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SOCIAL EQUITY IMPACTS OF CONGESTION MANAGEMENT STRATEGIES

WHITE PAPER

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White Paper: Social Equity Impacts of Congestion Management Strategies

Prepared for: California Air Resources Board

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Abstract

This white paper examines the social equity impacts of various congestion management strategies. The paper includes a comprehensive list of 30 congestion management strategies and a discussion of equity implications related to each strategy. The authors analyze existing literature and incorporate findings from 12 expert interviews from academic, non-governmental organization (NGO), public, and private sector respondents to strengthen results and fill gaps in understanding. The literature review applies the Spatial – Temporal – Economic – Physiological – Social (STEPS) Equity Framework (Shaheen et al., 2017) to identify impacts and classify whether social equity barriers are reduced, exacerbated, or both by a particular congestion mitigation measure. The congestion management strategies discussed are grouped into six main categories, including: 1) pricing, 2) parking and curb policies, 3) operational strategies, 4) infrastructure changes, 5) transportation services and strategies, and 6) conventional taxation. The findings show that the social equity impacts of certain congestion management strategies are not well understood, at present, and further empirical research is needed. Congestion mitigation measures have the potential to affect travel costs, commute times, housing, and accessibility in ways that are distinctly positive or negative for different populations. For these reasons, social equity implications of congestion management strategies should be understood and mitigated for in planning and implementation of these strategies.

Executive Summary

Congestion is worsening and vehicle miles traveled (VMT) are increasing in many cities across the United States (U.S.) and California. State, regional, and local governments have implemented or are considering a range of measures intended to curb congestion and its negative effects on the economy, the environment, and public health. However, social equity implications must be accounted for when crafting, piloting, and deploying congestion mitigation strategies. Since congestion management strategies may directly or indirectly affect transportation costs, commute times, housing, and access to jobs, education, and healthcare in ways that are positive or negative for different populations, the potential equity impacts of these strategies should be considered. At present, many of the social equity implications of congestion management strategies are not well understood and lack empirical research.

This white paper summarizes and provides a deeper understanding of the equity impacts of a variety of congestion management strategies by analyzing existing literature and synthesizing findings from 12 expert interviews with academic, non-governmental organization (NGO), public, and private sector respondents. We employ the Spatial – Temporal – Economic – Physiological – Social (STEPS) Equity Framework (Shaheen et al., 2017) to identify barriers and gaps in the literature and to classify and examine whether social equity barriers are reduced, exacerbated, or both by a particular strategy. The STEPS framework categorizes equity barriers to accessing transportation including considerations across spatial factors that compromise daily travel needs, temporal barriers that inhibit a user from completing time-sensitive trips, economic factors including direct and indirect travel costs, physiological barriers that make using certain travel modes difficult for disabled or older populations, and social factors like language or other barriers that detract from travelers' comfort with using transportation (Shaheen et al., 2017). We categorized each of the congestion management strategies of interest into six broader categories: 1) pricing, 2) parking and curb policies, 3) operational strategies, 4) infrastructure changes, 5) transportation services and strategies, and 6) conventional taxation. For example, distance-based pricing measures like vehicle miles traveled (VMT) fees are covered under the pricing category, and traffic signal priority (TSP) is included under the operational strategies category. A summary of key findings by category is presented below.

<u>Pricing</u>

Pricing approaches include strategies that charge users for their road use. These strategies can be implemented in a number of different ways, which have differing transportation equity impacts. We discuss the following seven pricing strategies: 1) cordon/area pricing, 2) distance-based pricing, 3) dynamic congestion pricing, 4) means-based pricing, 5) flat-rate tolls, 6) full-facility tolls, and 7) managed lanes.

Various forms of pricing may be effective at reducing congestion while generating revenue for public agencies. For example, in London, Stockholm, and Singapore where cordon or area pricing have been implemented, the results have been undeniably successful with respect to congestion reduction (Lehe, 2019). However, pricing approaches may only be effective at reducing congestion if other transportation modes, including public transit and active transportation infrastructure, are available and accessible, as was the case with London, Stockholm, and Singapore (Provonsha & Sifuentes, 2018; Ying-En et al., 2018). The pricing mechanism used, for example flat-rate or dynamic, will also influence the degree of effectiveness of the strategy. Dynamic pricing fluctuates with congestion, with the price of the toll rising with congestion. Thus, dynamic pricing is more effective at reducing peak period congestion, whereas flat-rate pricing is less effective since it does not incentivize drivers to change the time of day that they travel. In addition, not all pricing approaches produce the same equity outcomes. For example, if alternatives to driving are not readily available, distance-based pricing can create spatial and economic barriers for low-income road users, if costs and travel times increase for those that commute long distances (California Road Charge Pilot Program, 2017). While all pricing strategies can negatively impact equity by increasing travel time and costs for lower-income road users, there are also positive equity effects as well. Means-based fares and public transit expansion could help mitigate unintended negative equity impacts and could be especially helpful when more than one income threshold is used to determine discount rates (Cohen & Hoffman, 2019). At present, there are no distance-based or dynamic congestion pricing schemes that incorporate a means-based pricing distribution. However, one travel simulation study found that an income-based VMT fee is both more progressive than flat rate distance-based pricing schemes and may be just as effective at generating revenue (Yang et al., 2016). Relative to other pricing schemes, flat-rate pricing may be the most regressive form of pricing and in some cases might be unavoidable for some drivers depending on the geography of the region (Cohen & Hoffman, 2019; Ke & Gkritza, 2018). Full-facility tolls are charges a motorist pays to use a tolled facility in which prices fluctuate depending on the time of day or level of congestion. Similar to flat-rate tolls, the fee applies to every motorist entering the facility, and thus may be unavoidable for some drivers in a region and can create barriers due to spatial and economic factors. If full-facility tolls are priced variably based on congestion or time of day, low-income drivers may be more impacted if they have difficulty adjusting their schedule to avoid high tolls (Income-Based Equity Impacts of Congestion Pricing, 2008). Managed lanes, such as HOV, HOT, and express lanes, often allow for non-priced lane options and thus may not create the same spatial barriers as full-facility tolls. Managed lanes can alleviate temporal barriers for some drivers, but these may more often benefit high-income drivers who can afford to pay the toll. As mentioned, incorporating means-based pricing can help ameliorate some of these disparities. Additionally, the option of carpooling can allow low-income drivers to avoid high tolls while benefiting from reduced temporal barriers. Most experts we interviewed claimed that in general, the current system of unpriced roads is not equitable and that having an intentional focus on social equity from the beginning of any congestion mitigation program would help to produce equitable outcomes.

Parking and Curb Policies

Parking and curb policies are vital to managing congestion and can include a variety of approaches for pricing and controlling parking access. We discuss the following parking and curb policies: 1) dynamic parking pricing, 2) off-street parking pricing/policy, 3) parking navigation tools, 4) curbside management strategies, and 5) parking cash out.

It is estimated that 30 percent or more of the congestion in cities is due to searching for parking (Margreiter, 2017). In addition, free parking can encourage the use of driving, which can in turn increase congestion on freeways and arterial roads (Shoup, 1997). One strategy is dynamic parking pricing, which includes parking fees that fluctuate based on demand. Local congestion may be reduced, if drivers circle less looking for parking due to dynamic pricing. While parking costs may become unaffordable for low-income drivers, especially when demand is high, one study showed that low-income drivers are less sensitive to prices once they have parked (Chatman & Manville, 2018). This may be because low-income drivers have less flexibility to when and where they park or they may have been unaware of the new parking system. Further analyses are needed to examine parking usage by income level. For off-street parking, since the cost of providing private parking is often embedded in housing, goods, and service costs, reducing or eliminating off-street parking requirements can lead to more equitable outcomes, since parking costs would be paid only by those who use it. Additionally, innovative technologies may help drivers find available parking with less circling, while paying an appropriate price to park. However, parking navigation tools—technology that assists drivers in locating available parking via smartphone or other devices—may also make it easier to drive by reducing parking search time, which could lead to added congestion in some cases (i.e., induced demand). This could have negative effects on those who would otherwise have taken public transit, biked, or walked. While curbside management strategies can include curb pricing, they also include many other strategies that do not directly create pricing barriers. These strategies can include reducing obstructions to public transit and bicycle facilities and increasing accessibility for disabled travelers. As such, these strategies may create spatial, temporal, and physiological benefits, depending on how they are implemented. Parking cash out is another strategy that can better connect off-street parking costs with actual usage. This strategy can produce direct economic benefits to commuters and provide incentives to use transportation modes other than driving alone. Regardless, if updates to parking systems are made, parking availability and rates should be accessible without the need for smartphone apps, data plans, or other devices, and information should be displayed publicly and in multiple languages.

Operational Strategies

Operational strategies that modify how a transportation facility functions are integral to congestion mitigation. While some operational strategies may not directly reduce congestion, they can be implemented in conjunction with other strategies to improve overall performance. We cover the following operational strategies and related social equity impacts: 1) TSP, 2) ramp metering, 3) geofencing, and 4) public transit improvements.

Both traffic signal priority (TSP) and ramp metering are simple and effective operational strategies that can decrease temporal barriers for travelers. TSP can significantly increase public transit speeds and reliability, thus benefiting public transit riders (Hu et al., 2014). Ramp metering benefits freeway commuters by reducing the congestion associated with high volumes of vehicles attempting to merge at the same time. While geofencing is not widely used in transportation systems, at present, it may become more prevalent as the need for controlling traffic in congested downtown areas becomes more pressing. Transportation network companies (TNCs), like Uber and Lyft, already use geofencing in coordination with airports, and some cities in the UK are planning to use geofencing to reduce pollution from vehicles in areas with poor air quality (Garrett, 2015; Rushton et al., 2018). However, geofencing may require drivers to have a smartphone and data plan, and it may also prevent disabled passengers from getting close enough to their destinations if the correct exemptions are not in place. Additional public transit routes and other improvements can reduce spatial and temporal barriers for those living near new routes, especially for individuals without a car. Although public transit improvements can provide many benefits, increased fares are often a means of funding these improvements, which can disproportionately impact low-income individuals. Means-based public transit fares should be explored in cases where this may occur.

