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Authors

Ghaffar, Arash

Ahmed, Tanjeeb

Nam, Daisik

et al.

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Transport Pricing Policies and Emerging Mobility Innovations

Michael F Hyland, Ph.D., Assistant Professor, Civil and Environmental Engineering, University of California, Irvine
Daisik Nam, Ph.D., Assistant Professor, Asia-Pacific School of Logistics, Inha University
Tanjeeb Ahmed, Graduate Student Researcher, University of California, Irvine
Arash Ghaffar, Graduate Student Researcher, Civil and Environmental Engineering, Unicersity of California, Irvine

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16. Abstract
Transportation pricing policies aim to manage vehicular demand for parking, dense urban areas, roadways, and highway lanes. Although pricing policies take various forms, most were designed in a world before the sharing economy and ride-sourcing companies. Hence, the efficacy of existing pricing policies in a world with shared mobility services requires further consideration. Moreover, future pricing policies designed to handle private vehicles and shared ride-sourcing vehicles must consider the behavior of both sets of travelers and vehicle fleets. This study develops a conceptual framework to support systems level analysis of pricing policies for a world with private and shared vehicle usage. It qualitatively analyzes the impact of shared vehicles on the effectiveness of various pricing policies, while also considering the role of vehicle-to-infrastructure technology. This conceptual framework will support future research that uses activity-based travel demand and dynamic network assignment models to evaluate congestion pricing policies in an era of shared mobility. Additionally, the study presents a detailed review of the literature related to transportation pricing together with a trend analysis on congestion pricing policies in Transportation Research Board annual meeting titles and abstracts.

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Disclaimer

Transport Pricing Policies and Emerging Mobility Innovations

Michael F Hyland, Ph.D., Assistant Professor, Civil and Environmental Engineering, University of California, Irvine
Daisik Nam, Ph.D., Assistant Professor, Asia-Pacific School of Logistics, Inha University
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Executive Summary

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Transportation pricing policies aim to manage vehicular demand for parking, dense urban areas, roadways, and highway lanes. Although pricing policies take various forms, most were designed in a world before the sharing economy and ride-sourcing companies. Hence, the efficacy of existing pricing policies in a world with shared mobility services requires further consideration. Moreover, future pricing policies designed to handle private vehicles and shared ride-sourcing vehicles must consider the behavior of both sets of travelers and vehicle fleets. This study develops a conceptual framework to support systems level analysis of pricing policies for a world with private and shared vehicle usage. It qualitatively analyzes the impact of shared vehicles on the effectiveness of various pricing policies, while also considering the role of vehicle-to-infrastructure technology. This conceptual framework will support future research that uses activity-based travel demand and dynamic network assignment models to evaluate congestion pricing policies in an era of shared mobility. Additionally, the study presents a detailed review of the literature related to transportation pricing together with a trend analysis on congestion pricing policies in Transportation Research Board annual meeting titles and abstracts.

Transportation agencies and policymakers are considering transportation pricing policies to reduce roadway congestion and achieve environmental goals. Although a transportation system planner can look to existing pricing policies around the world for insights, their success differs by region. Hence, insights from one region to another are not necessarily transferrable. For example, while cordon-pricing works well around London it may not work well around Los Angeles. This implies there is a need for models that can assess the potential impacts of pricing policies before their actual (costly) implementation. While transportation system models that incorporate pricing policies exist, they do not properly capture the role of emerging transportation innovations like shared mobility, automated vehicles, and vehicle/infrastructure connectivity. Another important issue with pricing policies is equity. We need to ensure pricing policies produce equitable outcomes for travelers.

To better understand the potential impacts of pricing policies, there is a need for modeling tools that appropriately capture the effects of emerging transportation innovations like ridesourcing or shared-ride services and are sensitive to pricing policies. In other words, including emerging transportation innovations in transportation models is particularly important when evaluating pricing policies. For instance, ride sharing may be more attractive than transit under various pricing policies designed to discourage single-occupancy vehicle travel and parking.

Our review of the latest transportation pricing research suggests that although increasing attention is being paid to emerging transportation innovations, most studies tend to focus locally on one particular mode of travel, rather than the complete set of modes available to travelers. There are now available transportation simulation tools for agent-based modeling that can depict drivers' responses to various pricing and mobility options. Another advantage of agent-based modeling is a researcher can easily incorporate different combinations of transportation pricing policies to evaluate their separate and joint impact on transportation systems considering equity, efficiency, sustainability, and affordability.

