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RESEARCH ARTICLE

Case Study Evaluation of a New Approach to Price Metropolitan Highways for Congestion Relief, Sustainability and Equity

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ARTICLE INFO

Article history
Received: 2 September 2023
Revised: 20 October 2023
Accepted: 25 October 2023
Published Online: 8 November 2023

Keywords:
Transportation financing
Congestion pricing
Express bus
Carpooling
Cash reward
Travel demand management

ABSTRACT

This paper addresses the practically important challenge of devising efficient and politically feasible congestion pricing policies in the context of metropolitan highways. Congestion on metropolitan highways continues to grow while governments struggle to fund alternative modes of travel. The purpose of this paper is to explore the viability of a new approach to address highway congestion while also accommodating the mobility needs of those who don't drive. It involves creating congestion-priced lanes on limited access highways *without* adding new lanes. The lanes would be taken from general use and reserved for high-occupancy vehicles (HOV), transit vehicles and toll-payers, with cash rewards paid to HOV and transit users to attract solo drivers to shared travel. Variable tolls charged to lower-occupancy vehicles on the dedicated lanes would limit traffic demand on the lanes, keep traffic flowing, and fund the cash rewards. Rewards would be high enough to attract a sufficient number of drivers to ride as passengers instead so that congestion would be eliminated on the toll lanes and reduced on the remaining toll-free lanes through mode shifts. The policy-level analysis using a real-world case study of a radial highway segment with directional peaking suggests that this congestion pricing/cash rewards strategy could generate surplus revenues and provide financial support for bus rapid transit operating on the congestion-free lanes.

1. Introduction

Limited access highway facilities (a.k.a. freeways or motorways) serving metro areas across the world are being swamped by traffic. Congestion is endemic during peak commuting periods. One policy alternative would employ congestion pricing on the highways and use the revenues to fund alternatives to driving [1]. However, this approach has faced political obstacles due to strong public opposition to paying for road services that were previously free and due to concerns that drivers would divert to toll-free surface streets. There are also concerns that low-income drivers would face unaffordable toll rates.

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DOI: https://doi.org/10.55121/tdr.v1i1.87

The practical challenge is to devise an efficient and politically feasible congestion pricing policy in the context of metropolitan highways. This paper explores one such policy.

Congestion pricing has been successfully implemented in the central business districts of a few cities in Europe and in Singapore. But tolls have been imposed on all lanes of previously free metropolitan highways *only* in Singapore. A few metro areas in the U.S. have implemented congestion pricing on existing High-Occupancy Vehicle (HOV) lanes and on *new* lanes added to existing highways [2]. These lanes, known as High-Occupancy Toll (HOT) lanes, have provided toll-free service for HOVs and a new congestion-free travel choice for those who drive in lower-occupancy vehicles.

But *adding* HOT lanes has not significantly increased travel choices for those who don't drive, because the high costs for adding new lanes, and toll revenues that are usually insufficient to pay for these high costs, have made it difficult to fund enhanced transit services. Also, to limit the loss of revenue that results from free HOV use, vehicle occupancy requirements to be eligible for toll-free service are typically set at three persons or more per vehicle (a.k.a. HOV-3+), making it more difficult to form eligible carpools. Moreover, the added highway capacity further incentivizes low-density auto-centric development patterns difficult to serve by public transit.

If express toll lanes could instead be created by converting one or two *existing* lanes on metropolitan highways, surplus toll revenue could be generated and used to support express buses operating on the tolled lanes. Mobility hubs at activity centers on the highway could provide first and last mile connections to trip origins and destinations via on-demand mobility services, and protected bicycle lanes could be established for safe access to the mobility hubs. The number of lanes converted to priced lanes could depend on the total number of existing lanes but never exceed 50% of total capacity, e.g., only two lanes per direction on a facility with 4 lanes per direction. Toll-free lanes would always be available for those who do not want to pay tolls—thus addressing concerns about traffic diversion to alternate routes as well as concerns about the affordability of tolls for low-income travelers who have no choice but to drive.