Infrastructure Changes

Infrastructure changes involve transformations of land use that can contribute to reduced congestion. We discuss the social equity impacts associated with seven infrastructure changes: 1) park and ride facilities, 2) transit-oriented development (TOD), 3) car-free zones, 4) road diets, 5) pedestrian and bicycle infrastructure improvements, 6) complete streets, and 7) increased road capacity.

Park and ride facilities have the potential to reduce congestion on highways, if drivers substitute a vehicle trip with public transit to reach their final destination. However, these facilities mostly benefit automobile owners who are more likely to have higher incomes compared to the average public transit rider (Meek et al., 2009). TODs are developments centered around major public transit connections, which may reduce temporal barriers for residents. However, mode shift away from private vehicles among those living in TODs may be negligible, and the population increases due to new housing may in fact worsen congestion (Zhu et al., 2018). Various infrastructure changes that intend to limit car use or promote active transportation, like car-free zones, road diets, pedestrian and bicycle infrastructure improvements, and complete streets, can eliminate spatial barriers for those who do not own personal vehicles by creating routes that can be traveled without a vehicle or by improving the safety of existing routes (Ferenchak & Marshall, 2019). However, where these improvements are implemented and who they are intended to serve is critical, since they are often in areas that serve advantaged groups. In this sense, these improvements can have both positive and negative impacts. While they may spur job growth and provide economic benefits, they may also increase property values and potentially create economic barriers (Yu et al., 2018). It is important to consider how a particular set of infrastructure changes might affect surrounding communities and implement plans that mitigate possible negative consequences, like gentrification. Increased road capacity has the potential to create severe negative social equity impacts on the communities in which new roads or freeways are routed through, and it is often more difficult to mitigate these impacts after construction. While increased road capacity may in the short term decrease temporal and spatial barriers, it is more likely to induce travel demand if it is not prudently implemented (Chung et al., 2016).

Transportation Services and Strategies

Transportation services and other related strategies have the potential to mitigate congestion in certain circumstances. We discuss a variety of services and strategies: 1) shared mobility (automotive), 2) shared mobility (active), 3) courier network services (CNS), 4) pay as you drive (PAYD) insurance, 5) fleet pricing, and 6) telecommuting/flexible work hours.

Studies have shown that shared mobility services like carsharing and bikesharing reduce VMT and greenhouse gas (GHG) emissions (Shaheen et al., 2015) and may reduce congestion in some areas, if they replace a significant portion of private vehicle trips. Shared mobility and CNS may be able to address spatial barriers by providing mobility options and goods with a greater geographic reach than existing options. However, serving low-density areas may be challenging for operators to financially sustain and may require a subsidy to be affordable to lower-income users. Other strategies like PAYD insurance and fleet pricing may reduce congestion, since they could reduce demand for fleet-based modes that may increase congestion, like TNCs (SFCTA, 2018). Fleet pricing could reduce congestion by decreasing demand for particular transportation modes that increase congestion, but if these fees are passed along directly to all customers, they may preclude lower-income users from accessing the service. This could have negative economic, spatial, and temporal impacts for these users, and these impacts should be considered when implementing fleet pricing fees. Telecommuting is a strategy where employees work from home or have flexible work hours to avoid peak travel periods. This approach can have many positive equity benefits and has the potential to save workers money and time that would have otherwise been spent commuting. However, not all workers have access to flexible-location or flexible-schedule arrangements, as lower-wage and hourly workers have been shown to have less access to flexible work schedules (Swanberg et al., 2005).

Conventional Taxation

Conventional taxation strategies include fuel taxes, which are taxes applied per unit of fuel purchased, and have existed in the U.S. for decades as a primary means to pay for transportation infrastructure. Fuel taxes are viewed as regressive, especially when factoring in the association between income level and fuel-efficient vehicle ownership (Tovar Reaños & Sommerfeld, 2018). Many of the pricing strategies discussed in this white paper are viewed as alternatives to conventional fuel taxes.

The discussion that follows contains six main sections, including an: 1) introduction; 2) inventory of congestion management strategies that categorize and define measures discussed throughout the white paper; 3) review of relevant literature on social equity impacts, using the STEPS (Spatial – Temporal – Economic – Physiological – Social) Equity Framework (Shaheen et al., 2017) to classify barriers and opportunities; 4) synthesis of findings from 12 expert interviews conducted with private, public, NGO, and academic sector respondents, 5) list of supplementary metrics for analyzing social equity impacts, and 6) conclusion summarizing key results.

Introduction

Congestion is worsening in many areas across the state of California and the U.S. Many cities, states, and other governmental agencies across the U.S. have begun to implement or are considering implementing a range of congestion management strategies. These strategies include a wide range of approaches, including road pricing, parking and curb policies, operational strategies like traffic signal priority (TSP) and others, infrastructure changes, and transportation services like shared mobility.

While some research has focused on the potential travel time savings and environmental benefits of congestion management strategies, only a small body of work has focused on the potential equity impacts of such strategies. Disadvantaged communities may be more negatively impacted by certain strategies than other populations, and these effects must be understood and mitigated for when planning congestion management strategies. For example, distance-based roadway pricing could reduce congestion and provide additional revenue for state transportation agencies, but it may reduce low-income populations' ability to access jobs in communities that are far away from downtown employment centers. In this report, we explore past research and scenarios like these where uneven equity impacts may occur as a result of congestion mitigation measures.

While some progress has been made to remove barriers and improve transportation access to all communities, equity challenges still persist. In this white paper, we summarize literature and fill gaps in understanding with regards to the social equity implications of a wide variety of congestion management strategies. The document that follows contains five main sections including: 1) an inventory of congestion management strategies that categorizes and defines strategies discussed throughout the white paper, 2) a review of relevant literature on social equity impacts, using the STEPS (Spatial – Temporal – Economic – Physiological – Social) Equity Framework (Shaheen et al., 2017) to classify barriers and opportunities, 3) a synthesis of findings from 12 expert interviews conducted with private, public, NGO, and academic sector respondents, 4) a list of supplementary metrics for analyzing social equity impacts, and 5) a conclusion summarizing results.

Congestion Mitigation Measures Inventory

As part of this research effort, we compiled a list of congestion mitigation measures to examine further throughout the study. We developed this list through reviewing literature and receiving feedback from CARB and California Department of Transportation (Caltrans) staff members. A diverse range of approaches can be considered congestion management strategies, and we briefly define each strategy in Table 1. We divided each of these individual strategies into six broader categories including: 1) pricing, 2) parking and curb policies, 3) operational strategies, 4) infrastructure changes, 5) transportation services and strategies, and 6) conventional taxation. Please note that based on relevance and availability of existing research, some of the measures listed below are analyzed and discussed more in depth than others in the sections of this report that follow. In addition, some of the measures listed under operational strategies are not covered in this report due to lack of information on social equity impacts related to the particular strategy. Whether or not each measure is included as part of our analysis is identified in the column titled 'Included' in Table 1.

Table 1. Congestion Mitigation Measures Inventory

1	**Pricing**		**Included**
1.1	Cordon/Area pricing	Fees applied to motorists when entering and/or circulating in a specified area, typically a Central Business District (CBD).	Yes
1.2	Distance-based pricing	Motorist pays fees on a per distance basis. Similar to Road Usage Charge (RUC), Mileage Based User Fee (MBUF), and vehicle miles traveled (VMT) fees. Could include restricted access to specified areas or lanes where fee applies.	Yes
1.3	Dynamic or congestion pricing	Pricing on a tolled facility (or area) that fluctuates based on congestion levels. Price increases with increased congestion.	Yes
1.4	Means-based pricing	Pricing based on income level. Could be applied to public transit fares, road pricing, or other transportation-related fees.	Yes
1.5	Flat-rate pricing	Motorist pays set price to use tolled facility. Facilities could include highways, bridges, tunnels, or other infrastructure.	Yes
1.6	Full-facility tolls	Motorist pays to use tolled facility in which prices could fluctuate. The fee applies to every motorist entering the facility.	Yes
1.7	Managed lanes	Fees or regulations applied on specified lanes. Could include high occupancy vehicle (HOV) lanes (lanes dedicated to motorists with a minimum passenger requirement), high occupancy toll (HOT) lanes (HOV or fee paid if HOV requirement not met), or express lanes (fee paid to use lane, regardless of the number of passengers).	Yes
2	**Parking and Curb Policies**		**Included**
2.1	Dynamic parking pricing	Parking fees that fluctuate based on demand. Fees increase as parking availability decreases.	Yes
2.2	Off-street parking pricing/policy	Could include tax on parking facilities or reduced parking requirements for development.	Yes
2.3	Parking navigation tools	Technology that assists drivers in locating available parking. May use satellite imaging or sensors to identify either on-street or off-street parking.	Yes

2.4	Curbside management	Organizing and allotting curb space for bikesharing or scooter sharing, deliveries, passenger pick-up and drop-off, American Disability Act (ADA) access, emergency vehicles, automated vehicles (AVs) and shared automated vehicles (SAVs), and other potential uses.	Yes
2.5	Parking cash out	Employers offer a cash payout to employees instead of free parking at place of employment.	Yes
3		**Operational Strategies**	**Included**
3.1	Traffic signal priority (TSP)	Modified traffic signal timing that gives priority to public transit (e.g., buses); bikes; and/or pedestrians for the purpose of reducing travel time among users of these modes and increasing safety.	Yes
3.2	Traffic responsive / adaptive arterial signal control	Optimization of signal timing plans at traffic signals and signal coordination along arterials to minimize delays and stops.	No (due to lack of information)
3.3	Ramp metering	Traffic signaling to regulate the flow of traffic from highway on-ramps. Recent strategies include coordinated adaptive ramp metering and cooperation with dynamic speed limits and signal control of adjacent traffic signals.	Yes
3.4	Variable Speed Limits	Dynamic speed advisories to reduce speed variations during congested conditions.	No (due to lack of information)
3.5	Dynamic lane Control	Dynamic designation of lane usage to accommodate surges in traffic movements (merging/diverging/weaving).	No (due to lack of information)
3.6	Dynamic Shoulder Use	Temporal use of shoulders as mainline travel lanes on freeways to alleviate traffic congestion subject to safety constraints.	No (due to lack of information)
3.7	Managed Lanes	Restrictions on the use of travel lanes by certain vehicle classes (e.g., trucks) or movements (left turns at signalized intersections).	No (due to lack of information)
3.8	Dynamic Traveler Information	Real-time information on travel times and roadway conditions based on data from infrastructure detectors and probe vehicles and smart phones.	No (due to lack of information)