Contents

Introduction

Travel demand in metropolitan regions around the world has and continues to steadily increase, especially in areas with large populations. However, the supply of transportation facilities in metropolitan regions has remained stable in recent years, as the construction of additional road and rail capacity is both cumbersome and expensive. As increasing supply to meet travel demand is not a feasible or cost-effective solution in most metropolitan areas, transportation agencies and planners have sought other potential solutions to address traffic congestion. Traditional traffic reduction strategies are designed to shift travelers away from low occupancy vehicle trips and toward shared-rides and active and public transportation modes. These passive strategies have either proved unsuccessful or only acted as short-term solutions to traffic congestion. An alternative approach involves reducing congestion through more aggressive pricing strategies.

Congestion pricing is a means of travel demand management that aims to alleviate heavy traffic congestion and enhance network performance by shifting trips to different departure times, modes, destinations, and routes throughout the network. The first congestion pricing implementation occurred in Singapore in 1975, where drivers were charged a fixed toll to travel within the central business district (CBD) (*1*). Since then, several cities (such as London, Stockholm, Milan, and Tehran) have employed congestion pricing and seen notable reductions in traffic congestion (*2*). In these cases, area-based pricing resulted in changes in travel behavior, such as mode shifts to higher occupancy vehicles (HOVs), and reductions in pollution, both of which have long-term and widespread benefits. Currently, transportation agencies are implementing or at least considering several new pricing strategies to enhance the performance of network facilities, such as link-based pricing (*3*, *4*), distance-based pricing (*5*, *6*), high-occupancy toll (HOT) pricing (*7*, *8*), and parking pricing (*9*, *10*), at different times and locations, as well as through demand-independent (i.e., the pricing policy does not directly consider current demand), demand-responsive (i.e., the pricing policy responds to current demand levels), and demand-anticipatory pricing (i.e., the pricing policy not only responds to current demand levels but anticipates near-term future demand). Each of these strategies is described in more detail in the sections below.

Despite efficiently controlling traffic control and managing travel demand, early pricing systems lacked fairness and equity as they imposed a single toll on all road users regardless of the time of day or degree of road congestion, or the individual's travel characteristics. To efficiently and equitably price network facilities, novel pricing schemes are replacing the traditional flat-rate congestion pricing strategy. For example, new pricing systems charge users prices that vary across different times of the day or assign prices to network facilities based on current demand/congestion levels—the higher the demand for the facility, the higher the toll.

Recently, the advent of connected and automated vehicles (CAVs) and their potential for widespread use has motivated research that takes advantage of the benefits of connectivity and automation in the context of congestion pricing (*3*). Other research examines the prospects of shared-use automated vehicles (SAVs) replacing traditional modes of travel (*11*, *12*). Interestingly, research finds that automated and electric vehicles are likely to *increase* vehicle-miles traveled (VMT) from passenger cars (*13*), making congestion pricing an even more appealing option for reducing congestion, especially in urban areas (*3*).

This report develops a conceptual framework that considers transportation pricing strategies in relation to emerging transportation innovations (i.e., sharing, connectivity, automation) and the potential impacts on the transportation system. Moreover, the conceptual framework incorporates travel behavior and network models needed to capture the potential transportation system impacts of new transportation innovations and congestion pricing strategies simultaneously.

The report is organized as follows. The next section presents a trend analysis of studies presented at Transportation Research Board (TRB) annual meetings related to congestion pricing. The following section provides an overview of four main forms of transportation system pricing. We then discuss the role of emerging technologies in transportation and their relationship to transportation pricing strategies and changes in travel behavior. Finally, we conclude the report with a discussion of the importance of agent-based models that can consider combinations of transportation pricing policies and the entire set of travel options available to travelers, as agent-based models can capture the behavioral responses of individual travelers to multiple transportation pricing policies as the agent uses the transportation system to complete a set of daily activities.

Congestion Pricing Research Trend Analysis

To track the evolution of ideas about congestion pricing in the academic literature, we analyzed trends in studies related to congestion pricing each year between 2011 to 2020 based on 535 papers discussing pricing presented at the annual meetings of the Transportation Research Board (TRB). Selection was based on identifying words associated with pricing strategies as shown in Figure 1 below.