Motorists would oppose the lane "take-away" if it were to increase congestion on the remaining free lane(s). A solution would be to incentivize use of transit, carpools, and vanpools, by providing cash rewards high enough so that the resulting traffic reductions caused by mode shifts would ensure that congestion gets no worse on the remaining free lanes. Rewards would be funded by tolls. The lanes would be "HOTTER" lanes, i.e., lanes reserved for **H**igh-**O**ccupancy vehicles, **T**ransit vehicles and **T**olled vehicles on **E**xisting lanes with **R**ewards for those who share rides in transit, carpools, or vanpools [3].

The key question is—could a HOTTER lane network be financially viable in a real-world context? To answer this question, DeCorla-Souza and Minett [3] considered a project in the U.S. proposed by the Maryland Department of Transportation (MDOT) to build new HOT lanes on highways I-270 and I-495 in the Maryland suburbs of Washington, DC by *adding* new highway capacity (see Figure 1). The MDOT study's preferred alternative [4,5] involved expanding both highways to accommodate two new HOT lanes per direction. However, expanding the eastern segment of I-495, a facility that currently has 4 lanes per direction, was found to be infeasible due to right-of-way constraints and public opposition to the expansion. Therefore, the entire eastern segment of I-495 was eliminated from the study. DeCorla-Souza and Minett [3] evaluated the potential of HOTTER lanes on that segment of I-495. They evaluated two HOTTER lanes, created by converting half of the four lanes per direction, and found that costs for operations, including payment of cash rewards, would be less than half of total revenues, leaving a significant net revenue stream with a present value of about $1.5 billion.

The proposed HOT lanes on the remaining segments, i.e., the eastern segment of I-495 and a 12-mile segment on I-270, are opposed by Montgomery County, the jurisdiction in which these segments are located. Additionally, community and environmental organizations have filed a lawsuit against the planned project due to its environmental impacts. Due to the lawsuit and political opposition, the private company under contract to MDOT to develop the project as a public-private partnership terminated its contract with MDOT [6]. A HOTTER alternative could potentially address concerns expressed by project stakeholders since using existing lanes to create HOT lanes could reduce environmental impacts and generate a net revenue stream to fund transit.

The purpose of this paper is to evaluate the financial viability of HOTTER lanes on I-270. The I-495 highway previously evaluated by DeCorla-Souza and Minett [3] is a circumferential freeway with relatively balanced directional flows in the morning and afternoon peak periods. On the other hand, I-270 is a radial highway with heavy peaking southbound in the morning and northbound in the afternoon. So, it is important to evaluate how these characteristics would affect the viability of HOTTER lanes. The contribution of this paper is an examination of how HOTTER lanes might perform in the context of a commuter corridor with heavy directional traffic peaks, and whether HOTTER lanes could address the concerns of opponents of I-270 expansion by eliminating the need for expansion.

Section 2 summarizes the modeling methodology used to perform a policy-level evaluation of the HOTTER concept on I-270. Evaluation results are presented in Section 3. Section 4 discusses implications and Section 5 presents conclusions.

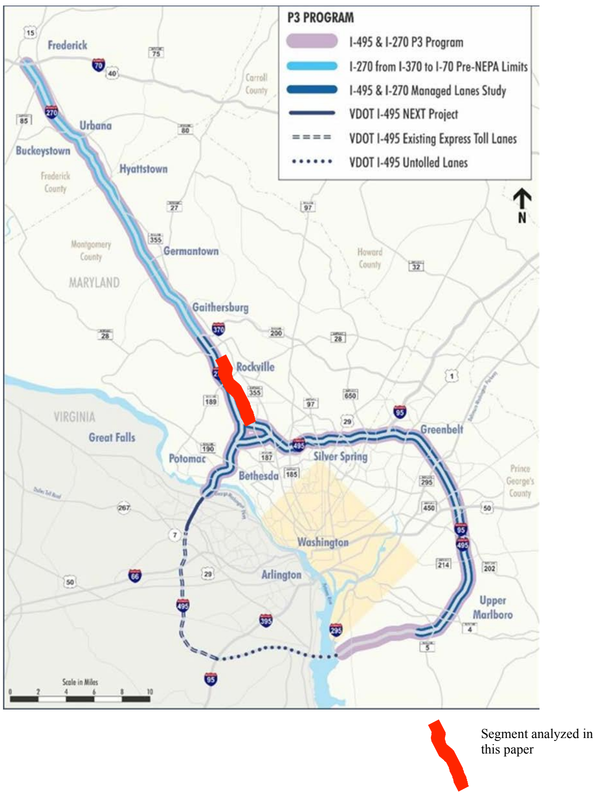

Figure 1. MDOT's managed lanes study and P3 program.