3.9	Queue Warning Systems	Driver alert of congestion formed traffic queues that are potential safety hazards (used in combination with variable speed limit and lane control systems).	No (due to lack of information)
3.10	Incident management	Procedures, equipment for quick detection, response and removal of traffic incidents and crashes.	No (due to lack of information)
3.11	Geofencing	Technology that uses a virtual boundary for a physical area. Could physically stop vehicles or other modes (e.g., automated vehicles or e-scooters) or simply alert motorists/travelers when crossing a boundary.	Yes
3.12	Public transit improvements	Could include increased capacity, dedicated lanes (e.g., bus rapid transit); frequency; attractiveness (e.g., WiFi, A/C) and/or improved real-time transit information; public transit planning technology; or timed transfers.	Yes
4	**Infrastructure Changes**		**Included**
4.1	Park and ride facilities	Parking lots or structures located immediately next to public transit connections and typically outside of congested central business districts (CBDs).	Yes
4.2	Transit oriented development (TOD)	Mixed land-use development centered around major transit connections and designed to encourage active transportation within the area.	Yes
4.3	Car-free zones	Areas that prohibit all vehicles or most private vehicles. Also known as pedestrian zones.	Yes
4.4	Road diet	A reduction of lanes and/or a narrowing of lanes usually to provide bike lanes, public transit only lanes, and/or parklets, as well as to reduce vehicle speeds.	Yes
4.5	Pedestrian and bicycle infrastructure improvements	Design that enhances safety and encourages active transportation. Includes well-maintained sidewalks, safe crossings, universal design, improved path connectivity, protected bike lanes, increased bike parking, visual attractiveness, and other elements.	Yes
4.6	Complete Streets	Control improvements in addition to design listed in 4.5 to facilitate efficient and safe travel for all road users (auto, transit, pedestrians, bicycles).	Yes
4.7	Increased road capacity	Creating additional lanes or building new roads, freeways, bridges, or tunnels.	Yes

5	Transportation Services and Strategies		Included
5.1	Shared mobility (automotive)	Shared use of a transportation mode involving an automobile (e.g., carsharing, carpooling, TNCs, microtransit, etc.) to decrease the need for private vehicle ownership and reduce travel demand.	Yes
5.2	Shared mobility (active)	Shared use of an active transportation mode (e.g., bikesharing, scooter sharing, etc.) to decrease the need for private vehicle ownership and reduce travel demand.	Yes
5.3	Courier network services (CNS)	Typically, app or web-based platforms allowing customers to purchase goods and have them delivered to their home. Delivery could be within the hour or within a few days of ordering, depending on service.	Yes
5.4	Pay as You Drive (PAYD) Insurance	A type of auto insurance in which cost is based on distance traveled and is often combined with conventional auto insurance factors (e.g., driving history). It may also take into account how, when, and where driving occurs, using tracking technology which collects data from the vehicle directly.	Yes
5.5	Fleet pricing	Fees applied to entire fleets of vehicles when in operation, such as taxis, TNC vehicles, carsharing vehicles, micromobility vehicles (e.g., bikesharing, scooter sharing), SAVs, and delivery/commercial vehicles.	Yes
5.6	Telecommuting /flexible work hours	Employees work from home (or at work hubs close to home) and/or have staggered/flexible work hours to avoid peak travel periods.	Yes
6	**Conventional Taxation**		**Included**
6.1	Fuel taxes	Tax applied per unit of fuel purchased.	Yes

Throughout the rest of this report, we explore the social equity implications of each of the measures listed in Table 1 above. In the next section, we use the STEPS (Spatial – Temporal – Economic – Physiological – Social) equity framework to summarize findings and gaps in the literature on social equity impacts pertaining to each particular strategy.

Literature Review and STEPS (Spatial – Temporal – Economic – Physiological – Social) Equity Framework

Each of these strategies listed in Table 1 have different considerations for social equity. For example, while a distance-based pricing approach may make it difficult for those living far away from employment centers to access job opportunities, a means-based policy that provides subsidies for low-income travelers may alleviate economic barriers for those who may not otherwise be able to afford certain transportation options. In addition, a single strategy may have diverging positive and negative equity impacts. Cordon/area pricing may provide temporal benefits by improving travel times for public transit users and those willing and able to pay additional fees for using private vehicles, but they have the potential to create economic and spatial barriers for low-income households.

To provide additional clarity around varying equity impacts due to different strategies, we use the STEPS equity framework developed by the Federal Highway Administration (FHWA) to examine whether social equity barriers are reduced, exacerbated, or both by a particular strategy (Shaheen et al., 2017). The STEPS framework categorizes equity barriers to accessing transportation including considerations across spatial factors that compromise daily travel needs, temporal barriers that inhibit a user from completing time-sensitive trips, economic factors including direct and indirect travel costs, physiological barriers that make using certain travel modes difficult for disabled or older populations, and social factors like language or other barriers that detract from travelers' comfort with using transportation (Shaheen et al., 2017). For background and reference, Table 2 below provides a summary definition of each transportation barrier or benefit as defined by the STEPS equity framework.

Table 2. STEPS Equity Framework Definitions

Transportation Barrier/Benefit	Definition
Spatial	Spatial factors that compromise daily travel needs (e.g., excessively long distances between destinations, lack of public transit within walking distance).
Temporal	Travel time barriers that inhibit a user from completing time-sensitive trips, such as arriving to work (e.g., public transit reliability issues, limited operating hours, traffic congestion).
Economic	Direct costs (e.g., fares, tolls, vehicle ownership costs) and indirect costs (e.g., smartphone, Internet, credit card access) that create economic hardship or preclude users from traveling. Indirect economic effects also include changes in property values, rent, wages, and risk of displacement due to transportation infrastructure projects or parking changes.
Physiological	Physical and cognitive limitations that make using standard transportation modes difficult or impossible (e.g., infants, older adults, and disabled).
Social	Social, racial, cultural, safety, and language barriers that inhibit a user's (e.g., women, immigrants, minorities) comfort with using transportation (e.g., neighborhood crime, poorly targeted marketing, lack of multi-language information).

Table 3 (below) and the associated legend show each congestion mitigation measure listed in Table 1 and use the STEPS equity framework to identify whether the strategy reduces or eliminates a barrier, exacerbates or creates a barrier, or could either eliminate or create a barrier, depending on implementation details. The color-coded symbols identify the elimination or creation of barrier effects both in Table 3 and throughout this entire section. If a particular area of Table 3 is blank (i.e., it does not have a color-coded symbol), this signifies that there are gaps in understanding in the literature for this particular barrier with regards to the corresponding congestion mitigation measure. In the remainder of this section, we examine relevant literature, describe potential equity implications, and clarify gaps in understanding regarding the equity considerations of each congestion management strategy.

Table 3. Congestion Mitigation Measures and STEPS Equity Framework Summary Table

#	Measure Category	Spatial	Temporal	Economic	Physiological	Social
1	**Pricing**					
1.1	Cordon/Area pricing	*Exacerbates or creates barrier*	*Reduces or eliminates barrier*	*Exacerbates or creates barrier*		
1.2	Distance-based pricing	*Exacerbates or creates barrier*		*Exacerbates or creates barrier*		*Exacerbates or creates barrier*
1.3	Dynamic or congestion pricing		*May eliminate or create barrier*	*Exacerbates or creates barrier*		
1.4	Means-based pricing			*Reduces or eliminates barrier*		
1.5	Flat rate pricing	*Exacerbates or creates barrier*		*Exacerbates or creates barrier*		
1.6	Full-facility tolls	*Exacerbates or creates barrier*	*May eliminate or create barrier*	*Exacerbates or creates barrier*		
1.7	Managed lanes	*Exacerbates or creates barrier*	*May eliminate or create barrier*	*Exacerbates or creates barrier*		*May eliminate or create barrier*
2	**Parking and Curb Policies**					
2.1	Dynamic parking pricing	*Reduces or eliminates barrier*	*Reduces or eliminates barrier*	*May eliminate or create barrier*		

#	Measure Category	Spatial	Temporal	Economic	Physiological	Social
2.2	Off-street parking pricing/policy		*Reduces or eliminates barrier*	*Reduces or eliminates barrier*	*Exacerbates or creates barrier*	
2.3	Parking navigation tools		*May eliminate or create barrier*	*Exacerbates or creates barrier*	*Reduces or eliminates barrier*	*Exacerbates or creates barrier*
2.4	Curbside management	*Reduces or eliminates barrier*	*Reduces or eliminates barrier*		*Reduces or eliminates barrier*	*Reduces or eliminates barrier*
2.5	Parking cash out	*Exacerbates or creates barrier*	*May eliminate or create barrier*	*Reduces or eliminates barrier*		
3	**Operational Strategies**					
3.1	Traffic signal priority (TSP)		*Reduces or eliminates barrier*			
3.3	Ramp metering	*May eliminate or create barrier*	*May eliminate or create barrier*			
3.11	Geofencing	*Reduces or eliminates barrier*	*Reduces or eliminates barrier*	*Exacerbates or creates barrier*	*May eliminate or create barrier*	*Exacerbates or creates barrier*
3.12	Public transit improvements	*Reduces or eliminates barrier*	*Reduces or eliminates barrier*	*Exacerbates or creates barrier*	*May eliminate or create barrier*	*May eliminate or create barrier*
4	**Infrastructure Changes**					
4.1	Park and ride facilities	*Reduces or eliminates barrier*	*Reduces or eliminates barrier*	*Exacerbates or creates barrier*		