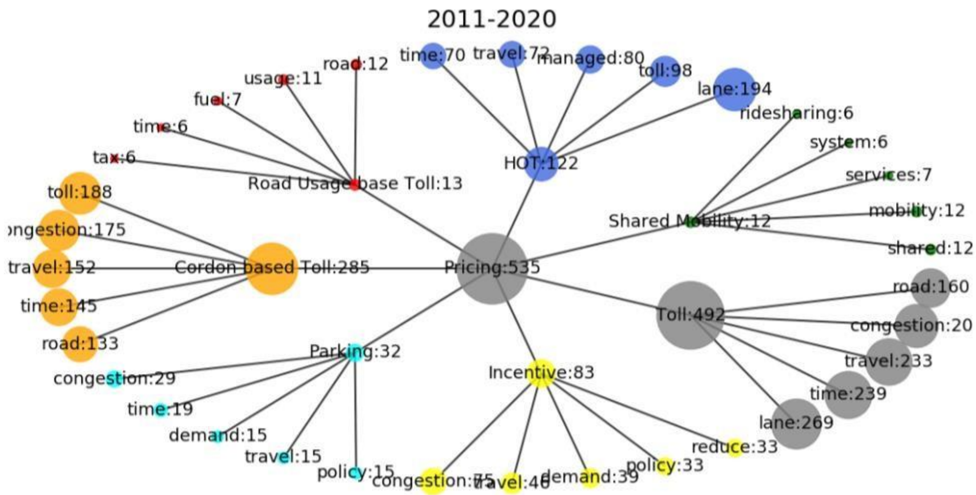

Figure 1. Hierarchy of Transportation Pricing Terms in TRB papers between 2011 to 2020

Figure 1 shows the top five relevant words for each type of transportation pricing policy. We defined seven types of pricing policies including parking fees, flat tolls, HOT lane tolls, road-usage-based tolls, cordon-based tolls, and incentive strategies (e.g., employer incentivize employer to not drive alone and park at office). We also track pricing studies that specifically consider shared mobility. The number next to each word indicates the number of papers that include the word in either their title or abstract.

Cordon-based tolls and HOT lanes dominate the types of pricing policies studied. Since congestion pricing aims to reduce congestion, the most relevant words in all seven types of pricing policies include congestion, travel, and time. Since HOT lanes are a designated lane-based toll, the terms 'lane' and 'managed' are highly associated with HOT lanes. Since road-usage based tolls are similar to vehicle mileage-based taxes, we can see the word 'tax' appearing in studies of this congestion pricing type.

Figure 2 indicates trends in the number of papers associated with words for each pricing strategy. Synonyms for each transportation pricing policy were also used to categorize a paper. For instance, we consider 'mileagebased toll,' 'road usage-based toll,' and 'road usage toll' as all referring to road-usage-based tolls. Traditional pricing strategies such as cordon-based tolls and HOTs have been popular research topics. Interestingly, there is an increasing tendency toward more shared-mobility research in pricing-related papers since 2017. Incentives are also a popular topic in transportation pricing research. However, the landscape of incentive-based research has changed: recently, shared mobility-related research on topics such as transportation network companies (TNC) and pooled-rides are prominent, whereas research before 2017 focused on demand management and transit.

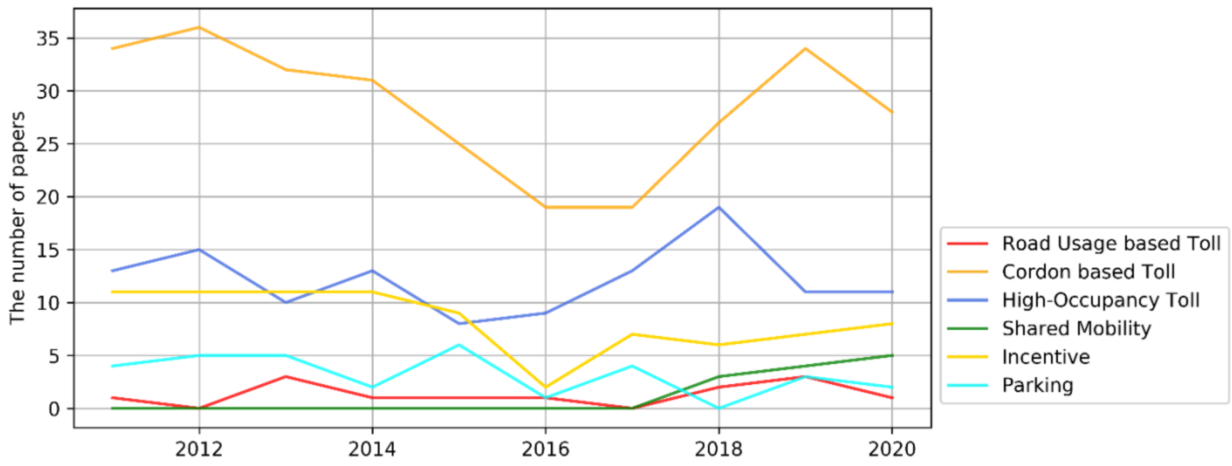

Figure 2. Trend Analysis of Papers Discussing Various Transportation Pricing Policies