Source: [5].

2. Methodology

2.1 HOTTER Configuration on I-270

I-270 has three general-purpose (GP) lanes and one HOV lane per direction, in addition to two collector-distributor (CD) lanes per direction which separate traffic getting on and off the freeway from through traffic (see Figure 2). Peak period travel demand and throughput volumes for a representative segment on I-270 are presented in Table 1 for 2017 (observed) and 2040 (forecasted). The data for the segment is representative of the travel conditions on much of I-270. Traffic volumes are directionally unbalanced. A cohort of traffic flows southbound in the morning (39,200 vehicles) and northbound in the evening (44,000 vehicles), and a second cohort travels northbound in the morning and southbound in the evening (26,100 and 28,400 vehicles respectively). Traffic patterns forecasted for 2040 are similar but higher.

Since the second traffic cohort is exposed to very little congestion, pricing this cohort is unnecessary. So, we evaluated the viability of the HOTTER concept if applied only in the peak directions—southbound in the morning and northbound in the afternoon. An alternative with two HOTTER lanes (1/3 of capacity) was considered, as shown in Figure 2. Two HOTTER lanes per direction would be consistent with existing HOT lanes in the Northern Virginia portion of the metro area; and two lanes would allow faster drivers to pass slower-moving vehicles, providing a better level of service than a single lane and increasing per lane capacity on the HOTTER lanes. Prior research by DeCorla-Souza [8] found that if a larger share of capacity were converted, greater traffic reductions would be needed and therefore a larger share of travelers would need to be incentivized to share rides; so, incentive payments would need to be made to more travelers *and* each payment would need to be higher. Consequently, costs for the rewards program would increase, reducing financial viability.

The HOTTER lanes would operate in the heavy direction only—tolls would be charged only in the southbound direction during the morning peak period (6 a.m. to 10 a.m.) and only northbound during the evening peak period (3 p.m. to 7 p.m.). To be consistent with the rest of the HOT network across the state line on the Virginia segment of I-495, only buses and 3-person carpools (HOV3) would be exempt from tolls.

2.2 Modeling Process

An Excel-based spreadsheet model called **P**ricing **A**nd **S**hared **T**ravel **E**stimation (PASTE) was used to evaluate the HOTTER concept for I-270 at a sketch-planning level. PASTE model runs are available at https://tinyurl.com/mpe4n8wt. PASTE begins with peak period hourly demand for vehicle and person travel observed in 2017 or forecasted for 2040 (as shown in Table 1) and proceeds to assess the HOTTER scenario for the morning southbound/evening northbound (MSEN) cohort, i.e., the cohort subjected to heavy congestion. The step-by-step process is described below.

Step 1: PASTE calculates target traffic volumes for general purpose (GP) and HOTTER lanes, assuming the need to accommodate two-thirds of the total baseline (observed or forecasted) freeway traffic in the four GP lanes to ensure that congestion levels on those lanes would be unchanged from the baseline. HOTTER lane volumes would need to be no higher than the level that could support a minimum speed of 55mph, i.e., 1,600 vehicles per hour per lane.

Table 1. Peak period travel demand (vehicles per hour) on I-270 at Montrose Road.

		Morning southbound, evening northbound cohort		Morning northbound, evening southbound cohort	
	Hourly period	**Year 2017 (observed)**	**Year 2040 (forecasted)**	**Year 2017 (observed)**	**Year 2040 (forecasted)**
Morning	**6 a.m.-7 a.m.**	9,300	10,300	4,200	4,700
	7 a.m.-8 a.m.	10,800	12,000	6,100	6,900
	8 a.m.-9 a.m.	10,000	11,000	8,300	9,400
	9 a.m.-10 a.m.	9,100	10,100	7,500	8,600
	Total AM period	**39,200**	**43,400**	**26,100**	**31,700**
Evening	**3 p.m.-4 p.m.**	10,500	11,500	6,700	7,500
	4 p.m.-5 p.m.	11,400	12,600	7,300	8,000
	5 p.m.-6 p.m.	11,400	12,600	7,500	8,400
	6 p.m.-7 p.m.	10,700	11,800	6,900	7,800
	Total PM period	**44,000**	**48,500**	**28,400**	**29,600**

Source: Maryland Department of Transportation [7].

