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Life-cycle Greenhouse Gas Emissions and Costs of the Deployment of the Los Angeles Roadway Network

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WORKING PAPER

Life-cycle Greenhouse Gas Emissions and Costs of the Deployment of the Los Angeles Roadway Network

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1 Introduction

The roadway network in Los Angeles County has grown to over 28,000 total miles in less than a century. Despite the extent of this infrastructure system, there is a poor understanding of the long-term financing and environmental costs of building and maintaining this infrastructure, and how this infrastructure deployment has incentivized automobile travel. In this project, we have developed a novel methodology and model to assess urban roadway construction with its associated capital, operating, maintenance, and rehabilitation energy requirements and environmental impacts, with a focus on understanding the connection between embedded (infrastructure deployment) and emergent (vehicle travel) effects. The City Road Network Life-Cycle Assessment model (CiRN-LCA) uses inputs from the Pavement Life-cycle Assessment Tool for Environmental and Economic Effects (PaLATE) to create an urban-scale life-cycle environmental and economic model that can assess the long-run costs of all major roadways (local, collector, arterial and highway/freeway) in an urban region and their associated impacts (Horvath, 2003). This model will then be linked with historical vehicle travel data to understand how infrastructure deployment enables the emergent behavior of automobile travel and its associated costs and impacts. Our preliminary methods and results are presented here.

2 Methodology

The embedded impacts of roadways are a function of the year the roadways were constructed and their maintenance and rehabilitation schedules. The historical deployment of the roadway infrastructure was determined through GIS analysis. A spatial analysis of building data from the Los Angeles County Assessor's office was conducted to determine an approximate average building age for each Travel Analysis Zone (TAZ) in Los Angeles County ("Cross Reference Roll," 2009; "GIS Tax Parcel Base Map," 2009). We assume that roadway infrastructure was deployed at the same time as the buildings around them were constructed. To avoid skewed results, the year of construction for each road is assigned the average building age of the TAZ it is contained in less one standard deviation (essentially the 67-percentile oldest building). The underlying assumption is that most roads were constructed around the time that the first buildings in a neighborhood were being constructed. The result is a network database that details the historic deployment of roadways in Los Angeles County (Figure 1).

Understanding when roads were deployed is critical to the costs, energy use, and emissions associated with life-time maintenance of each road as well as how lane miles have enabled automobile travel.. Separate cross-sectional designs were developed for each roadway type based on guidelines published by Los Angeles County, The State of California and AASHTO and used to estimate emissions for both construction and maintenance (*Policy on Geometric Design of Highways and Streets*, 2011; *Standard Plans*, 2010; *Standard Street Dimensions*, 1999). Other inputs such as construction and maintenance equipment, energy mixes and distances traveled in the transport of materials to the site were estimated from previous studies (Chester, Horvath, & Madanat, 2010). Wearing layer resurfacing is capitally intensive and the rate at which it occurs is highly dependent on municipal budgets.. A 2001 study found significant variability in resurfacing schedules within different areas of the county ranging from 8-32 years (Martin, Smith, & Moore, 2001). We assume that major resurfacing events for each road occur every 13 years. Cost estimations for roadway construction and maintenance are based on average per mile values from the American Road and Transportation Builders Association("FAQs,"). These data are then coupled with historical vehicle miles traveled and average fuel economy data from the California Highway Performance Monitoring System and the Federal Highway Administration Highway Statistics series and historical fuel prices from the Energy Information Agency (*California Public Road Data, 1996-2011*, 2011; EIA, 2012; *Federal Highway Statistics Series*, 1945-2011)