Figure 3 shows the details of the research trends. Shared mobility in conjunction with pricing studies begin to pop up in 2018. Five out of nine incentive-based research topics addressed shared mobility in 2020 (*14–18*). Incentives and shared mobility are related (see 'passenger' in incentive and 'incentive' in shared mobility). Recent pricing research tends to take the heterogeneity of travelers, agent-based models, and time dynamics into account. We also observed that recent research tends to be more stand-alone, meaning that each study focuses on a single pricing strategy.

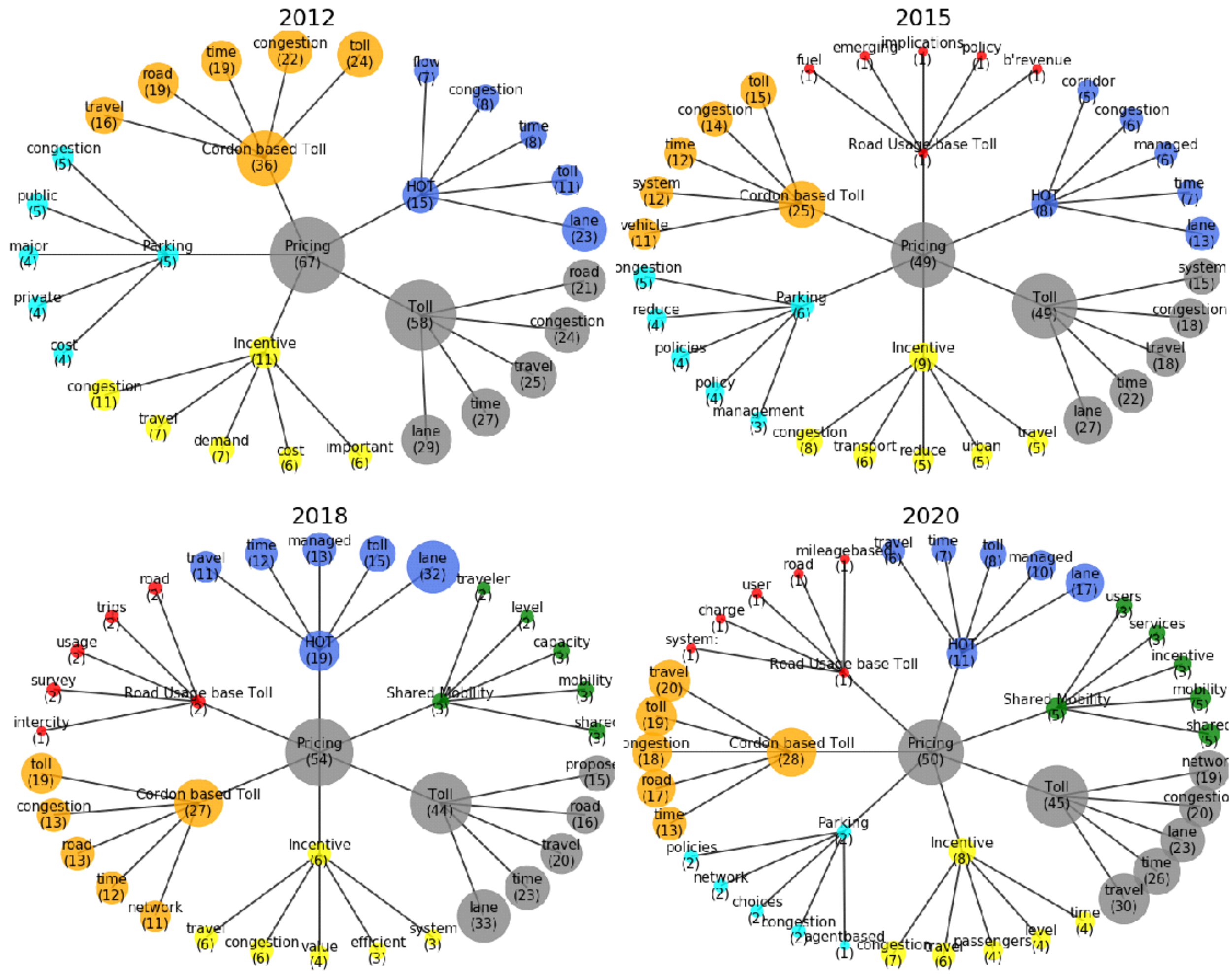

Figure 3. Hierarchy of Transportation Pricing Terms in TRB papers for Four Distinct Years

Overview of Transportation Pricing Strategies

In this section, we provide an overview of four different types of transportation pricing strategies, namely (i) cordon- or zone-based pricing, (ii) road-usage-based pricing, (iii) HOT lane pricing, and (iv) parking pricing.

