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A New Approach to Calculating Dynamic Pricing of High-Occupancy-Toll (HOT) Lanes Can Improve the Performance of Travel Corridors

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Issue

As traffic congestion continues to worsen in urban areas, policymakers are seeking innovative solutions to maximize existing road infrastructure and improve travel times. High-occupancy-toll (HOT) lanes offer a promising solution by allowing single-occupancy vehicles (SOVs) to use underutilized carpool lanes for a fee, reducing congestion in regular lanes. In fact, the total number of HOT lane deployments in the United States has experienced exponential growth over the past few decades, as illustrated in Figure 1. In addition to improving the performance of the travel corridor, HOT lanes can generate new revenue sources to support the construction of additional HOT lanes or other road-related improvements.

There are two operational objectives for optimizing the operation of HOT lanes: (i) maintain free-flow conditions on HOT lanes and (ii) move as many vehicles as possible through HOT lanes to minimize the travel corridor's total delay.[1] Meeting these objectives will help guarantee trip time reliability of both HOVs and paying SOVs and minimize congestion on general purpose (GP) lanes. The key factor in achieving these objectives is the price charged to SOVs, which determines the percentage of SOVs choosing to use the HOT lanes. This in turn requires operators to adjust the toll fee in response to changing levels of traffic congestion. However, achieving these goals efficiently is contingent upon dynamic pricing strategies where tolls are adjusted in real time in response to traffic levels to maximize the total throughput while preventing queuing on the HOT lanes.

Current pricing methods often struggle to set the right toll in real-time, leading to HOT lanes that are either underused or too congested. This reduces their effectiveness in managing traffic and can frustrate drivers.[2] Our research aims to develop more effective ways to set HOT lane prices in real-time, ensuring they are used efficiently and provide reliable travel times for all drivers. Improving HOT lane operation can lead to reduced congestion, shorter commute times, and more efficient use of existing road infrastructure - all without the need for costly new road construction.

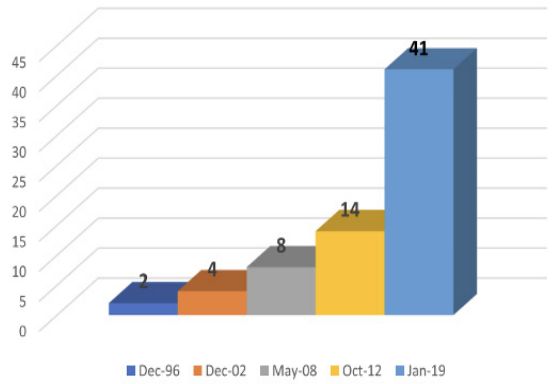

Figure 1. Growth of HOT lane deployments in the US over the past few decades

Key Research Findings

Existing pricing methods struggle to maintain optimal traffic flow. Today's HOT lane pricing strategies often miss the mark. They typically use fixed time-of-day pricing, infrequent adjustments based on historical data, or short-term dynamic pricing using pre-set rules. These methods can't always respond effectively to unexpected traffic changes. Sometimes they increase tolls when HOT lanes are underutilized, worsening overall congestion. They also struggle to quickly resolve congestion once it forms in

HOT lanes. The key challenge is balancing two objectives in real-time: maintaining free-flow conditions in HOT lanes while maximizing their use. Current systems lack the sophisticated, real-time decision-making capabilities needed to consistently achieve this balance across varying traffic conditions.

Our approach for measuring HOT lane efficiency informs real-time toll adjustments and in turn optimizes HOT lane use. We developed the concept of 'Residual Capacity' - essentially, the unused space on HOT lanes. The ideal situation is when this unused space is zero, meaning the HOT lanes are being used to their full potential without becoming congested. Our system uses real-time traffic data to continuously adjust tolls. If congestion starts forming on HOT lanes, the price increases. If there's unused capacity, the price decreases. This helps maintain optimal traffic flow at all times.

Our approach adapts to driver behavior using real time data. As mentioned above, current toll setting methods often use historical data and/or rely on assumptions related to driver behavior. Our method uses real time data (i.e., HOT lane occupancy and toll price) to estimate important factors, like how much drivers value their time, and makes toll price adjustments accordingly to optimize traffic throughput. This makes the system more adaptable and easier to implement in new locations.

Our approach has been validated in simulations and is ready for real world testing. Our approach goes beyond traditional trial-and-error methods. We used rigorous mathematical analysis to demonstrate that our system consistently achieves and maintains optimal traffic flow in HOT lanes. This mathematical foundation provides a strong assurance that the system will perform reliably across a wide range of traffic conditions, even when faced with unexpected changes. While these results are highly promising, the next crucial step is real-world validation through pilot projects with transportation agencies. These pilots would allow us to fine-tune the system for specific road conditions, demonstrate its effectiveness in actual traffic environments, and address any practical implementation challenges.

Policy Considerations and Future Research

Methods we developed contribute significantly to the advancement of stable and effective dynamic pricing strategies for HOT lanes, and offer a promising avenue for enhancing the efficiency of transportation systems. Future research will focus on encouraging collaboration between researchers, policymakers, and transportation authorities to refine and implement these approaches, building upon these methodologies.

More Information

This policy brief is drawn from two research articles prepared by Wenlong Jin with the University of California, Irvine.

1. Wang, X., Jin, W.L. and Yin, Y. A control theoretic approach to simultaneously estimate average value of time and determine dynamic price for high-occupancy toll lanes. IEEE Transactions on Intelligent Transportation Systems 22(11): 7293-7305, 2020. https://doi.org/10.1109/TITS.2020.3007160

2. Jin, W.L., Wang, X. and Lou, Y., Stable dynamic pricing scheme independent of lane-choice models for high-occupancy-toll lanes. Transportation Research Part B: Methodological 140: 64-78, 2020. https://doi.org/10.1016/j.trb.2020.07.008

For more information about findings presented in this brief, please contact Wenlong Jin at wjin@uci.edu.

[1]B. G. Perez, C. Fuhs, C. Gants, R. Giordano, and D. H. Ungemah, "Priced managed lane guide," Federal Highway Administration, Washington, DC, Techncal Report FHWA-HOP-13-007, 2012.

[2]Y. Yin and Y. Lou, "Dynamic tolling strategies for managed lanes," J. Transp. Eng 135(2): 45–52, 2009.

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