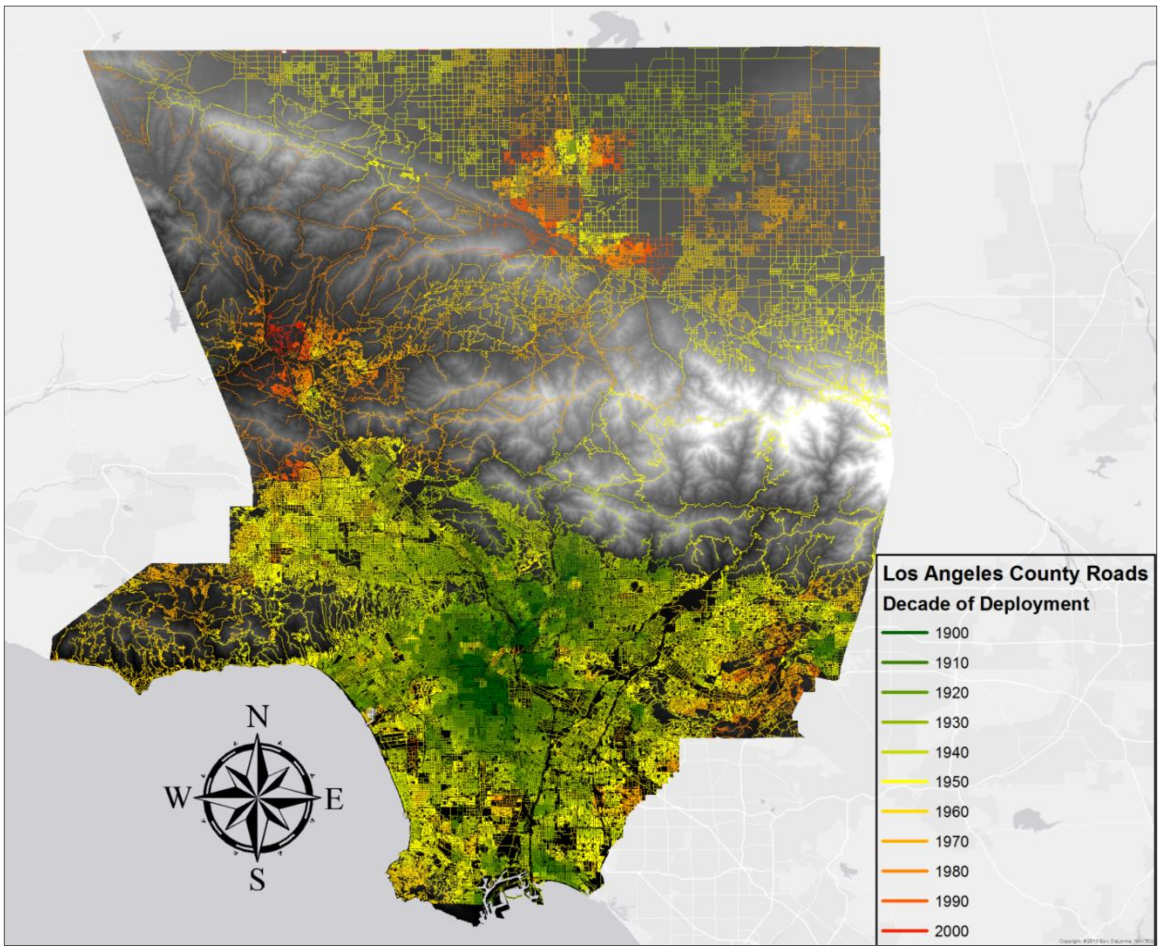

Figure 1: Spatial-temporal deployment of the Los Angeles roadway network. Roads in older areas of the county (Downtown, Long Beach) are represented by green colors and the newer areas (Santa Clarita, Landcaster, Palmdale) are orange and red. The Los Angeles Basin in the southen part of the county is sperated from the high desert in the north by the San Gabriel Mountains. The grey scale topographic is provided for clarity of the natural land form. Areas of lower elevation are characterized by black shading which transitions towards to white as elevation increases. The highest point in Los Angeles County is Mt. San Antonio (10,068 ft).

3 Results

The assessment shows the majority of the roadway network in Los Angeles was built between 1935 and 1959. This corresponds to the rise of the personal automobile as the dominant form of travel as well as the development of suburbs. In the figure below (Figure 2), the red dotted line represents the annual deployment of roads in miles and each color represents the cumulative road mileage by classification. Dated aerial photographs of Los Angeles have been used to validate these results. While there is some discrepancy in certain areas of the county, a majority share of the roadways follow the development pattern shown in Figure 2.