Cordon-Based and Zone-based Pricing

In cordon-based pricing strategies, a user is charged whenever their vehicle crosses a pre-defined cordon. As the most popular pricing system in Asia and Europe, it is applied around dense city-centers to keep out traffic during peak hours (*19*). Depending on the application, vehicles can be charged for moving-into and/or moving-out of the cordoned area (*20*).

One of the most important advantages of cordon-based pricing is its ease of implementation, both in real-world situations and transport modeling (*21*). One of the downsides of the cordon-based pricing is its binary nature, as vehicles immediately outside the cordoned area do not pay any congestion fee. As such, congestion often forms along major arterials and highways that bypass cordoned areas.

Compared with zone-based pricing, cordon-based pricing does not charge for movement within the cordoned area, which means its efficiency depends on the position of the tolling stations. Other commonly reported disadvantages of cordon-based pricing include its lack of flexibility in changing the location of tolling stations to respond to changes in traffic conditions and its disproportionate effects between the people living outside the cordon compared to people living inside the cordon. But by including multiple cordons and screenlines, as well as implementing time-dependent, and direction-dependent pricing, these equity issues can be mitigated (*22*).

Singapore implemented the first cordon-based pricing strategy using an area licensing system (*23*). It successfully reduced traffic volume by 44 percent in the cordoned downtown area. Moreover, speeds within the cordon increased by 20 percent with an equal decrease in speed on the alternative routes outside the cordon. These effects on traffic congestion were likely the result of various changes in travel behavior, such as drivers' varying departure times, modes, routes and destinations and the share of HOVs, which increased by 11 percent (*23*).

Although there is no practical example of cordon-based pricing in the U.S., there are many toll roads, which can be considered smaller-scale versions of cordon-based pricing. With toll roads, users are required to pay a charge to use a specific section of the road and as a result the congestion in the designated section can be reduced. The charges on the toll roads can also be varied as in the case of Interstate 370 in Maryland (*24*). Research finds that the effectiveness of toll roads is highly dependent on the availability of alternate routes, proportion of trips with schedule restrictions (e.g., commuting trips), and volume of traffic (*25*).

Road-Usage-based Pricing

The introduction of the road-usage pricing dates to 1982 when the State of Oregon imposed tolls on heavy vehicles to fully capture the external costs they imposed on the transportation network (*26*). The principal mechanisms of road-usage based pricing fall into two categories: tolls charged for entering the network links, and tolls paid for each mile/minute of driving through a link or set of links. Pricing a specific subset of network links tends to disperse trips over the road network and toward unpriced links by reducing the difference in travel times between over-used and unused or under-used network links.

As with other pricing policies, road pricing can affect travelers' trip choices by encouraging them to use alternative modes of travel and shifting peak-hour trips to off-peak times. Recent studies (*4*) (*5*) find variable-rate road-usage pricing more efficient than flat-toll schemes.

Several states such as Nevada, Minnesota, Iowa, California, and Oregon have investigated applications of mileage-based toll road systems (*27*). An Oregon pilot program involved imposing a mileage-based fee on 300 volunteers during 2006-2010 with two scenarios: all-day fixed fee and peak/off-peak rates. The results indicate that drivers changed their travel behavior by reducing their travel especially during rush hours (*28*). Also, as people became more aware of the cost of short trips, the flat fee induced travelers to combine trips. However, travelers tended to group unnecessary trips with their rush-hour trips, thereby increasing total rush hour VMT.

The Puget Sound Regional Council experimented with metering 500 vehicles using GPS where drivers were charged for using the otherwise un-tolled freeways in Seattle. Travelers significantly changed their travel patterns due to the pricing system (*27*).

A few studies researched the potential influence of road usage pricing on both traditional and new transport modes. Using agent-based simulation methods, Simoni et al. (*3*) implemented several pricing strategies including road-usage pricing along with a strong market penetration of CAVs in Austin, TX. All pricing schemes led to a decrease in non-automated vehicles, CAVs, and SAV trips together with an increase in transit ridership and non-motorized modes. Social welfare measures increased after pricing scenarios led to a reduction of VMT and vehicle hours of delay in the network.

