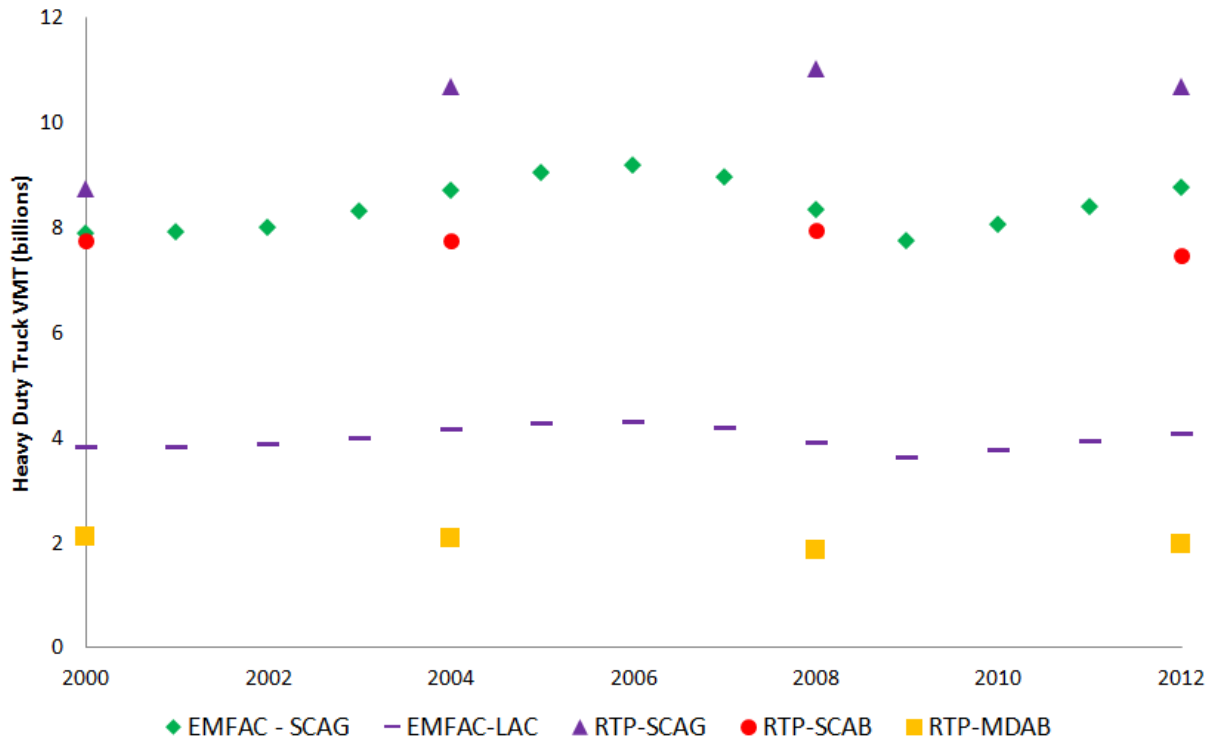
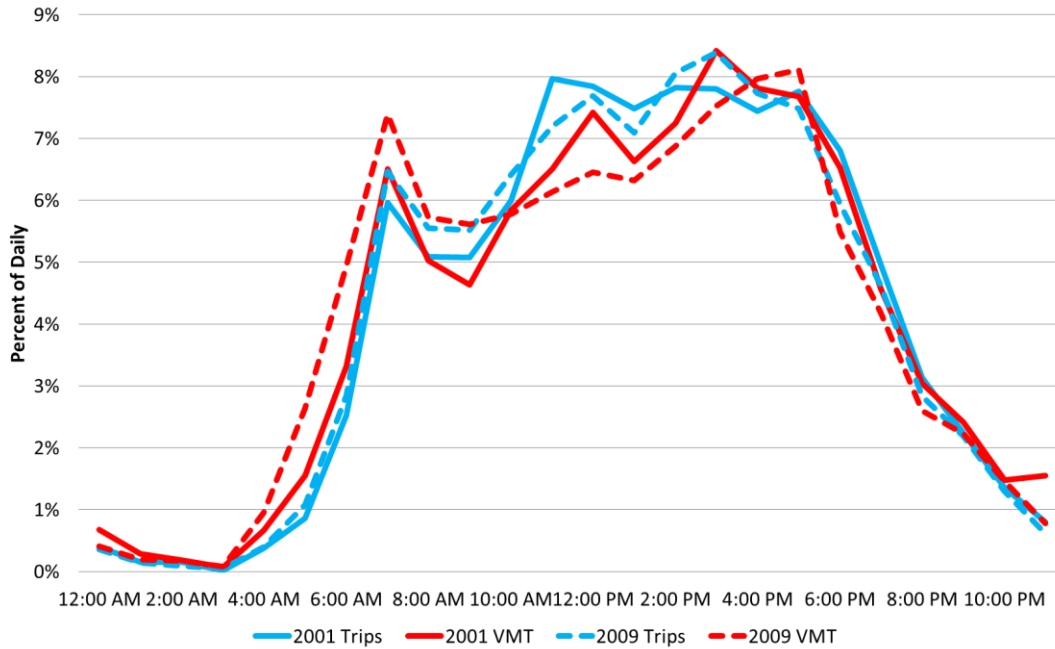


Figure S4: Heavy Duty Truck VMT 2000-2012

## S5. Daily VMT Distribution

Figure S4 compares the distribution of daily trips and VMT derived from the 2001 and 2009 NHTS. While there are slight deviations based on measurement type and survey year the overall pattern is fairly consistent (FHWA, 2001, 2009).



**Figure S5: Distribution of Daily Vehicle Trips and VMT by Time-of-Day 2001, 2009**

## S6. Driver Demographics

Though shifts in driver demographics were cited in the literature as a possible cause of Peak Car the results proved inconclusive. In this section we describe the methodology used to estimate changes in driver demographics between 2002 – 2010 and explain why the demographic results are inconclusive.

### *S6.1 Methods*

Changes in driver demographics, specifically related to age, has been identified as a potential leading cause of shifts in auto VMT over the last decade (Kuhnimhof et al., 2013). Data specific to Los Angeles that detail the demographics of drivers are not publically available. California state distributions of driver age are used as a proxy for Los Angeles and are applied to the number of drivers licenses between 2002 and 2010 in Los Angeles to estimate changes in driver demographics (CADMV, 2014; FHWA, 1995-2010; Los Angeles Almanac, 2014a). The results are compared to changes in driver demographics in the LA-MSA between the 2001 and 2009 NHTS for validation (FHWA, 2001, 2009). Only NHTS respondents who identified themselves as a driver were used in the validation. Average annual VMT totals for different age groups were computed by analyzing the vehicle use characteristics of persons who identified themselves as drivers in the 2001 and 2009 NHTS (FHWA, 2001, 2009).

### *S5.2 Results*

Changing driver demographics, specifically the general aging of the population, can impact overall vehicle travel demand (Table 1). Despite decreases in annual VMT for younger drivers and an increase for drivers older than 65 from 2001-2009, there is still a dramatic reduction in average annual VMT as individuals reach retirement age. On average, the demand for vehicle travel has fallen at the individual level from 2001-2009 with reductions in annual VMT for most age groups, and reductions in average trip length in Los Angeles.

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