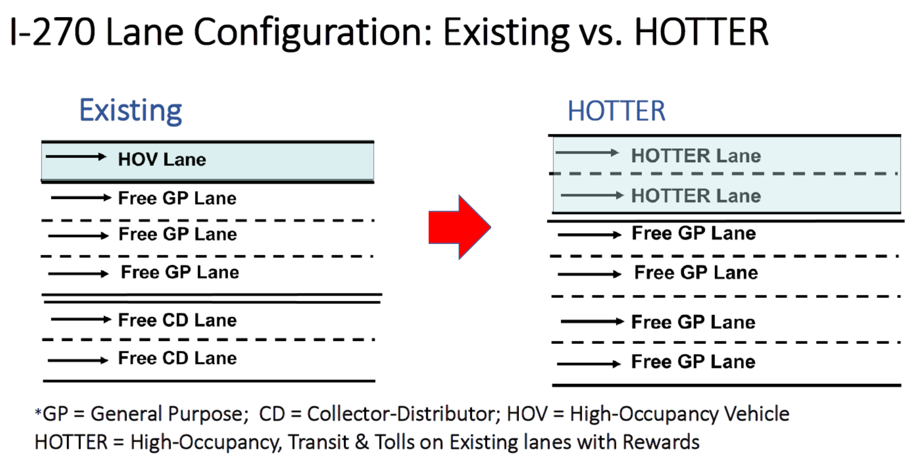

Figure 2. Conversion of existing I-270 lane configuration to HOTTER configuration.

Step 2: Based on the target traffic volume in the four GP lanes and the number of vehicles that could be accommodated in HOTTER lanes at 55 mph, PASTE calculates how many commuter drivers would have to be induced to switch to traveling as transit or carpool passengers, and how many commuters who currently drive alone would need to provide rides to commuters in carpools. Existing commuter/non-commuter splits and average vehicle occupancies were obtained from data from the metropolitan planning organization [9,10].

Step 3: New transit and carpool users are likely to change their departure times from home because the HOTTER lanes would offer them toll-free access to an uncongested facility at any time. Data on HOT lane usage by transit and HOV3 on I-95 in Northern Virginia, for 3 weeks in May 2022, was used to estimate the temporal demand shift. Checks were then made to ensure that the resulting total demand in any hour of the two peak periods did not exceed the targets for the four GP lanes and two HOTTER lanes.

Step 4: Based on the percentage of commuters that would need to travel as transit or carpool passengers, PASTE estimates the amount of cash incentive that would need to be provided, after deducting the value of the benefit they would gain in time savings on the uncongested HOTTER lanes in comparison to the adjacent GP lanes. PASTE also similarly estimates the amount of incentive that would need to be provided for carpool drivers. The level of incentives is calculated using regression equations developed by Minett et al. [11]. The cash value of time savings is calculated based on the difference between average hourly speeds on GP lanes and HOTTER lanes, using the

Bureau of Public Roads (BPR) equation and the value of travel time savings recommended by the U.S. Department of Transportation [12]. Although the real value of time might increase by 2040, we used the same value of time for 2017 and 2040 to ensure that the estimates of cash incentives needed are not understated. We made an allowance for "buffer time" savings perceived by travelers, in addition to actual calculated time savings. (Buffer time is the additional time that trip-makers must allow for in their travel plans on congested facilities to allow for variability in trip times and ensure that they will arrive at their destination on time.)