High-Occupancy Toll Lane Pricing

Pricing HOV facilities, known as High Occupancy Toll (HOT) lane pricing, allows lower-occupancy vehicles to pay a price to access less-congested managed lanes (*29*) to maximize combined throughput of vehicles on the freeway as well as maintaining a minimum level of service. Since the first HOT lane was implemented in 1995 in Orange County, CA, the concept of converting under-used HOV lanes to HOT lanes became popular among transportation planners and agencies (*30*). Several studies have considered the main objectives of HOT lanes (*31*). With the proper application of HOT pricing, it is possible to enhance highway/freeway operations, achieve a better distribution of flow between HOT and general purpose lanes, lower GHG emissions and generate higher revenue from tolls (*32*). To achieve the best overall results, the toll rates should be adjusted in real-time according to traffic conditions. As an example, the I-394 HOT lanes in Minnesota adjust prices based on the prevailing traffic conditions every three minutes (*33*). After tolling was implemented, vehicle flow increased by 48 percent but there was a reduction in the proportion of HOVs, the cause of which is unclear. There was also a 21 percent increase in the proportion of transit modes.

To achieve the best performance measures, several model-based studies and experiments have focused on the dynamic optimization of HOT pricing (*8*). Zhang et al. (*8*) used a feedback-based tolling algorithm to dynamically optimize HOT lane prices, updated every five minutes, on five HOT lane sections on the southbound SR-167 corridor in Washington State. Their strategy improved speeds on general purpose lanes by 26.2 percent while using the unused capacity of the HOT lanes. They also studied the sensitivity of HOT pricing strategies to changes in travel demand as well as the impact of overutilizing HOT lanes. Another model-based study by Wan Li et al. (*7*) considered performance measures for maximizing toll revenues and maintaining a minimum speed of 45 mph on HOT lanes as well as accounting for travel time reliability, trip purpose, departure time choice, and level of income. By including individual and trip characteristics into their analysis, their pricing system led to higher toll revenue, greater travel time savings, and similar travel speeds on both general purpose and HOT lanes.

Despite all the effort put into advancing HOT lane pricing, none of the previous studies considered how introducing CAVs and SAVs into the network could affect road performance. Also, to the best knowledge of the authors, little effort has been put into the potential equity issues HOT pricing might raise. Thus, a toll setting strategy needs to be developed that both addresses the future market penetration of shared mobility options as well as the welfare of individual road users before and after HOT pricing implementation.

Congestion-based Parking Pricing

One pricing strategy which impacts the pattern of daily traffic in city centers is parking pricing. Research suggests that searching for parking significantly adds to VMT and Vehicle Hours Traveled (VHT) in urban networks (*31*, *32*). Higher parking costs and limited parking access influence drivers' travel choices (departure time, mode, and destination location) (*9*, *36*) and direct traffic outside of city centers and toward less congested areas. Transportation economists suggest parking pricing is effective in relieving traffic congestion in major cities (*9*). Also, pricing parking is well accepted by the public, and it is easy to apply prices to parking facilities and more straight-forward compared with other pricing systems (*9*). However, parking pricing is "imperfect" as parking rates are imposed on travelers at their destination, rather than based on their travel route, and so do not capture the impacts of travel duration and route choice (*37*).

New technologies such as mobile devices, location-based services, and wireless sensors have paved the way for real-time updates of parking availability and cost information (*38*). These technologies can help travelers make more informed decisions about where to travel and when to travel, as they can provide travelers information about parking availability and parking prices.

Optimizing parking pricing can reduce traffic during evening peak hours on major roadways (*39*, *40*) and mean shorter walking distances from parking locations to final destinations (*10*), however, it can also lead to a decrease in parking revenues if the prices are optimized for purposes other than revenue generation. With parking operators optimizing parking price and individuals being given access to information about where to find parking, travelers can modify their trip plans by shifting their mode, route, or departure time which can reduce total VMT as less time is spent searching for parking. One study of 11 major cities found searching for parking accounts for up to 30 percent of traffic congestion (*41*).

Although the concept of parking pricing is far from new, its recent implementation is novel (*42*). Throughout the last decade, parking pricing has been applied across the world, particularly in the U.S., producing changes in travel behavior and network performance. Case studies in the U.S. show that a 10 percent increase in parking fees generates a 1-3 percent reduction in private passenger car trips. Also, pricing previously free parking spots reduces home-based work trips by 10 to 30 percent (*43*).