#	Measure Category	Spatial	Temporal	Economic	Physiological	Social
4.2	Transit oriented development (TOD)	*Reduces or eliminates barrier*	*May eliminate or create barrier*	*May eliminate or create barrier*	*Reduces or eliminates barrier*	*May eliminate or create barrier*
4.3	Car-free zones	*May eliminate or create barrier*	*Reduces or eliminates barrier*		*May eliminate or create barrier*	
4.4	Road diet	*Reduces or eliminates barrier*	*May eliminate or create barrier*			
4.5	Pedestrian and bicycle infrastructure improvements	*Reduces or eliminates barrier*	*Reduces or eliminates barrier*	*May eliminate or create barrier*	*Reduces or eliminates barrier*	*May eliminate or create barrier*
4.6	Complete Streets	*Reduces or eliminates barrier*	*Reduces or eliminates barrier*	*May eliminate or create barrier*	*Reduces or eliminates barrier*	*May eliminate or create barrier*
4.7	Increased road capacity	*May eliminate or create barrier*	*May eliminate or create barrier*	*May eliminate or create barrier*		*Exacerbates or creates barrier*
5	**Transportation Services and Strategies**					
5.1	Shared mobility (automotive)	*May eliminate or create barrier*	*May eliminate or create barrier*	*May eliminate or create barrier*	*May eliminate or create barrier*	*May eliminate or create barrier*
5.2	Shared mobility (active)	*May eliminate or create barrier*	*May eliminate or create barrier*	*May eliminate or create barrier*	*May eliminate or create barrier*	*May eliminate or create barrier*

#	Measure Category	Spatial	Temporal	Economic	Physiological	Social
5.3	Courier network services (CNS)	*May eliminate or create barrier*	*May eliminate or create barrier*	*May eliminate or create barrier*	*May eliminate or create barrier*	*May eliminate or create barrier*
5.4	Pay as You Drive (PAYD) Insurance	*May eliminate or create barrier*		*May eliminate or create barrier*		
5.5	Fleet pricing	*May eliminate or create barrier*	*May eliminate or create barrier*	*Exacerbates or creates barrier*		
5.6	Telecommuting/ flexible work hours	*Reduces or eliminates barrier*	*Reduces or eliminates barrier*	*Reduces or eliminates barrier*	*Reduces or eliminates barrier*	*May eliminate or create barrier*
6	**Conventional Taxation**					
6.1	Fuel taxes	*Exacerbates or creates barrier*		*Exacerbates or creates barrier*		

1) Pricing

Various forms of pricing may be effective at reducing congestion while generating revenue, but not all pricing approaches produce the same results. Flat rate tolls that are required all day, for example, do not encourage drivers to travel during less congested hours and thus may not reduce peak period traffic congestion. It is also important to note that many pricing strategies can be used simultaneously. For instance, cordon pricing could be dynamic as well, if the pricing fluctuates based on how many drivers enter a specified zone. Distance-based pricing could use flat rates that do not fluctuate. Regardless of which pricing strategies are used, they may only be effective at reducing congestion if other transportation modes are available and accessible (Provonsha & Sifuentes, 2018; Ying-En et al., 2018). Additionally, all of these pricing strategies may have social equity implications if they exclude non-English speakers or require credit cards and have restrictive upfront costs. These potential barriers can be mitigated depending on the implementation of the pricing strategy. For example, the National Cooperative Highway Research Program (NCHRP) provides both a discussion of language barriers associated with toll implementation and rate changes, as well as guidelines for mitigating these barriers (NCHRP, 2018). Below, we discuss further the social equity implications specific to many pricing strategies including: 1) cordon/area pricing, 2) distance-based pricing, 3) dynamic congestion pricing, 4) means-based pricing, 5) flat-rate tolls, 6) full-facility tolls, and 7) managed lanes.

1.1 Cordon/Area pricing

Cordon or area pricing is a term used to describe charges applied to motorists when entering and/or circulating in a specified area, typically a Central Business District (CBD).

Related STEPS Equity Framework Barriers:

Spatial	Temporal	Economic
Exacerbates or creates barrier	*Reduces or eliminates barrier*	*Exacerbates or creates barrier*

In several cities where cordon or area pricing have been implemented, the results have been undeniably successful with respect to reducing congestion (Lehe, 2019). As such, cordon and area pricing could play a role in alleviating temporal barriers that exist for those commuting by public transit or those willing and able to pay charges incurred by using private vehicles. However, cordon and area pricing have the potential to create economic and spatial barriers to transportation for low-income households and individuals. For residents living just outside the pricing zone, traveling into the zone by private vehicle may become too costly, and alternatives such as public transit may be similarly expensive or stations may be unreasonably far from their origins or destinations. In order to achieve the outcome of reduced congestion without creating spatial and economic barriers, the accessibility and affordability of transportation alternatives need to be considered. Means-based fares and public transit expansion could help mitigate these unintended side effects, which we discuss later in this pricing section. In the future, automated vehicles may be incentivized to circle instead of park in downtown urban areas, which could lead to an increase in congestion and emissions along with negative equity impacts. One study of AV circling and parking costs recommends time-based area pricing combined with distance- or energy-based charges to account for externalities due to driving (Millard-Ball, 2019).

1.2 Distance-based pricing

Distance-based pricing refers to policies where motorists pay fees on a per distance basis. These fees are also referred to as Road Usage Charging (RUC), Mileage Based User Fee (MBUF), and vehicle miles traveled (VMT) fees, among other terms. They can include restricted access to specified areas or lanes where the fee applies.

Related STEPS Equity Framework Barriers:

Spatial	Economic	Social
Exacerbates or creates barrier	*Exacerbates or creates barrier*	*Exacerbates or creates barrier*

Distance-based pricing can create spatial and economic barriers for low-income households and individuals if the costs of commuting rise for those that commute long distances (California Road Charge Pilot Program, 2017). In many cases, affordable housing may only be available at greater distances from employment opportunities and social activities, so distance-based pricing could cause a disproportionate financial burden for certain households and individuals. However, distance-based pricing mechanisms which take these factors into account and mitigate for negative outcomes by providing subsidies or incentives for certain populations may be able to overcome these challenges. Depending on the mechanism used to record distance traveled, privacy of personal information is also a major concern for implementing distance-based pricing. Although distance-based pricing may not present temporal barriers for individuals, it is important to note that travel time could increase if drivers optimize their routes with the goal of traveling fewer miles (Yang et al., 2016). Further research is needed to determine whether distance-based pricing has any effect on physiological barriers, and if temporal barriers become problematic for those attempting to decrease their mileage fees.

1.3 Dynamic congestion pricing

Dynamic congestion pricing is a form of tolling that fluctuates based on congestion levels in real time. The more congested the lane or facility is, the higher the cost to use it.

Related STEPS Equity Framework Barriers:

Temporal	**Economic**
May eliminate or create barrier	*Exacerbates or creates barrier*

Since dynamic congestion pricing can become costly during peak commute hours, low-income drivers may face economic barriers to using these lanes. Dynamically priced lanes may offer lower travel times and relief from temporal barriers. However, these benefits are contingent on the lack of economic barriers. Additionally, low-income drivers may be financially burdened if temporal constraints, such as rigid work schedules, restrict them from using dynamically priced facilities during off-peak hours when it may be affordable. Research has shown that low-income individuals, women, African Americans, and those who are less educated, are significantly less likely to have flexible work hours (Swanberg et al., 2005; Golden, 2008). However, although low-income workers are more likely to have rigid work schedules, they also are less likely to commute during peak hours, especially low-income women (Blumenberg, 2016). In current studies, equity concerns regarding dynamic congestion pricing are mostly focused on high occupancy tolls (HOT) lanes. These studies show that low-income individuals are as likely to support the implementation of HOT lanes and are interested in using them, as compared to high-income individuals. However, actual use of these lanes show that low-income individuals are less likely to use these lanes compared to other income levels, and whether this is due to spatial or economic barriers was not determined in these studies. As mentioned earlier, we can only infer that this reason is due to the fact that low-income drivers are more likely to work non-standard hours and commute during non-peak times. Further research is also needed regarding the social and physiological barriers associated specifically with dynamic congestion pricing, as only inferences can be made regarding impacts on gender and racial equity. Considering potential AV and SAV impacts in the future, one study found that dynamic congestion pricing strategies would be more effective in terms of social welfare gains compared to distance-based and full-facility pricing strategies (Simoni et al., 2019).

1.4 Means-based pricing

Means-based pricing is a term used to describe transportation charges based on income level. Means-based pricing could be applied to public transit fares, road pricing, or other transportation-related fees.

Related STEPS Equity Framework Barriers:

Economic
Reduces or eliminates barrier

Means-based pricing is perhaps the least regressive form of pricing since it applies charges to travelers based on income. Regardless of what transportation mode means-based pricing is applied to, it may be able to reduce economic barriers to this transportation mode. Although economic barriers may not restrict most low-income individuals from using public transit, the lowest-income individuals may still be burdened by public transit costs (Rice, 2004). Furthermore, low-income households that do own personal vehicles spend a higher percentage of their budget on transportation expenditures than do higher-income households. If other forms of congestion pricing are to be implemented, means-based pricing can mitigate the negative social equity impacts associated with these new policies. Means-based pricing could especially be helpful when more than one income threshold is used to determine discount rates (Cohen & Hoffman, 2019). Currently, there are no distance-based or dynamic congestion pricing schemes that incorporate a means-based pricing distribution. However, one study used a travel model for Maryland to examine the potential use of distance-based charges in combination with means-based fee structures (Yang et al., 2016). The study found that an income-based VMT fee is both more progressive than flat rate distance-based pricing schemes and may be just as effective at generating revenue.