Step 5: Based on the mode shifts calculated in prior steps, PASTE calculates the morning traffic flows, and then the changes to afternoon flow as the same cohort of commuters return from work in the reverse direction. PASTE assumes that a person leaving home as a driver in the morning will return home as a driver in the afternoon, and all morning transit riders and HOV3 users will return during the afternoon peak period, distributed by hour based on HOT lane experience on I-95 in Northern Virginia, as discussed above.

Step 6: Since the resulting afternoon flows by hour could be higher than the targeted volume, we further adjusted the required mode shifts in an iterative process, starting at step 2 above, until the afternoon flows did not exceed the target demand volume for each hour. Because travel demand in the afternoon is higher, a greater number of passengers and carpool drivers must be incentivized in the morning, increasing the cost of incentives. Required traffic reductions are governed by needs in the highest peak hour in the afternoon. Thus, GP lane traffic reductions in the morning peak hours and afternoon peak shoulder hours are higher than reductions required to maintain baseline GP lane level of service during those hours.

Step 7: PASTE subtracts toll-exempt vehicles from HOTTER lane capacity to estimate the amount of capacity that would be available in the HOTTER lanes to 'sell' to toll-payers during each hour of the morning and afternoon peak periods. The average toll rates that would apply are estimated based on the percent of HOTTER lane capacity available for toll payers. Average toll rates during the morning and afternoon peak periods were first derived from toll rates in the MDOT's study [5]. Resulting hourly rates ranged from \$0.72 per mile to \$1.08 per mile in the morning and from \$0.87 per mile to \$1.23 per mile in the afternoon.

Step 8: PASTE then calculates gross toll revenues, total costs for cash incentives, total costs for toll collection, total costs for operation of the shared ride program, and net operating revenue. Costs for toll collection are estimated at \$0.20 per toll transaction based on toll collection costs in FHWA's TRUCE model [13]. Costs for carpool program operation are estimated at \$0.25 per carpool participant based on a small-scale app-based on-demand carpool program implemented in the San Francisco Bay area [14].

Step 9: PASTE first estimates the traffic that would divert from other routes and from off-peak and other hours within the peak period to the GP lanes during peak periods to take advantage of the changed (faster) speeds on the GP lanes facilitated by lower traffic volumes. The volume of diverted traffic per GP lane is estimated as half of the difference between the initial estimated volume per lane and the prior observed or forecasted volume per lane. This diverted traffic would slow the GP lanes back down, but they would still be faster than before. These relatively faster speeds would induce new traffic such as traffic due to travelers changing their destination choices or simply making new trips; and in the longer run, from changes in residential and employment location choices. PASTE uses long-term travel demand elasticity with respect to travel time of –0.5 [15] to estimate the amount of induced travel that might occur in the long run. PASTE then calculates final speeds on the GP lanes after allowing for both diverted and induced travel using the BPR equation.

3. Results

3.1 Model Output

Table 2 summarizes the key results for model years 2017 and 2040. The model results indicate that there will be significant surplus operating revenue after accounting for incentive payments and all other costs of operations. Daily costs for operations, including costs for cash incentives, are less than half of estimated daily toll revenues, i.e., less than \$80,000 in costs vs. about \$200,000 in revenue, suggesting that even if required cash incentives are significantly higher than those calculated for the analysis, the HOTTER concept would still be financially viable.

A comparison of results from the model runs for 2017 and 2040 indicates that the number of toll-payers and gross toll revenue would decrease over time, because there would be less capacity available for toll-payers, which would occur because shared travel users would increase over time, drawn to shared modes by the higher cash incentives that must be provided when traffic demand increases and greater shifts to shared modes would be needed. However, the 2040 toll rates used in our analysis do not reflect rate increases over time which could occur as a result of higher values of time due to increasing real wages or increasing congestion in the general purpose lanes which would increase the value of congestion-free service in the HOTTER lanes. Consequently, net revenues would likely stay stable over time.

Our analysis shows that the rate at which commuters would need to switch to traveling as passengers would be 25.5% of total commuters in 2017. By 2040, it would grow to 29.7%, due to the overall growth in traffic demand forecasted in the MDOT study. Thus, passenger uptake is within the upper bound estimated by Minett et al. [11]. According to Minett et al. [11], up to 50% of all commuters would be willing to travel as passengers if offered a cash reward that is high enough.

