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Spatiotemporal Dynamics of Daily and Per Capita VMT in California: A County-Level Analysis (2019–2023)

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Introduction

California seeks to redefine mobility, trading gridlock and pollution for climate resilience, yet Vehicle Miles Traveled (VMT)—the fundamental metric for assessing transportation system performance—keeps rising. Despite ambitious state mandates, including the Global Warming Solutions Act (AB 32) and VMT-focused policies (SB 375, SB 743), the state measured a record annual VMT of 344.0 billion miles in 2023. This aggregate figure obscures a critical truth: VMT recovery after the pandemic is profoundly uneven across the state. The brief decline in 2020 induced by the pandemic proved to be only a temporary stabilization. This study dissects the spatiotemporal dynamics of Daily VMT (DVMT) and per capita DVMT across all 58 California counties from 2019 to 2023. We move beyond simple averages to ask: Which local factors truly determine how much an individual drives? By integrating spatial analysis and advanced modeling, this research delivers targeted, evidence-based insights. We found that the success of California's climate goals hinges on changing the physical structure of our communities, not just on macroeconomic shifts.

Study Methods

We analyzed county-level Daily VMT (DVMT) data from 2019 to 2023, primarily sourced from the Highway Performance Monitoring System (HPMS). Our comprehensive approach relied on two primary methodologies: GIS-supported spatial analysis and advanced predictive modeling.

Spatial Analysis and Clustering: We used GIS mapping and time-series K-means clustering to identify and group the 58 counties into five distinct archetypal clusters. These clusters were defined by their DVMT and per capita DVMT trajectories before, during, and after the acute pandemic period. This approach revealed distinct regional responses, such as the sharp VMT drop in high density tech hubs versus the resilience of rural and logistics centers.

Predictive Modeling of Efficiency: To determine the causal drivers of travel efficiency, we focused specifically on per capita DVMT. This metric isolates genuine shifts in travel behavior from the confounding "noise" of population growth. By using Variance Inflation Factor (VIF) analysis to remove highly correlated factors, we carefully refined and selected six independent variables—including population density, per capita real GDP, housing units per 1,000 people, level of poverty, commuting time per employee, and public transit mode share.

We then rigorously compared six regression models: four traditional linear approaches (OLS, Ridge, LASSO, Elastic Net) and two advanced ensemble tree-based machine learning algorithms (Random Forest and Gradient Boosting). This comparison was designed to assess whether VMT determinants follow simple linear relationships or exhibit complex, non-linear interactions.

Findings

The time-series cluster analysis confirmed a profound divergence in post-pandemic recovery. Counties classified as "Urban Jobs" (Cluster 1) show DVMT stabilization at levels 10–12% below their 2019 per capita baseline, consistent with the sustained adoption of remote work. In sharp contrast, "Rural Recreational" counties (Cluster 4) routinely exhibit high driving intensity (60–80+ miles per person per day) and have seen their travel volumes either stabilize or increase above 2019 levels. This confirms that a single, statewide VMT reduction strategy cannot succeed. The most compelling finding demonstrates the superior predictive power of machine learning models. While the

four linear regression models explained only 64–66% of the variance in per capita DVMT, the ensemble tree-based models (Random Forest and Gradient Boosting) achieved R^2 values of 0.98 and 0.99, respectively. This overwhelming performance gap confirms that traditional linear methods fundamentally fail to capture the complex, non-linear reality of contemporary travel behavior. Feature importance analysis across the high-performing models clearly identified the dominant drivers of travel efficiency. Population density and housing units per 1,000 people emerged as the most critical predictors of per capita DVMT. The evidence suggests a critical trade-off: development defined by high housing units per 1,000 people—a metric characteristic of sprawling, auto-oriented patterns—is strongly associated with increased driving. Conversely, a higher percentage of workers commuting by public transportation is robustly associated with lower per capita DVMT.

K-means cluster analysis was used to analyze the spatial-temporal travel patterns and trends across California counties before, in the middle, and after COVID-19 pandemic. Machine learning models explained over 98% of county-level travel variation.

Policy/Practice Recommendations

Policymakers must abandon "one-size-fits-all" VMT reduction efforts. Our results demand differentiated, context-sensitive policy responses.

- Prioritize Land Use in Urban Centers: VMT reduction efforts must focus strategically on Urban and Suburban Clusters, where high densities and transit networks make substantial reductions feasible. Strategies should aggressively limit auto-oriented, low-density development while increasing housing density and transit accessibility in key corridors.
- Align Funding with System Use: Declining per capita DVMT in high-income urban areas confirms that gas tax revenues will decrease over time. This necessitates the urgent piloting and evaluation of Road Usage Charging (RUC) policies to ensure sustainable infrastructure funding.
- Protect Rural Equity: Applying a flat, per-mile RUC risks exacerbating spatial inequities, disproportionately penalizing rural residents who drive long distances out of necessity and lack alternatives. Policy frameworks must differentiate between essential VMT and tourist/recreational VMT. State funding formulas should be updated to incorporate "visitor VMT" to ensure that rural jurisdictions, which bear the burden of high tourist traffic, are adequately funded for road maintenance. Furthermore, regulatory frameworks must consider modified VMT thresholds for rural housing projects to avoid blocking necessary development.

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