1.5 Flat-rate pricing

Flat-rate pricing are set charges that a motorist pays to use a tolled facility, regardless of the time of day or level of congestion. Facilities that use flat rate tolls could include highways, bridges, tunnels, or other infrastructure. Flat-rate fares are commonly used in public transit systems.

Related STEPS Equity Framework Barriers:

Spatial	Economic
Exacerbates or creates barrier	*Exacerbates or creates barrier*

Depending on the geography of a region, flat rate tolls may be unavoidable for some drivers. As such, flat rate tolls can act as a barrier induced by both spatial and economic factors and may be the most regressive form of pricing relative to dynamic, distance-based, and means-based pricing (Cohen & Hoffman, 2019; Ke & Gkritza, 2018). With regards to public transit, low-income riders are more likely to travel during off-peak hours and for shorter distances. Thus, low-income public transit riders may pay a much higher per-mile fee than high-income public transit riders and may even cross-subsidize high-income commuters who travel during peak periods (Giuliano & Hanson, 2017). Flat rate tolls may also be less efficient at reducing congestion since they do not incentivize drivers to travel during off-peak hours (Metro Vancouver Mobility Pricing Study, 2018).

1.6 Full-facility tolls
Full-facility tolls are charges a motorist pays to use a tolled facility in which prices fluctuate depending on the time of day or level of congestion. The fee applies to every motorist entering the facility, similar to flat rate tolls.

Related STEPS Equity Framework Barriers:

Spatial	Temporal	Economic
Exacerbates or creates barrier	*May eliminate or create barrier*	*Exacerbates or creates barrier*

Since full-facility tolls are highest during prime travel times, low-income commuters may disproportionately bear the cost or be forced to travel at more inconvenient times if no other route exists. Similar to flat rate tolls, full-facility tolls can create barriers due to spatial and economic factors, but unlike flat rate tolls, temporal constraints must also be factored in. In some cases, low-income individuals may have more difficulty adjusting their schedule to avoid high tolls (Federal Highway Administration [FHWA], 2008). However, depending on income level, full-facility tolls can also serve to lessen temporal barriers since reducing congestion may increase travel speeds. Additionally, if high quality public transit options serve these facilities, travel times and reliability could also improve, further removing temporal barriers for public transit riders.

1.7 Managed lanes
Managed lanes encompass high occupancy vehicle (HOV) lanes (lanes dedicated to motorists with a minimum passenger requirement), high occupancy toll (HOT) lanes (HOV or fee paid if HOV requirement is not met), or express lanes (fee paid to use lane, regardless of the number of passengers).

Related STEPS Equity Framework Barriers:

Spatial	Temporal	Economic	Social
Exacerbates or creates barrier	*May eliminate or create barrier*	*Exacerbates or creates barrier*	*May eliminate or create barrier*

Similar to dynamic congestion pricing, managed lanes may create economic barriers for drivers who cannot afford to use express or toll lanes that would provide them with temporal benefits. One study showed that both income and residential location contributed to high use of HOT lanes by high-income households; however, these lanes are used by people of all income levels (FHWA, 2008). With regards to gender, studies of two HOT lane corridors in Southern California found that women make greater use of the lanes than men. However, while this suggests that women may derive more benefit from these lanes than men, the fees could also be more regressive for women who have lower average incomes than men (Weinstein & Sciara, 2006). Additionally, all income groups equally approve of tolled lanes because they value reliable travel times when they need it. Moreover, managed lanes also include HOV lanes, and thus the option of carpooling may allow low-income drivers to avoid high tolls yet benefit from reduced temporal barriers. One study showed that immigrants in Southern California are more likely to carpool than non-immigrants, and thus may benefit from HOV and HOT lanes (Blumenberg & Smart, 2014). This study also showed that carpooling rates increased as the concentration of immigrants increased within a neighborhood. Although the option of carpooling may be viable for some, spatial barriers could prevent informal carpooling, while economic and social barriers could prevent the use of carpooling or other pooled services, like pooled TNCs. Further research is needed regarding the physiological benefits or barriers managed lanes may present, however, providing discounts to tolled lanes for those with disabled placards most likely serves as a benefit for these users. Research shows varying results regarding the privacy concerns with using electronic transponders. For example, one report showed that FasTrak transponder adoption rate in the Bay Area may have initially been slow due to privacy concerns (Riley, 2008; Li, 2007). As discussed with regards to dynamic congestion pricing, language could be a barrier to using tolled lanes (NCHRP, 2018). Some research has shown that non-English speakers are less likely to use tolled lanes, but they are more likely to use HOV lanes (Lam & Small, 2003).

2) Parking and Curb Policies

Parking and curb policies are an important component of congestion mitigation. It is estimated that 30 percent or more of traffic in cities is due to searching for parking (Margreiter, 2017). Likewise, free parking for employees and business patrons encourages the use of driving, increasing traffic on freeways and arterial roads (Shoup, 1997). By implementing new off-street and on-street parking policies, existing parking space can be optimized while additional parking can be minimized for more equitable use of curb space. Furthermore, new technology may assist drivers to find available parking with less circling while paying the appropriate price for it. In this section, we describe various parking and curb policies and discuss the potential social equity impacts of each of them including: 1) dynamic parking pricing, 2) off-street parking pricing, 3) parking navigation tools, 4) curbside management strategies, and 5) parking cash out.

2.1 Dynamic parking pricing

Dynamic parking pricing refers to parking charges that are based on an area's parking demand. The parking cost adjustment may either change in real-time or after analyzing past parking demand and adjusting accordingly.

<u>Related STEPS Equity Framework Barriers:</u>

Spatial	**Temporal**	**Economic**
Reduces or eliminates barrier	*Reduces or eliminates barrier*	*May eliminate or create barrier*

Dynamic parking pricing can reduce the time spent looking for parking, thus reducing both temporal and spatial barriers to reaching one's destination. If many drivers spend less time looking for parking as a result of dynamic pricing, then local congestion may be reduced and all drivers in the area could also benefit from reduced temporal barriers. Although the cost of parking may become unaffordable for low-income drivers when demand is high, leading some drivers to use street parking less often, one study showed that low-income drivers are less sensitive to prices once they have parked (Chatman & Manville, 2018). This may be because low-income drivers have less flexibility with respect to when and where they park, or they may have been unaware of the new parking system. Further studies are needed to explain the observed trends between rate changes and parking usage by income level. Additionally, applying dynamic parking pricing to both off-street and on-street parking may allow for more parking availability and lower rates (Pierce et al., 2015). The economic barriers resulting from dynamic parking may not be the cost of parking itself, since dynamic parking pricing also results in less expensive parking in areas of low demand, but rather the need for a smartphone or other devices to obtain parking information. In order to address this issue, parking availability and rates should be made accessible without the need for smartphone apps, data plans, or other devices. Furthermore, means-based pricing could be incorporated in conjunction with dynamic parking pricing. Although social and physiological barriers are not discussed in current studies, when dynamic parking pricing is used in combination with parking navigation tools, they may assist disabled persons with finding dedicated disabled parking more efficiently (parkDC, 2019). In the future, AVs and SAVs that can cruise cheaply instead of park at potentially more expensive parking spots will need to be accounted for in order to decrease congestion, emissions and other externalities due to driving (Millard-Ball, 2019).

2.2 Off-street parking pricing/policy

Off-street parking policy reform refers to changes to current regulations regarding parking minimums, as well as introducing special taxes on off-street parking facilities to incentivize the optimization of parking space. Minimum parking requirements for new and existing development could either be reduced, eliminated, or replaced by a parking maximum (i.e., establishing a maximum number of parking spaces that a new development is allowed to build).

<u>Related STEPS Equity Framework Barriers:</u>

Temporal	Economic	Physiological
Reduces or eliminates barrier	*Reduces or eliminates barrier*	*Exacerbates or creates barrier*

Policy changes in off-street parking can encourage the use of transportation modes other than personal vehicles, and can in some cases decrease congestion and relieve temporal barriers. Additionally, since the cost of providing private parking is embedded in the cost of housing, goods, and services, all residents or shoppers pay the price of parking regardless of whether they actually use this parking (Shoup, 2016). Reducing or eliminating parking requirements can allow for more equitable outcomes, in which the cost of parking is paid for by those who use it. This can indirectly reduce economic barriers by reducing other living costs. It should be emphasized, however, that if parking policy changes are not carefully mandated, they could present physiological barriers if no or too little parking is available for disabled persons.

2.3 Parking navigation tools

A parking navigation tool is a technology that assists drivers in locating available parking. This technology may use data collection or sensors to identify available on-street or off-street parking and convey this information to drivers via smartphone or other devices.

<u>Related STEPS Equity Framework Barriers:</u>

Temporal	Economic	Physiological	Social
May eliminate or create barrier	*Exacerbates or creates barrier*	*Reduces or eliminates barrier*	*Exacerbates or creates barrier*

Parking navigation tools can expedite the process of finding parking, which is often difficult in dense urban areas. For that reason, these tools can reduce temporal barriers associated with parking, and may indirectly benefit other road users as a result of decreased cruising. However, these tools may encourage driving in some cases by making it easier to find parking spots, which would have negative impacts on congestion by encouraging those who would otherwise have taken public transit, biked, or walked to drive instead. They may also assist disabled persons with finding dedicated disabled parking more efficiently and informing non-disabled drivers of areas they cannot park (parkDC, 2019). However, parking navigation tools most likely require smartphones and internet access, and can therefore create economic barriers to low-income users. The information may also not be available in all languages, thus creating social barriers to using them. One way to mitigate for some of these issues would be to apply parking navigation to devices that display this information publicly, such as on a display screen located at the entrance of a parking garage, and in several languages.

2.4 Curbside management

Curbside management strategies refer to organizing and allotting curb space for public transit and bicycle/pedestrian infrastructure as first priorities, followed by bikesharing or scooter sharing, deliveries, passenger pick-up and drop-off, American Disability Act (ADA) access, emergency vehicles, AVs and SAVs, parklets, storm-water management, vehicle parking, electric-vehicle charging, space for local businesses, and mobile vendors.