3.2 Financial Viability Analysis

Average weekday net operating revenues in 2017 are estimated at $0.138 million in 2021 dollars after accounting for cash rewards and operating costs for toll collection, carpool occupancy verification, and rewards distribution. The 2040 estimate is a little lower ($0.121 million) in real 2021 dollars, but it does not account for real increases in toll rates, as discussed above. Net annual operating revenues of about $34.5 million can be expected assuming HOTTER operation only during the peak periods in the peak direction, on 250 work weekdays a year.

Costs for tolling infrastructure maintenance are estimated at about $4 million per year (in 2021 dollars) for the 12-mile segment based on the TOPS-BC model [16]. The resulting net annual revenue stream would be $30.5 million per year. Over a 30-year period of operations, its present value at a 4% *real* discount rate is about $550 million. This estimate does not account for capital investment costs for the implementation of HOTTER lanes and capital investment and start-up costs for the carpooling program. We estimate these costs at about $37 million (see Table 3). Thus, a surplus of over $500 million in net present value would be available.

Table 2. Summary of model results for morning southbound evening northbound cohort.

Result	**2017**	**2040**
Commuters traveling as passengers (% of total)	25.48%	29.71%
Carpool drivers as a % of total commuters	6.39%	7.44%
Daily incentive needed to attract a sufficient number of drivers to switch to passenger mode (before subtracting value of time savings on HOTTER lanes)	$4.10	$5.55
Daily incentive needed to attract a sufficient number of drivers to pick up passengers (before subtracting value of time savings on HOTTER lanes)	$0.00	$0.50
% Reduction in morning traffic volumes with HOTTER lanes	10.00%	13.38%
% Reduction in evening traffic volumes with HOTTER lanes	8.47%	11.37%
Gross toll revenue in AM peak period	$115,891	$109,326
Gross toll revenue in PM peak period	$94,257	$88,849
Gross toll revenue per day	$210,148	$198,175
Total cash incentive expenditures per day	$65,101	$69,947
Total carpool program operating costs for occupancy verification and distribution of rewards	$3,455	$4,455
Total operating costs per day for toll collection	$3,064	$2,643
Total operations costs per day (including incentive costs)	$71,620	$77,045
Net daily revenue	**$138,528**	**$121,130**

Table 3. Capital cost estimates for HOTTER lanes on I-270.

Cost component	***Cost*** [1]	***2021 $*** [2]
Costs to convert lanes to HOTTER lanes [3]	$18,000,000	$32.0 million
Startup costs for carpooling program [4]	$5,000,000	$ 5.4 million
Total capital costs		**$37.4 million**

1 From source data

2 Based on CPI Inflation Calculator at: https://www.bls.gov/data/inflation_calculator.htm (US Bureau of Labor Statistics)

3 Based on data for 1-35W (Minnesota) for converting 30 miles of HOV lanes to HOT lanes (17).

4 Based on costs for implementing the *incenTrip* program (Washington DC metro area) at: https://incentrip.org/

4. Discussion

4.1 Key Findings

The results of our analysis suggest that a stream of surplus revenues could be generated from HOTTER lanes that use one-third of available capacity on a radial highway with directional peaking of traffic. The results supplement prior analyses of HOTTER lanes using half of available capacity (i.e., 2 lanes out of 4 lanes) for a heavily congested circumferential highway with traffic peaking concurrently in both directions [3].

A second finding is that, unlike HOT lanes created by adding lanes, which need to recover the huge investment costs for expanding highways by imposing tolls throughout the day, HOTTER lanes can be free from tolls during off-peak hours and in the off-peak direction during peak periods when there is little or no congestion. This allows the spreading of traffic over all lanes and allows traffic to flow more efficiently, benefiting all travelers. Also, when tolls are charged only when they are needed to manage congestion, tolling is less likely to be seen by the public as a "money grab" and is less likely to face public opposition.