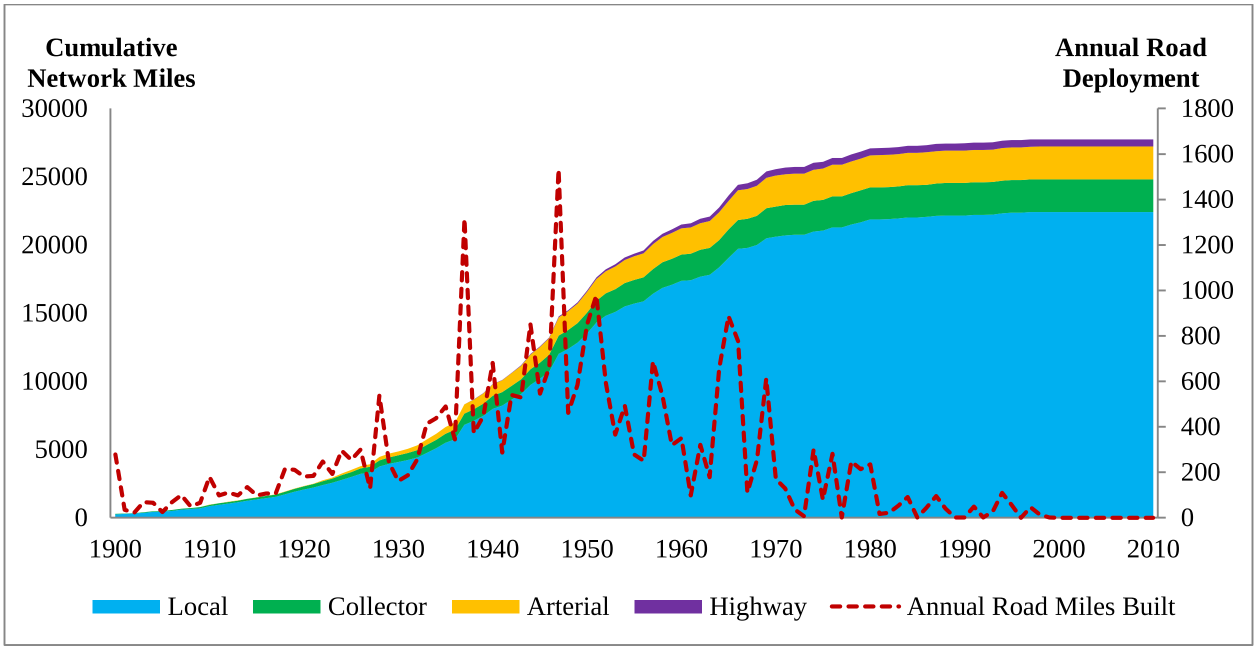

Figure 2: Historic Deployment of Road Network Infrastructure 1900-2010. The red dotted line represents the annual deployment of road miles. New roadway construction peaked around 1950 and has since declined towards no activity. The colors represent the cumulative miles of roadways by classification.

The construction of this infrastructure has led to increasing economic investment and embedded environmental impacts. The environmental impacts are dominated by material production which accounts for 72-74% of the initial construction energy use and resultant GHG emissions of an asphalt road and 93-95% for concrete highways. The production of asphalt bitumen, hot mix asphalt production, Ready-Mix Concrete production, cement production and steel production are the greatest contributors. Localized impacts from construction processes and equipment are small, <1.5%, for all road times. The total embedded energy use and CO2e emissions resulting from initial construction from 1900-2010 is approximately 140,300 TJ and 10,600 Gg. Maintenance activities continually embed energy and CO_2 into the network through in place recycling and additional virgin materials. When the impacts associated with maintenance are included the cumulative embedded impacts are 4.4 times greater for energy (620,780 TJ) and 4.7 times greater for CO2e (49,780 Gg).

