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Cordon-Metering Rules for Present-Day and Future Cities

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POLICY BRIEF

BACKGROUND AND OBJECTIVES

In recent years, urban traffic congestion has emerged as a significant challenge for cities worldwide leading to increased travel time, higher energy consumption, and elevated emissions. The emergence of Connected and Automated Vehicles (CAVs) is poised to significantly alter the transportation landscape, offering a promising opportunity to address these challenges. CAVs, through their ability to communicate with each other and with traffic infrastructure, enables the orchestration of traffic flow with unprecedented precision, optimizing route selection, and ensuring the efficient utilization of road networks. Through the strategic deployment of CAVs, it is conceivable to hold the potential to revolutionize traffic management and control systems, and significantly enhance the efficiency and sustainability of transportation systems.

In exploring the impact of introducing CAVs on the entire road network, existing research has been conducted from both micro-control and macro-control strategy perspectives. The majority of studies adopt a microscopic control viewpoint, investigating the effects of CAVs on traffic. These studies focus on road networks with a limited number of intersections, like corridor level or at the network level. Consequently, this narrows their applicability in large-scale network research. Also, when the research extends to the big city level (with an increased number of intersections and nodes), the aforementioned methodologies may become ineffective in the context of large-scale network studies due to limited computational resources. As a result, it becomes essential to adopt big network-level models from a macroscopic perspective.

Following these thoughts, this study investigates macro-control strategies for managing CAVs in city-level networks. It introduces an approach that utilizes speed advisories to regulate the entire network’s traffic flow, sidestepping the complexity of micro-level modeling for specific intersections or lanes. By simplifying the control process, this method not only reduce computational demands but also effectively moderating traffic conditions. The strategic adjustment of CAV speeds on a network-wide scale is poised to alleviate congestion and cut energy consumption, thereby offering a scalable solution to traffic management challenges.

METHODOLOGY

The study introduces a novel Area Transmission Model (ATM) based on the Macroscopic Fundamental Diagram (MFD), designed for city-wide network traffic modeling. The team formulated the challenge as a mixed integer nonlinear programming model, tackling the inherent nonlinearity in both the objective function—focused on the square of speed—and constraints, which involved nested min-max conditions. To address this complex problem, the commercial solver Gurobi was employed. The model's effectiveness was validated through a toy experiment using Python on a PC with an AMD Ryzen 7 5700G processor and 64.0 GB of RAM, showcasing the model's practical utility. The methodology also integrates a macro-optimization control strategy that uses speed advisories to manage traffic flow and mitigate congestion, improving energy efficiency. The approach was applied to Madison as a case study to explore optimal speed advisory solutions, demonstrating significant potential to enhance urban traffic management systems.

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RESEARCH FINDINGS

The study conducted two simulation experiments to evaluate the effects of a novel network modeling approach on traffic congestion using an Optimal Speed Advisory (OSA). Initially, congestion patterns were observed from the 2nd to the 40th minute, with significant buildup occurring by the 40th minute, primarily due to high volumes of CAVs commuting from suburban to downtown areas. This pattern was consistent with typical urban rush hour dynamics, causing bottlenecks as traffic converged on central business districts. Notably, after the 20th minute, no new traffic entered the network, leading to a gradual reduction in congestion as existing vehicles moved toward their destinations without additional incoming traffic, ultimately clearing by the 120th minute.

In contrast, the second experiment incorporated the OSA to control CAV speeds, which maintained traffic density at manageable levels throughout the simulation, preventing significant congestion. Remarkably, the most congested point occurred around the 20th minute, but congestion quickly dissipated, resulting in minimal congestion by the 60th minute. This demonstrates that with the OSA-based strategy, all traffic efficiently reached its destinations within just 60 minutes, effectively reducing congestion resolution time by half compared to the initial experiment. These findings underscore the strategic advantage and operational efficiency of the OSA, presenting a compelling case for its application in urban traffic management. The effectiveness of the proposed approach and the successful management of traffic flow highlight the potential of this modeling technique in enhancing traffic systems in real-world scenarios.

The deployment of our OSA solution presents a highly effective strategy for mitigating traffic congestion, as demonstrated by the comprehensive comparison between simulations with and without the control strategy. Notably, the adoption of the strategy resulted in all traffic reaching its destination in half the time required by the scenario without the strategy, underscoring the strategy's effectiveness in optimizing traffic efficiency and reducing delays. The qualitative comparison further highlights the solution's capability to improve system performance across multiple dimensions, including a 30.1% reduction in energy consumption, a 23.7% decrease in total travel delay, and a notable improvement in congestion resolution, with traffic densities smoothed out to maintain maximum and average levels within acceptable bounds. This methodology demonstrates the potential for improving traffic management practices, highlighting a promising path forward for optimizing urban transportation systems.

POLICY AND PRACTICE RECOMMENDATIONS

To effectively manage urban traffic and reduce congestion, traffic management authorities are encouraged to implement OSAs. These advisories have proven effective in simulations for easing traffic flow and reducing travel times by dynamically adjusting speeds based on real-time traffic conditions. Notably, the success of OSAs does not solely depend on connected and automated vehicles; they can be significantly effective if there is a high level of compliance from all drivers.

Public communication is crucial for the success of these traffic management initiatives. Authorities must clearly articulate the benefits and functionalities of such technologies to ensure public understanding and cooperation. Moreover, continuous investment in technology and infrastructure, such as traffic sensors and dynamic signaling systems, is essential. This investment should be accompanied by regular training for traffic management personnel to ensure they are well-versed in the latest technologies and strategies.

Furthermore, continuous monitoring and evaluation are vital to gauge the effectiveness of implemented strategies like OSAs and make necessary adjustments. This proactive approach allows for the ongoing refinement of traffic models and adaptive strategies, catering to evolving urban dynamics. Ultimately, this enhances the overall traffic management system and ensures smoother commutes for city residents, contributing to a more sustainable urban environment.

For more information on this project, download the entire report at nicr.usf.edu or contact **nicr@usf.edu**

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