4.2 Implications

The results from this paper evaluating the *radial* I-270 highway and the prior paper evaluating the *circumferential* I-495 highway [3] together suggest that it might be possible to implement a *network* of HOTTER lanes throughout a metro area's highway network to create a high quality free-flowing bus rapid transit (BRT) system. HOTTER lanes could fund multimodal travel options with surplus revenue from tolls willingly paid by low-occupancy vehicle drivers to avail themselves of premium congestion-free service. Network effects and cash rewards could increase the pool of transit riders, allowing more frequent service with shorter headways. The pool of commuters choosing to carpool would also increase, resulting in more and better carpool matches. In the long run, better transit service frequency could influence residential and employment location choices, leading to more transit-oriented development patterns that increase transit viability. Thus, HOTTER lane networks could create a virtuous cycle — more transit riders and carpoolers, leading to more frequent transit service and better carpool ride matches, leading to more transit riders and carpoolers.

Networks of HOTTER lanes would thus provide many public benefits. By reducing traffic and vehicle miles travelled in peak periods, HOTTER lanes would support climate and sustainability goals. By generating surplus revenue to support express transit services and by rewarding users of shared travel modes, HOTTER lanes would increase accessibility for those who don't drive and enhance transportation equity. Improved access to jobs would provide economic as well as social benefits. Free-flowing freeway lanes could make the operation of automated transit vehicles feasible, thus reducing transit operating costs. Bus rapid transit (BRT) operating on a HOTTER network could be put in place in a few years instead of the decades it would take to create a BRT network by adding new HOT lanes. Drivers would have new choices to avoid congestion—whether by riding on transit or in a carpool or by driving alone and paying a variable toll. Reduced reliance on automobiles and opportunities to deploy connected and automated vehicle technologies on HOTTER lanes would help reduce crashes. Some traffic engineering studies have shown that variable tolls to manage traffic can increase throughput by avoiding breakdown in flow [18]. Highway agencies would be able to reduce congestion much faster than they could using traditional highway expansion. By reducing the need for highway expansion, public agencies could deploy their capital budget savings for other pressing needs such as safety improvements and highway system preservation.

4.3 Implementation Challenges

Despite the significant societal benefits and lack of any real harms, there will be opponents due to misperceptions among some members of the public. Taking a lane could be perceived negatively, because motorists may believe that the remaining lanes will get more congested as a result. It will be challenging to convince motorists that congestion will be reduced because traffic in regular lanes will be reduced. Some stakeholders may perceive a "diversion" of highway user revenue (from tolls) for non-highway purposes. It will be challenging to convince them that highway users will benefit significantly from the "diversion" because of congestion reduction when some drivers are incentivized to shift to transit or carpools.

4.4 Recommendations for Further Research

To obtain results with a higher level of confidence in specific metro areas, we suggest that planners could undertake targeted surveys in corridors of interest to get more reliable estimates of the willingness of commuters to travel as passengers and the magnitude of cash incentives that might be needed. If the PASTE model results suggest financial viability, a thorough assessment of the performance impacts should be undertaken, including non-commuter mode shifts, using transportation demand models and microsimulation of freeway operations, and a detailed evaluation of the technical and financial viability of the approach.

5. Conclusions

The main contribution of this paper is a confirmation that there is a practical, efficient, and more politically feasible congestion pricing approach to relieve congestion on metropolitan highways and more specifically in a radial freeway corridor. Our I-270 case study policy-level evaluation suggests that the HOTTER concept could be a financially viable solution to congestion on I-270 and could generate surplus revenues. Thus, it could be a solution to the opposition to highway expansion that has stalled progress on addressing congestion in that corridor.

Another contribution of this paper is a demonstration of the ability of the PASTE model to analyze the impacts of a HOTTER alternative on a radial highway. The model, available at https://tinyurl.com/mpe4n8wt, can be used by planners to perform high-level policy evaluations of HOTTER alternatives in various contexts.

Author Contributions

The authors confirm that Patrick DeCorla-Souza and Paul Minett both contributed to the development of this paper including study conception and design; data collection; modeling and runs; analysis and interpretation of results; draft manuscript preparation; and manuscript editing.

Conflict of Interest

The authors declare no conflict of interest

Disclaimer

Patrick DeCorla-Souza authored this paper in his personal capacity. The views expressed in this paper are those of the authors and not necessarily the views of the U.S. Department of Transportation (USDOT) or the Federal Highway Administration (FHWA).

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