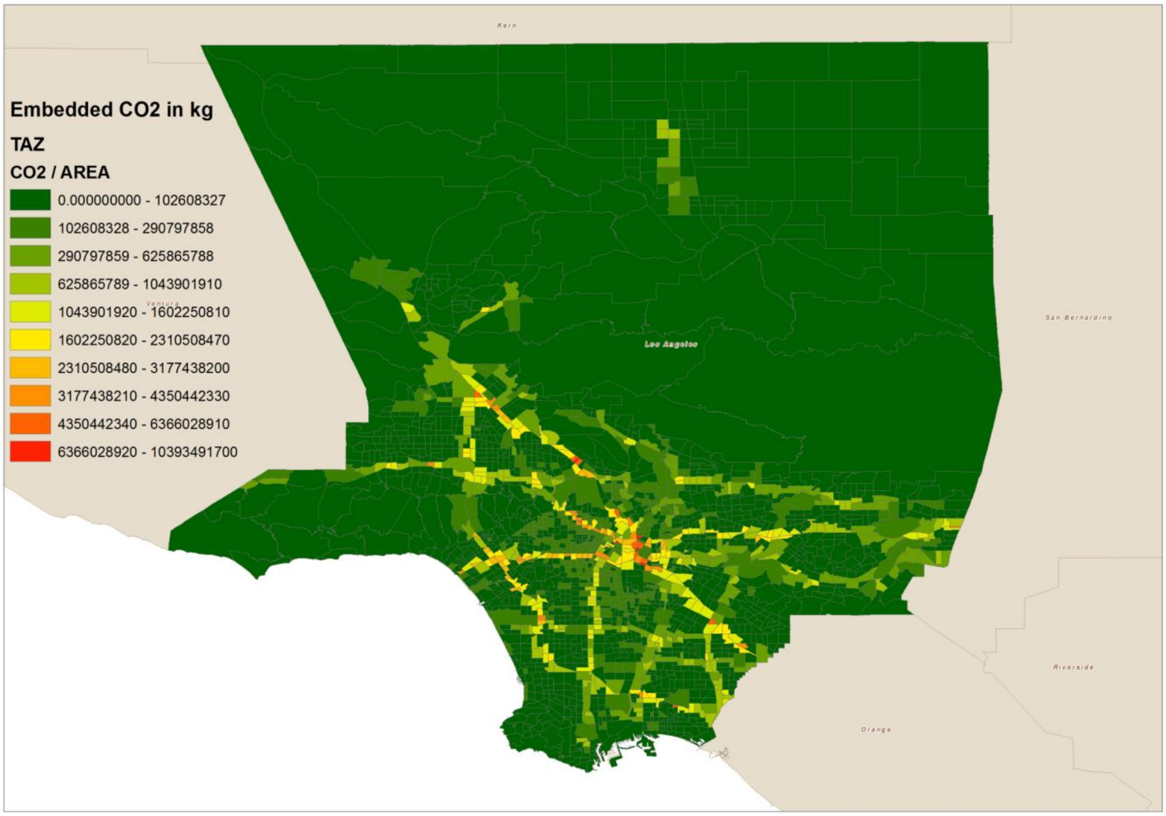

Figure 2: Embedded CO_2 (kg) in the Los Angeles County Network 1900-2010. This figure illustrates the total embedded CO_2 in the road network by TAZ. Red colors represent the highest while green colors represent the least. The transit corridors associated with major highway infrastructure are clearly visible.