<u>Related STEPS Equity Framework Barriers:</u>

Spatial	Temporal	Physiological	Social
Reduces or eliminates barrier	*Reduces or eliminates barrier*	*Reduces or eliminates barrier*	*Reduces or eliminates barrier*

Effective curbside management can reduce obstructions (e.g., delivery trucks) to public transit and bicycle facilities, thus increasing public transit and bicyclist speeds and improving safety. As a result, these strategies can reduce the temporal and spatial barriers for both public transit riders and bicyclists. Congestion may be reduced as well, if more people opt for active transportation and public transit instead of driving. Another outcome of curb space management is increased accessibility for disabled travelers, which directly leads to reducing physiological barriers that may currently exist (Roe & Toocheck, 2017). In addition, parklets (repurposing vehicle parking spaces for pedestrian use) may have positive social impacts by providing traffic calming while increasing safety and livability and promoting active transportation (Birdsall, 2013). Although current studies discuss spatial, temporal, physiological, and social benefits associated with curbside management strategies, they do not discuss potential economic impacts. Indirectly, curbside strategies may benefit low-income individuals since they are more likely to use public transit and active transportation, however, there have not been studies which discuss the direct relationship. In the future as AVs and SAVs become more commonplace, large swaths of on-street parking may be able to be eliminated and replaced with AV/SAV pickup zones that take up less curb space overall. The curb space formerly dedicated to on-street parking could be repurposed for pedestrians, active transportation users, or could create additional roadway capacity (Ma et al., 2018). The ways in which municipalities repurpose reclaimed curb space due to AVs and SAVs will have important implications for social equity.

2.5 Parking cash out

Parking cash out is a term used for a monetary payout received by employees from employers in exchange for free parking at their place of employment. The payouts are generally distributed on a monthly basis or along with paychecks.

Related STEPS Equity Framework Barriers:

Spatial	Temporal	Economic
Exacerbates or creates barrier	*May eliminate or create barrier*	*Reduces or eliminates barrier*

Parking cash outs can produce direct economic benefits to commuters and provide incentives to use transportation modes other than driving alone. Although the payouts are not limited to transportation funds, the payouts can serve as a means to reduce economic barriers to using public transit or shared mobility services. In some cases, spatial barriers may prevent employees from opting to give up parking for a cash payout. For example, giving up parking at work may be difficult if an employee lives or works in areas where no public transit options exist, or where shared mobility services may not be practical options. Even if alternative transportation options exist for employees, temporal barriers can arise if employees must commute long distances or if the options provide unreliable service. Although the time-cost of switching modes may be mitigated through parking cash outs, the value of reliable transportation may exceed the travel time value. This is especially true for employees with rigid work schedules or other time constraints, such as childcare responsibilities, that may require reliable transportation.

3) Operational Strategies

Operational strategies that modify how a certain transportation facility functions are integral to congestion mitigation. While some operational strategies may not directly reduce congestion, they can be implemented in conjunction with other congestion strategies to increase overall performance. Although the operational strategies we discuss here are typically beneficial for positive social equity outcomes, they must be implemented with care and designed to include all individuals. In this section we discuss the social equity implications that should be considered with respect to the following operational strategies: 1) traffic signal priority (TSP), 2) ramp metering, 3) geofencing, and 4) public transit improvements. We note that some of the measures listed under operational strategies in Table 1 are not covered in this section due to lack of information on social equity impacts related to the particular operational strategies.

3.1 Traffic signal priority (TSP)

Modified traffic signal timing that gives priority to public transit (e.g., buses, light rail) for the purpose of reducing travel time among users of these modes and increasing safety.

Related STEPS Equity Framework Barriers:

Temporal
Reduces or eliminates barrier

Traffic signal priority can significantly increase public transit speeds and reliability and thus can decrease temporal barriers for transit riders (Hu et al., 2014).

3.3 Ramp metering

Ramp metering is a strategy that uses traffic signaling to regulate the flow of traffic from highway on-ramps. Recent strategies include coordinated adaptive ramp metering, cooperation with dynamic speed limits, and signal control of adjacent traffic signals.

<u>Related STEPS Equity Framework Barriers:</u>

Spatial	Temporal
May eliminate or create barrier	*May eliminate or create barrier*

Ramp metering is a simple and effective method to keep traffic on freeways flowing without the congestion associated with high volumes of vehicles attempting to merge all at once. This strategy can significantly reduce temporal barriers for freeway commuters. Ramp metering that operates in coordination with real-time conditions may be the most effective at mitigating congestion (Lu et al., 2019). It should be noted, however, that different ramp metering operations yield different results, often balancing the effectiveness of the system with spatial equity. Effective ramp metering may generate long queues, sometimes leading to spillover traffic on nearby surface streets. This may lead to an unequal spatial distribution of travel time benefits related to both reliability and speed. To mitigate this inequity, ramp metering can be operated in such a way that prevents spillover on surface streets (e.g., queue override), but this may result in decreased travel speeds on highways (Zhang & Levinson, 2005; Shehada & Kondyli, 2019).

3.11 Geofencing

Technology that uses a virtual boundary for a physical area. Geofencing could physically stop vehicles or other modes (e.g., automated vehicles or e-scooters) or could simply alert motorists or travelers when crossing a boundary.

<u>Related STEPS Equity Framework Barriers:</u>

Spatial	Temporal	Economic	Physiological	Social
Reduces or eliminates barrier	*Reduces or eliminates barrier*	*Exacerbates or creates barrier*	*May eliminate or create barrier*	*Exacerbates or creates barrier*

Currently, geofencing is not widely used in transportation systems, but it may become more prevalent as the need for regulating traffic in congested areas becomes more pressing. TNCs use geofencing in coordination with airports, and cities in the UK may begin to use geofencing to reduce pollution from vehicles in poor air quality zones (Garrett, 2015; Rushton et al., 2018). Geofencing could be a useful tool for mitigating congestion by preventing vehicles (private and/or for-hire) from entering dense urban areas or dedicated public transit lanes, or from parking in disabled parking spaces. As a result, geofencing can help reduce temporal and physiological barriers. On the other hand, geofencing may require drivers to have a smartphone and an internet connection, which both have associated costs that could burden certain road users. Depending on how it is implemented, geofencing may have negative effects related to dividing a community, although more research is needed on this topic. Geofencing may also prevent disabled passengers from getting close enough to their destinations. This is especially of concern for those with visual impairments who may need to arrive directly at their destination and instead are dropped off at an alternate location due to geofencing. Additionally, these applications may exclude individuals if the information is not conveyed in their language. Further research is needed to examine how geofencing may impact equity.

3.12 Public transit improvements

Public transit improvements could include increased capacity, dedicated lanes (e.g., bus rapid transit); increased frequency; attractiveness (e.g., WiFi, A/C) and/or improved real-time transit information; public transit planning technology; or timed transfers.

<u>Related STEPS Equity Framework Barriers:</u>

Spatial	Temporal	Economic	Physiological	Social
Reduces or eliminates barrier	*Reduces or eliminates barrier*	*Exacerbates or creates barrier*	*May eliminate or create barrier*	*May eliminate or create barrier*

New public transit routes can directly mitigate spatial barriers for those living near new routes, especially for individuals without personal vehicles. Temporal barriers can also be reduced for public transit riders by increasing public transit speeds when improvements involve creating dedicated lanes and coordinated timed transfers. Temporal barriers can also be reduced by decreasing wait times through improved real-time transit information or increased service frequency. New public transit routes can eliminate the need for specialized transportation modes which are often not easily accessible for economic, spatial, or temporal reasons. Public transit is often more accessible to those with physiological limitations that prevent them from driving a vehicle or using TNCs (e.g., wheelchair users), however, design for physiological accessibility is critical. Social barriers can also be mitigated, but only if public transit improvements are specifically designed to do so, for example, if transit information is made available in different languages. Public transit improvements may benefit immigrants, since immigrants in California use public transit at twice the rate of non-immigrants, although commuting by private vehicle is still the dominant mode overall (Blumenberg & Evans, 2010). This is a non-trivial matter since immigrants make up approximately 27 percent of California’s population. It is also worth noting that public transit use by immigrants varies significantly by region, country of origin, and time spent living in the U.S. Poor and working-class women are also often dependent on public transportation, as they are more likely to have less access to personal vehicles. In households that have fewer vehicles than drivers, women often lack access to these vehicles while at the same time they are typically more burdened by household and childcare responsibilities (Giuliano & Hanson, 2017). While access to vehicles may address the mobility needs of women, public transit improvements can still relieve barriers to accessibility in many ways, such as more frequent and reliable service; improved safety (e.g., well-lit bus stops); and accommodation for strollers. Although public transit improvements can provide many benefits, increased fares are often a means of funding these improvements, and can thus lead to economic barriers for low-income individuals.

4) Infrastructure Changes

The infrastructure changes we describe in this section often involve drastic transformations of land-use that can contribute to reduced congestion, if implemented prudently. In general, analyzing the current jobs-housing balance of an area may help determine the most appropriate infrastructure change needed, if infrastructure changes are needed at all. For example, an area that has an excellent balance of jobs and housing may be better suited for car-free zones than park and ride facilities. It is also important to consider how these infrastructure changes will affect the surrounding communities and to implement plans that mitigate possible negative consequences, such as gentrification. In this section we discuss the unique social equity impacts associated with various infrastructure changes: 1) park and ride facilities, 2) transit oriented development (TOD), 3) car-free zones, 4) road diet, 5) pedestrian and bicycle infrastructure improvements, 6) complete streets, and 7) increased road capacity.

4.1 Park and ride facilities

Park and ride facilities are parking lots or structures located immediately next to public transit connections and typically outside of congested central business districts (CBDs). Park and ride facilities are often free of charge or very inexpensive in order to incentivize public transit use by vehicle owners.