San Francisco's parking pricing system, known as SFPark, adjusts prices in response to changes in parking space occupancy in eight major areas of the city that include approximately 7000 on-street parking spaces and 12,250 off-street parking spaces in parking garages and one parking lot (*44*). San Francisco Municipal Transportation Agency's (SFMTA) self-evaluation and an external evaluation found that SFPARK reduced local congestion and vehicle emissions (*43*, *45*). In 2016, The San Francisco Parking Supply and Utilization Study (PSUS) considered fee-based parking pricing that produced a moderate reduction in congestion in Northeast San Francisco. The $3-all day flat fee had the largest effects: 1.5 percent reduction of personal vehicle trip,1.2 percent increase of transit ridership, 2.6 percent reduction of VMT, and 4.4 percent reduction of vehicle hours of delay. Additionally, research suggests that the political challenges of applying a peak-hour fee system are less daunting than an all-day fee system (*45*).

The concept of parking pricing has been broadly used both in theory and application (*43*, *46–48*) and with all the growing attention to parking pricing performance analysis, transportation agencies and planners have to consider how to integrate novel pricing systems with a transportation network that combines both traditional vehicles and emerging transportation innovations. Improvements and the application of new technology in both monitoring traffic conditions, as well as parking availability and price, boost the traveler's knowledge about potential alternative modes, routes, departure times, and destination/parking locations. Previous applications of parking pricing showed it could help reduce congestion; however, it is important to understand the potential effects of emerging transportation innovations on current parking pricing as well as the impacts of alternative pricing policies.

Technology

Major recent innovations in transportation include Connectivity, Automation, and Shared Mobility. Connectivity enables tracking vehicles within the transportation system and using this information to determine toll values more precisely. Automation allows vehicles to have access to information about travel time and costs (which comes from Connectivity). Fully automated vehicles will be able to change travel plans in response. Shared mobility has added new modes (most importantly ride-sourcing service provided by TNCs) and vehicles to the transportation system. Table 1 summarizes the relationship between pricing systems discussed in this report and Connectivity, Automation, and Shared Mobility.

Table 1. Congestion Pricing Policies and Emerging Transportation Technologies

Technology Pricing Strategy	Connectivity	Automation	Shared Mobility
Cordon-based Pricing	Easier to track vehicles entering and exiting a cordon area for better control over number of vehicles	Decide on the entrance into the cordon area based on the cordon toll and acceptable traveler's price	More SAV ridership within cordon area than outside cordon due to the division of cordon toll cost among shared mobility users
Road-usage Pricing	Monitor vehicle mileage on each priced/unpriced link	Change of routes to the destination based on user's preference such as his/her travel time and travel cost limitations	Same effects on CAVs, but more SAV ridership because of trip cost sharing among travelers
HOT Lane Pricing	Keep track of vehicles' occupancies as well as number and speed of vehicles in GP and HOV lanes	Shifting to/from GP lanes to HOT lanes (and vice versa) based on user's preference	More use of SAVs with high occupancies and division of cost of use
Parking Pricing	Monitor vehicles' destination locations as well as parked vehicles present in each area	Adjust traveler's final location based on acceptable parking price and their ability to use other motorized (transit/ridehailing) and non-motorized travel modes	Emergence of shared mobility reduces parking needs of travelers, therefore parking pricing leads to a change in mode share

Behavioral Changes from Pricing Strategies

The performance of a pricing policy depends heavily upon the extent to which it can influence travel behavior, including choice of departure time, destination, mode, route, and lane (*49*). Depending on the type of pricing strategy, one or more of these choices can be influenced. Table 2 portrays the effect of the four congestion pricing policies on five dimensions of travel behavior. It shows that departure time and mode choice are affected by all the policies. Users tend to change their departure times to avoid the pricing period and shift to transit or HOV to avoid costs or share the costs. Destination choice is highly affected by parking pricing, although cordon pricing also has some effect if alternate destinations are available. Choice of route is mainly affected by distance-based road usage pricing. The tendency to change lanes is only affected by HOT pricing.