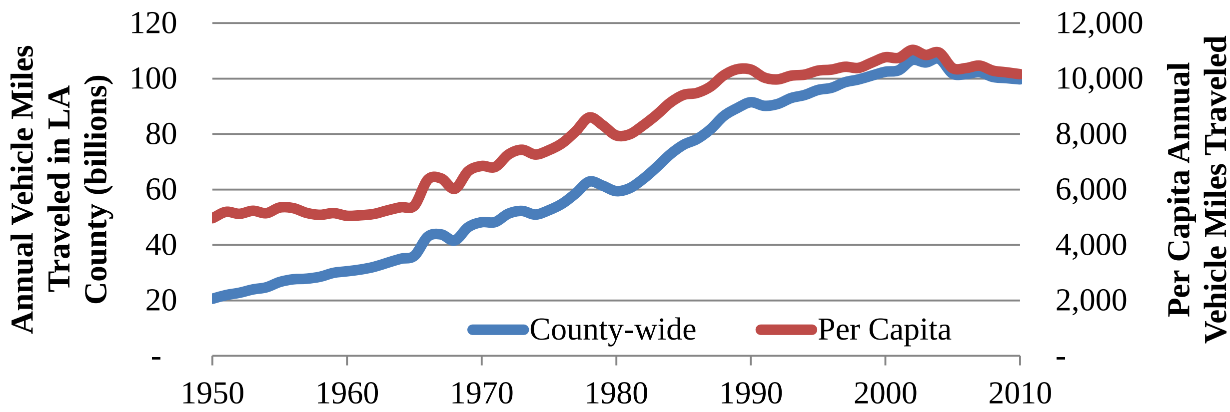

Figure 4: Vehicle Travel on Los Angeles Roadways Over Time

Figure 4 shows that Los Angeles County has reached a plateau in yearly VMT and VMT per capita at approximately 100 billion and 10,000 per year respectively in 2003. While there are likely multiple variables contributing to this plateau it should also be noted that Los Angeles has had very little new roadway deployment over the last three decades, implying that natural limits to the use of the infrastructure have been reached.

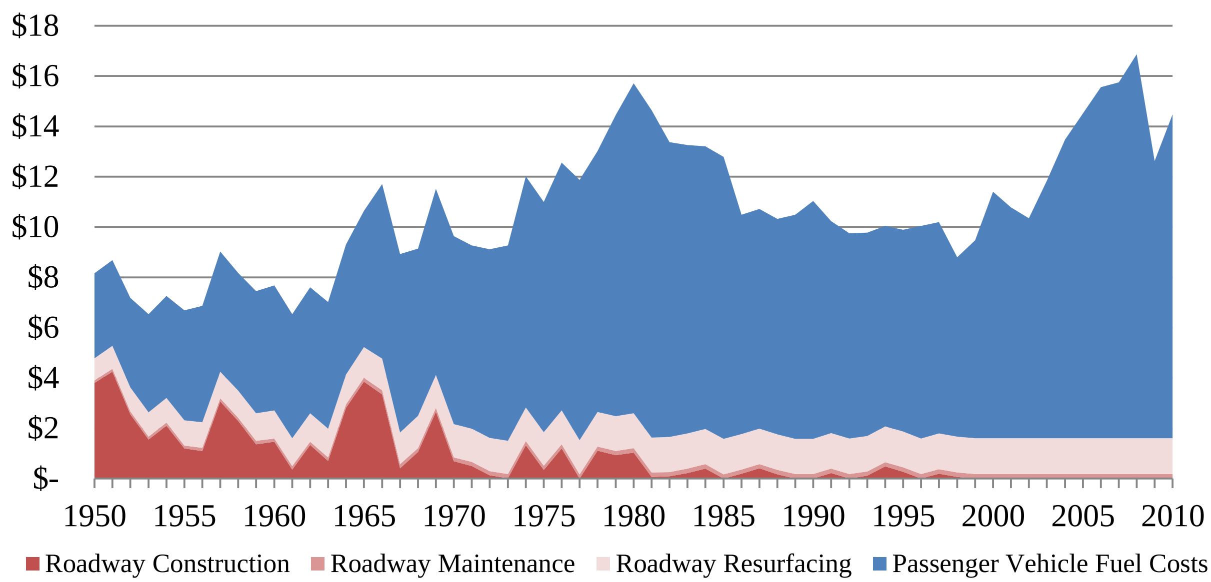

Figure 5: Los Angeles Roadway Costs (in billion 2010 dollars) with Passenger Vehicle Fuel Costs