<u>Related STEPS Equity Framework Barriers:</u>

Spatial	Temporal	Economic
Reduces or eliminates barrier	*Reduces or eliminates barrier*	*Exacerbates or creates barrier*

Park and ride facilities can reduce spatial barriers by providing convenience for vehicle owners who may live far away from public transit stops (Ai et al., 2018). Since park and ride facilities are often located in suburban areas, they have the potential to reduce congestion by encouraging drivers to substitute driving for an entire trip with public transit to reach their final destinations, which may be located in congested CBDs. This can lead to decreased temporal barriers for drivers who may often face traffic delays. The main equity issue regarding park and ride facilities is that they are heavily subsidized and they mostly benefit automobile owners who are more likely to have higher incomes compared to other transit riders (Meek et al., 2009). Additionally, park and ride facilities may increase automobile use if they are located in more urban areas, especially when there are no strategies in place to ensure that drivers who can take advantage of the low-cost parking are actually using public transit and not simply acquiring convenient and cheap parking (Mingardo, 2013).

4.2 Transit oriented development (TOD)

Transit oriented development refers to mixed land-use development centered around major transit connections that is designed to encourage public transit use and active transportation within the area.

Related STEPS Equity Framework Barriers:

Spatial	Temporal	Economic	Physiological	Social
Reduces or eliminates barrier	*May eliminate or create barrier*	*May eliminate or create barrier*	*Reduces or eliminates barrier*	*May eliminate or create barrier*

Residents within or near a TOD may benefit from both reduced spatial and temporal barriers since public transit, jobs, and other opportunities may be located directly next to them. This could also reduce barriers for those with physiological limitations that prevent them from driving a vehicle or using TNCs (e.g., wheelchair users), however, there is limited literature regarding the physiological barriers of TODs. Although temporal barriers may be ameliorated by TODs, there have been few studies that examine the actual time-savings of residents. In fact, current literature shows that mode shifts away from private vehicles may be negligible, and the population increase due to new housing developments may actually worsen traffic conditions (Zhu et al., 2018). More research is needed in this regard, particularly on the effects of parking requirements and their potential inhibiting effects of utilizing TODs for reducing congestion. Additionally, if public transit has limited operating hours or infrequent and unreliable service, residents and commuters may be affected temporally if no other transportation modes are available to them. TODs also have the potential to provide economic benefits since job creation is often a result of new development. If affordable housing is included as part of a TOD project, this can be another economic benefit for low-income households. With that said, property values may increase near TODs, and while this benefits existing property owners, it typically burdens renters. Any new housing that is not required to be affordable is often too expensive for low-income households, and as a result, TODs may spur gentrification and displacement, thus creating racial and social inequities (Giuliano & Hanson, 2017). Numerous studies have examined the spatial, economic, and social equity effects of TODs, and often reveal conflicting results. The reasons for these results are often complex, including factors such as: pre-planning outreach efforts, real estate market trends, and support of affordable housing by city, regional, and state levels (Baker & Lee, 2019).

4.3 Car-free zones

Car-free zones, also known as pedestrian zones, are areas that prohibit all vehicles or most private vehicles.

Related STEPS Equity Framework Barriers:

Spatial	Temporal	Physiological
May eliminate or create barrier	*Reduces or eliminates barrier*	*May eliminate or create barrier*

Although car-free zones create spatial barriers for drivers, they also may decrease both temporal and spatial barriers for pedestrians, bicyclists, and public transit riders as a consequence of significant congestion reduction. Residents within the area may also benefit from both direct and indirect health benefits associated with car-free zones, namely, improved air quality and increased active transportation. Traffic-related injuries and deaths typically reduce dramatically within these zones. Although several benefits result from car-free zones, questions need to be addressed as to whether automobile traffic, and the associated negative impacts, will be shifted elsewhere (Nieuwenhuijsen, 2016). If traffic is re-routed through vulnerable communities, then car-free zones could be a source of decreased social equity. Additionally, car-free zones could also create a barrier for those with physiological limitations who may depend on personal vehicles or door-to-door transportation services.

4.4 Road diet

A road diet involves a reduction of lanes and/or a narrowing of lanes usually to provide bike lanes, pedestrian refuge islands, and/or parklets, as well as to reduce vehicle speeds.

<u>Related STEPS Equity Framework Barriers:</u>

Spatial	Temporal
Reduces or eliminates barrier	*May eliminate or create barrier*

One of the major goals of road diets is to reduce vehicle speeds in order to increase safety for pedestrians and bicyclists. While this goal may increase travel times for drivers, it also often leads to increased pedestrian and bicycle flows (Neuner, 2015). Therefore, road diets may both create temporal barriers for drivers, as well as reduce spatial and temporal barriers for pedestrians and bicyclists, who benefit from new bicycle routes. Similar to car-free zones, road diets may shift automobile traffic to other roads.

4.5 Pedestrian and bicycle infrastructure improvements

Pedestrian and bicycle infrastructure improvements refer to road designs that enhance safety and encourage active transportation. Approaches can include well-maintained sidewalks, safe crossings, universal design, improved path connectivity, protected bike lanes, increased bike parking, visual attractiveness, and other elements.

<u>Related STEPS Equity Framework Barriers:</u>

Spatial	Temporal	Economic	Physiological	Social
Reduces or eliminates barrier	*Reduces or eliminates barrier*	*May eliminate or create barrier*	*Reduces or eliminates barrier*	*May eliminate or create barrier*

Pedestrian and bicycle infrastructure improvements can eliminate spatial barriers for individuals who do not own personal vehicles by creating routes that can be traveled without a vehicle or increasing the safety of existing routes (Ferenchak & Marshall, 2019). For example, destinations separated by freeways may have short distances but might be effectively inaccessible to pedestrians or bicyclists. In dense urban areas, traveling by bicycle may be the quickest mode of transportation (Faghih-Imani et al., 2017). Thus, creating infrastructure for bicyclists may reduce temporal barriers as well. Immigrants commute by walking or cycling at much higher rates than non-immigrants, especially in the first few years of living in the U.S. However, a lack of infrastructure still prevents many more from traveling via active transportation (Chatman & Klein, 2009; Handy et al., 2008). Bicycling rates among women are often much lower than for men; however, studies have shown that many women are interested in biking but are concerned about their safety. Thus, there is a high potential to increase biking among women if infrastructure improvements enhance actual and perceived safety (Le et al., 2019). For individuals with physiological limitations, traveling by foot or by wheelchair may be a primary transportation mode. Even in areas where pedestrian infrastructure exists, traveling may still be logistically challenging or dangerous for wheelchair users and those with visual impairments. It is critical that universal design is incorporated in pedestrian improvement plans in order to reduce physiological barriers (Aghaabbasi et al., 2019). Further research is needed to examine the direct economic effects pedestrian and bike infrastructure has on those it serves. However, these improvements may assist households in financial savings if they can safely travel by foot or bike rather than by other costly forms of transportation. It also should be noted that pedestrian and bicycle improvement projects are often implemented in areas that serve more advantaged groups and are often associated with gentrification (Lee et al., 2017; Stehlin, 2015). As such, pedestrian and bicycle infrastructure improvements may not be intrinsically equitable, even though low-income and minority populations are less likely to have access to personal vehicles (Giuliano & Hanson, 2017). Consideration of where these improvements are implemented and who they are intended to serve is critical so as to enhance social equity rather than degrade it.

4.6 Complete Streets

Complete streets are streets designed to facilitate efficient and safe travel for all road users (pedestrians, bicyclists, public transit users, and drivers). Complete streets include pedestrian and bicycle infrastructure improvements listed in section 4.5, as well as public transportation improvements listed in section 3.4, and improvements to enhance the connectivity between these modes. Complete streets may also create space for sidewalk dining, social gathering, and relaxing. As such, complete streets may support commerce and enhance property value.

<u>Related STEPS Equity Framework Barriers:</u>

Spatial	Temporal	Economic	Physiological	Social
Reduces or eliminates barrier	*Reduces or eliminates barrier*	*May eliminate or create barrier*	*Reduces or eliminates barrier*	*May eliminate or create barrier*

Since complete streets encompass pedestrian, bicycle, and transit improvements, the associated STEPS equity framework barriers and benefits are similar to Sections 3.4 and 4.5. Spatial and temporal benefits are derived from improvements following the complete streets approach, such as priority public transit lanes and protected bike lanes. Allocation of street space to benefit these high-occupancy and non-motorized modes could improve social equity outcomes (Caltrans 2010). Economic barriers may not directly prevent individuals from benefiting from complete streets, however, research shows that complete streets may create indirect effects on the local economy and affect local residents. These effects may be both positive and negative; complete streets may spur job growth, thus providing economic benefits, but they may also increase property values and potentially create economic barriers (Yu et al., 2018). However, whether complete streets decrease housing affordability is still a question of future research. Another interesting social benefit of complete streets is enhanced gender equity. Research shows that improved walkability of complete streets increases the proportion of women as pedestrians, whereas men outnumbered women prior to street improvement and in areas of poor walkability (Jensen et al., 2017). As with other infrastructure changes, universal design that makes facilities accessible for older adults and those with disabilities is key to reducing possible physiological barriers.

4.7 Increased road capacity

Increased road capacity includes creating additional lanes or building new roads, freeways, bridges, or tunnels.

Related STEPS Equity Framework Barriers:

Spatial	Temporal	Economic	Social
May eliminate or create barrier	*May eliminate or create barrier*	*May eliminate or create barrier*	*Exacerbates or creates barrier*

Increased road capacity may reduce spatial and temporal barriers, particularly for those with personal vehicles and households who live in suburban or rural areas. This may also increase employment opportunities, and thus create economic benefits for some households (van Hengel et al., 1999). However, these economic benefits may be inequitably distributed. In addition, increased road capacity is more likely to induce travel demand if it is not prudently implemented (Chung et al., 2016). For example, new lanes or roads could be tolled and the revenue generated could be used to fund public transit (Giuliano & Hanson, 2017). This could mitigate the effect of long-term induced demand, while providing more efficient and equitable means of transportation. Additionally, increased road capacity is historically intertwined with environmental injustice issues and has the potential to create severe negative social equity impacts on the communities through which new roads or freeways are routed. In fact, removing highways that are routed through communities often revitalizes the surrounding area, both socially and economically (Handy, 2015). Further studies are needed to examine the physiological barriers or benefits increased road capacity may pose.

