

EV FOCUSED ENERGY-OPTIMAL DRIVING BEHAVIOR ACROSS URBAN AND HIGHWAY CYCLES IN DIFFERENT DRIVING CONDITIONS

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Abstract

Understanding how driver behavior, vehicle operating conditions, and stochastic traffic environments influence energy efficiency is essential for developing robust eco-driving strategies and next-generation intelligent driving systems. This paper consolidates studies spanning fundamental efficiency modeling, controlled acceleration–deceleration simulations, driver-behavior sensitivity analyses, and full-factorial design-of-experiments (DOE) with probabilistic traffic signals. A key challenge in analyzing driver behavior is the lack of structural information in conventional speed–time driving cycles. To address this, driving cycles are decomposed into explicit route representations consisting of stop signs, traffic signals, and speed-limited zones. This decomposition enables the formulation of two distinct classes of driving systems: distance-bound trips, where arrival time is unconstrained, and distance-and-time-bound trips, where the vehicle must traverse a fixed distance within a prescribed time window. This distinction provides a unifying framework for interpreting driver behavior and energy-efficiency trade-offs. Using this framework, simulations show that for distance-and-time-bound trips, optimal energy consumption arises from minimizing average velocity, with triangular speed profiles providing theoretical optima. While acceleration and deceleration profiles do influence efficiency, their effect remains modest (3 – 4%) compared to vehicle speed and auxiliary (aux) power consumption. These results reveal an aux-dependent optimal vehicle speed as the dominant factor governing total energy use. Building on these insights, a full-factorial DOE evaluates the influence of anticipation, acceleration and deceleration aggressiveness, speed-limit adherence, and aux consumption across diverse driving cycles: NYCC (urban with dense traffic), UDDS (urban with moderate traffic), HFEDS (light highway), and US06 (high-speed highway). Across all cycles, aux loads and vehicle speed consistently emerge as the most influential parameters. Acceleration and deceleration aggressiveness exhibit comparatively minor effects, while anticipation plays a secondary but meaningful role in urban driving, particularly under frequent stopping.

Extending the analysis to realistic traffic environments, DOE studies with probabilistic traffic signals introduce traffic density as a stochastic parameter governing signal states and pedestrian encounters. These studies demonstrate that traffic density and stochastic red-light encounters significantly affect low-speed urban cycles, yet have minimal impact on highway-dominant routes due to reduced signal frequency. Driver influence is shown to be strongly context-dependent: the relative benefit of slow versus fast driving can invert depending on aux load and traffic conditions. Across all cycles, however, the maximum driver-controlled efficiency swing remains limited to approximately 30 - 75 Wh/mi, substantially smaller than efficiency variations driven by environmental and contextual factors. Together, these studies provide a unified, route-aware framework for quantifying the interplay between driver behavior, trip constraints, traffic stochasticity, and vehicle efficiency. The results highlight that while driver behavior matters, operating context overwhelmingly governs achievable efficiency, underscoring the importance of predictive, adaptive, and traffic-aware energy-management and eco-driving strategies.