Figure 5 shows that when the costs associated with the Los Angeles County roadway network are analyzed over time a correlation between the rate of growth of VMT and road miles and roadway miles can be seen. Through the early 1980's there was still active roadway construction within the county represented by the dark red. The deployment of these roads is a significant upfront cost borne by the state, county and individual municipalities. Once built, roadways undergo several different type of maintenance during their lifetime. In the above figure, Roadway Maintenance represents minor events such as pothole and crack filling while Roadway Resurfacing represents the costs associated with the reconstruction of the entire wearing layer. While new roadway construction has decreased to nearly zero in the last decade, maintenance still represents a cost of nearly 1.5 billion dollars annually. A majority share of the costs associated with roadways is directly paid for by vehicle owners. The total fuel costs are calculated based on average yearly fuel economy, average yearly cost of gasoline, and annual VMT. The plateau effect seen in VMT and the improving fuel economy in cars has seen the cost of overall fuel consumption fall despite consistent increases in the average price of fuel.

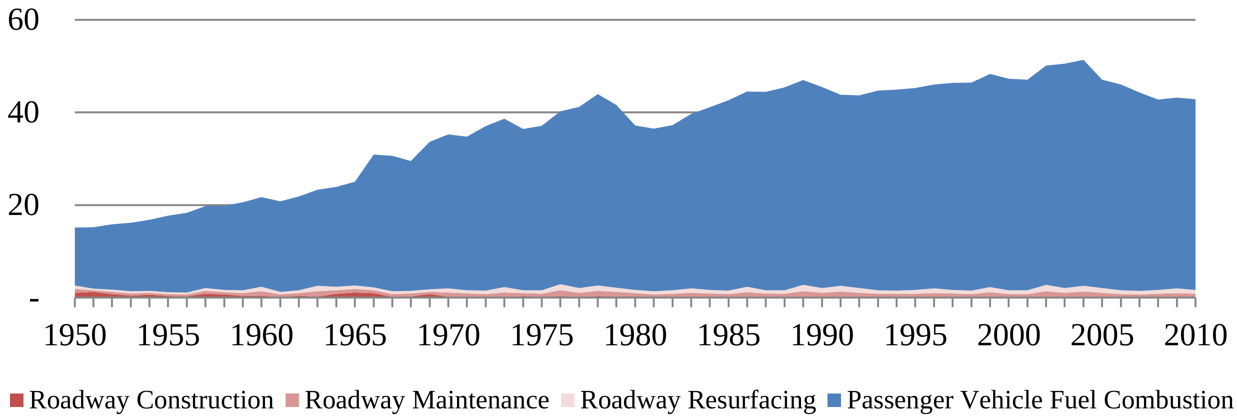

Figure 6: Greenhouse Gas Emissions (Teragrams CO_2e) from Roadway Provision and Emergent Passenger Vehicle Travel

Figure 6 shows annual greenhouse gas emissions over time. While the emissions associated with the roadways are significant they are only a small fraction compared to the emissions generated by fuel combustion. Cumulative vehicle emissions from 1945-present are 43 times greater than those embedded in the network.

4 Discussion

The direct economic and environmental burden of roadway construction and scheduled maintenance are both significant. However, when they are compared to the emergent effects of induced vehicle travel they are only a small fraction of the total impact. From an economic perspective, the increased expenditure in roadway deployment over time has increased the cost of travel on the average consumer. A larger roadway network enables additional travel. Roadway network expansion happens further and further from the county center and the newer suburban developments are built at greater distances from one another. When greenhouse gas emissions are analyzed we see a similar trend. The increase in annual VMT results in increased emissions from direct combustion on a per capita basis. Understanding the mechanisms behind the plateau in VMT is important and will be investigated further.

Attempts to reduce the environmental end economic impacts of roadways should emphasize changes in travel behavior of individuals, which may be effected by the infrastructure design. Proper management of roadways and the increased use of new and longer lasting pavement materials and processes could help reduce the economic burden of roadways for Los Angeles County.

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