Table 2. Behavioral Implications of Transportation Pricing Policies

Pricing Behavioral Changes	Cordon	Road Usage	HOT	Parking
Departure Time	High impact *Shifts traffic to off-peak hours*	High impact	Low impact *Depends on schedule flexibility*	High impact *Shifts traffic to off-peak hours*
Destination	Low impact *Depends on suitable alternatives*	No impact	No impact	High impact
Mode	High impact *SOV to HOV*	High impact *Auto to transit*	High impact *SOV to HOV*	High impact *Auto to transit*
Route	Very low impact *Affect thru-traffic*	High impact	Very low impact *Affect through traffic*	No impact
Lane	No impact	No impact	High impact	No impact

There are several implications from the effects of different pricing policies on each type of travel behavior. Area-based congestion pricing policies are more likely to impact users' departure times and therefore shift traffic from peak hours to off-peak hours (*50*, *51*). The effect on mode choice depends largely on the availability of alternative modes in the cordoned area. Zheng et al. (*50*) analyzed this particular situation by incorporating a pricing policy that increases accessibility to bus services. This combined pricing strategy resulted in much higher travel time savings per unit of toll, which reduced congestion more with a lower toll price. Moreover, by inducing travelers to shift to busses (5% increase), this strategy reduced the total number of vehicles on the road which also helps to relieve congestion in other areas. Applying cordon-based pricing without considering the availability of alternative modes is less effective and can also contribute to congestion outside of the cordoned area by diverting traffic. The availability of alternatives is also important in influencing changes in travel behavior for other congestion pricing strategies such as link- and HOT-based pricing.

Since CAVs are controlled by a computer, not a human, congestion pricing policies may not lead to the same changes in travel behavior. For instance, parking policy will be inappropriate for SAVs but can be effective to some extent for private CAVs. SAVs are likely to have a 'next passenger' to serve after completing their current trip, such that they will not need to park for more than a few minutes. Conversely, privately-owned CAVs will often not have other passengers to serve, as such, they may just want to park while their owner completes their activity nearby. Also, compared with humans, CAVs can better process real-time information about travel times and cost of multiple alternative routes, which will result in more efficient navigation and better use of existing road capacity. Moreover, applying new technology to charging fees and monitoring the results can make any congestion pricing policy more efficient. In this regard, combining congestion pricing policy with SAVs holds great promise since these vehicles will be equipped with the most advanced technology, which will significantly reduce the users' need to consider payment methods or choose alternate routes. Along with cordon pricing, most congestion pricing strategies show an increased proportion of trips shifting to high-occupancy modes if viable alternatives are present (e.g., transit and carpool). SAVs, especially with ride-pooling, is highly capable in this context. To ensure the effectiveness of a congestion pricing policy with SAVs it is important to consider other mode alternatives within the pricing structure. According to Kaddoura et al. (*52*), however, imposing a charge only on SAVs to reduce its congestion impacts can create a mode shift towards personal cars, which could be counterproductive.

Discussion and Conclusions

Transportation agencies and policymakers are considering transportation pricing policies to reduce roadway congestion and achieve environmental goals. Although a transportation system planner can look to existing pricing policies around the world for insights, their success differs by region. Hence, insights from one region to another are not necessarily transferrable. For example, while cordon-pricing works well around London it may not work well around Los Angeles. This implies there is a need for models that can assess the potential impacts of pricing policies before their actual (costly) implementation.

Moreover, while transportation system models that incorporate pricing policies exist, they do not properly capture the role of emerging transportation innovations like shared mobility, automated vehicles, and vehicle/infrastructure connectivity.

Another important issue with pricing policies is equity. We need to ensure pricing policies produce equitable outcomes for travelers.

To better understand the potential impacts of pricing policies, there is a need for modeling tools that appropriately capture the effects of emerging transportation innovations like ride-sourcing or shared-ride services and are sensitive to pricing policies. In other words, including emerging transportation innovations in transportation models is particularly important when evaluating pricing policies. For instance, ride sharing may be more attractive than transit under various pricing policies designed to discourage single-occupancy vehicle travel and parking.

Our review of the latest transportation pricing research suggests that although increasing attention is being paid to emerging transportation innovations, most studies tend to focus locally on one particular mode of travel, rather than the complete set of modes available to travelers. There are available transportation simulation tools, such as MATsim and POLARIS, for agent-based modeling that can depict drivers' responses to various pricing and mobility options. For example, POLARIS, the agent-based integrated travel demand model, and network operations modeling software developed at Argonne National Labs by Auld et al. (*53*) can incorporate various congestion pricing policies and has a set of modules for incorporating shared mobility services. Another advantage of agent-based modeling is a researcher can easily incorporate different combinations of transportation pricing policies to evaluate their separate and joint impact on transportation systems considering equity, efficiency, sustainability, and affordability.

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