5) Transportation Services and Strategies

Transportation services and other related strategies have the potential to mitigate congestion under some circumstances. For example, shared mobility services like bikesharing and carsharing have been shown to reduce VMT and GHG emissions (Shaheen et al., 2015), and may reduce congestion in certain areas if they replace a significant amount of private vehicle trips. Other strategies like pay as you drive insurance and fleet pricing may reduce congestion as well, especially if they reduce demand for fleet-based modes that might increase congestion, like TNCs (SFCTA, 2018). However, those seeking to implement these services or strategies should be aware of important equity considerations, which we discuss further in this section. We cover a broad range of transportation services and strategies: 1) shared mobility (automotive), 2) shared mobility (active), 3) courier network services (CNS), 4) pay as you drive (PAYD) insurance, 5) fleet pricing, and 6) telecommuting/flexible work hours.

5.1 Shared mobility (automotive)

Shared use of a transportation mode involving an automobile (e.g., carsharing, carpooling, TNCs, microtransit, etc.) to decrease the need for private vehicle ownership and reduce travel demand.

Related STEPS Equity Framework Barriers:

Spatial	Temporal	Economic	Physiological	Social
May eliminate or create barrier	*May eliminate or create barrier*	*May eliminate or create barrier*	*May eliminate or create barrier*	*May eliminate or create barrier*

Automotive shared mobility services encompass a wide range of transportation modes and strategies and provide both opportunities and challenges for all five STEPS equity framework barriers (Shaheen et al., 2017). Shared mobility may be able to address spatial barriers by providing additional mobility options that have greater geographic reach than existing options. However, lower density areas may pose a challenge for operators to provide high-quality, cost-effective shared mobility services. Temporal barriers can be addressed by reducing wait and travel times and providing increased reliability when public transit is not available or has reduced service. However, automotive shared mobility services are subject to temporal fluctuations in demand and shortages in supply that may result in unreliable wait times or vehicle unavailability during certain times of the day. Shared mobility can decrease household transportation costs by allowing users to pay for mobility on an as-needed basis as compared to upfront costs associated with purchasing a household vehicle. At the same time, some services may be prohibitively expensive and many require payment with a credit or debit card, making them inaccessible to those who are unbanked. Automotive shared mobility can also address physiological barriers by providing on-demand options where public transit or paratransit is not available and by more efficiently dispatching a range of vehicle types based on a user's specific needs. However, provision of access for people with disabilities and equivalency of service standards are challenges that still need to be addressed for many shared mobility modes. Social barriers can be addressed if providers and policymakers develop appropriate marketing and educational materials around automotive shared mobility services and engage with relevant community organizations to incorporate input and feedback. Note that while automotive shared mobility modes have the potential to decrease congestion (e.g., carpooling), others may increase congestion in certain contexts. For example, a study of TNC impacts on congestion in San Francisco found that 51 percent of the increase in daily vehicle hours of delay between 2010 and 2016 was attributable to the introduction of TNCs (SFCTA, 2018). A study of individuals' willingness to share AV trips in the future found that users are less sensitive to the presence of strangers during a commute trip compared to during a leisure trip. The study also found that the ability to use travel time productively may encourage higher-income individuals to share rides even if they are slightly less comfortable and take slightly longer (Lavieri & Bhat, 2019).

5.2 Shared mobility (active)

Shared use of an active transportation mode (e.g., bikesharing, scooter sharing, etc.) to decrease the need for private vehicle ownership and reduce travel demand.

Related STEPS Equity Framework Barriers:

Spatial	Temporal	Economic	Physiological	Social
May eliminate or create barrier	*May eliminate or create barrier*	*May eliminate or create barrier*	*May eliminate or create barrier*	*May eliminate or create barrier*

Active shared mobility modes, like bikesharing and scooter sharing, have many of the same equity implications with respect to the STEPS equity framework as outlined in the automotive shared mobility discussion above. However, there are a few key equity and congestion management differences that we discuss in this section. Physiological barriers may be more difficult to address with active shared mobility modes compared to automotive ones, since older, younger, and disabled populations may not be physically able to ride bicycles or scooters, for instance. Some active shared mobility modes may be cheaper to use than other forms of shared mobility and private vehicle ownership, making them more accessible from an economic standpoint. In addition, many bikesharing systems, in particular, offer discounted memberships for lower-income users (ITDP, 2014). However, since active shared mobility systems, like docked bikesharing, dockless bikesharing, and scooter sharing, typically service pre-determined geographical areas, spatial barriers can exist if these services are not available in disadvantaged communities. One study of 42 U.S. bikesharing systems found that the 60 percent of census tracts with the greatest economic hardship contained less than 25 percent of bikesharing stations (Smith et al., 2015). We should note that the distribution of active shared mobility can vary by city, and the advent of dockless micromobility services may be able to reach a more diverse user base in cities than docked systems (Shaheen & Cohen, 2019). More research is needed to determine the equity impacts of dockless micromobility services. Active shared mobility modes also have the ability to reduce congestion, especially since a portion of trips are replacing private vehicle modes, like personal driving and TNCs. A study of scooter sharing users in San Francisco found that 41 percent of those surveyed would have taken a TNC or used a private vehicle for their last trip, if scooter sharing were not available (SFMTA, 2019). This effect has beneficial implications for reducing congestion, since it allows some users to shift from automobile-oriented modes to bicycles or scooters with much smaller environmental and congestion impacts. At the same time, it should be noted that active shared mobility can sometimes replace trips that would have otherwise been made by walking. The same study found that 31 percent of scooter sharing users in San Francisco would have walked, if scooter sharing were unavailable for their most recent scooter trip (SFMTA, 2019).

5.3 Courier network services (CNS)

Typically, app or web-based platforms allowing customers to purchase goods and have them delivered to their home. Delivery could be within the hour or within a few days of ordering, depending on service.

Related STEPS Equity Framework Barriers:

Spatial	Temporal	Economic	Physiological	Social
May eliminate or create barrier	*May eliminate or create barrier*	*May eliminate or create barrier*	*May eliminate or create barrier*	*May eliminate or create barrier*

Similar to shared mobility, CNS provide both opportunities and challenges along all five STEPS equity framework barriers. CNS can reduce spatial barriers by delivering goods to those living far from stores or restaurants instead of requiring travel to access goods (Shaheen et al., 2017). While this would be useful for those living in less dense and rural areas, delivering in these areas may not be financially sustainable for CNS companies and may require a subsidy to be affordable to low-income users. Temporal barriers may be addressed since shopping can be completed at any time of the day and whenever is convenient for each particular customer. CNS services typically require a computer or smartphone with access to a stable internet connection as well as a credit or debit card, which poses an economic barrier for some users. Additionally, these services may be more expensive than traditional shopping and may require costly memberships. CNS can both mitigate and create barriers to those with physiological limitations. If CNS apps or websites are not equipped to be accessible to those who are visually impaired, for example, then they may be excluded from using such services. Additionally, older adults may need special assistance with using or learning to operate CNS services. However, these services can also mitigate for physiological barriers since they may eliminate the need to travel to pick up goods, which could be a challenge for those with physiological limitations. Social inequities may arise with CNS services if they exclude certain communities based on perceived lack of demand or demographic profiling.

5.4 Pay as You Drive (PAYD) Insurance

A type of auto insurance in which cost is based on distance traveled and is often combined with conventional auto insurance factors (e.g., driving history). It may also take into account how, when, and where driving occurs, using tracking technology which collects data from the vehicle directly.

Related STEPS Equity Framework Barriers:

Spatial	Economic
May eliminate or create barrier	*May eliminate or create barrier*

Similar to distance-based pricing, PAYD insurance may negatively impact certain users if they live far away from their workplace and incur higher costs under a distance-based insurance plan. However, PAYD insurance may have positive economic effects for those that do not drive frequently or that commute shorter distances but still require vehicle ownership. Depending on the type of insurance scheme, spatial inequities may arise if those that drive in areas that insurance companies deem higher risk are charged more than they were previously and cannot afford rate increases. Although there are no studies to date on possible spatial inequities of PAYD insurance, past research suggests that redlining in traditional auto insurance plans can be a factor that adversely affects minority and poorer neighborhood residents (Ong & Stoll, 2007).

5.5 Fleet pricing

Fees applied to entire fleets of vehicles when in operation, such as taxis, transportation network company (TNC) vehicles (also known as ridesourcing and ridehailing); carsharing vehicles; micromobility vehicles (e.g., bikesharing, scooter sharing); SAVs; and delivery/commercial vehicles.

Related STEPS Equity Framework Barriers:

Spatial	Temporal	Economic
May eliminate or create barrier	*May eliminate or create barrier*	*Exacerbates or creates barrier*

Fees placed on vehicle fleets are a commonly-applied method to increase city budgets, provide funds to better manage fleets, and curb negative societal effects like congestion or emissions. Fleeting pricing is especially important to consider to reduce the negative impacts of transportation modes that involve deadheading (traveling without a passenger between trips), like taxis, TNCs, SAVs, and others. Depending on how they are enacted, fleet fees may have positive spatial and temporal effects by decreasing demand for particular services that contribute to traffic congestion or emissions. At the same time, if these fees are passed along directly to customers, they may preclude certain users from accessing the service. This could have negative economic, spatial, and temporal impacts for these users. Therefore, fleet pricing must consider and mitigate for possible impacts to low-income users. As vehicle automation technology improves, fees placed on SAV fleets may help curb negative congestion and emission impacts that might result from increased adoption. Some cities like San Francisco are already considering taxing SAV trips, and the 2018 California Assembly Bill 1184 allows the city to levy a tax on each SAV trip originating within city limits (Grau Ruiz, 2019).

5.6 Telecommuting/flexible work hours
Employees work from home (or at work hubs close to home) and/or have staggered/flexible work hours to avoid peak travel periods.

Related STEPS Equity Framework Barriers:

Spatial	Temporal	Economic	Physiological	Social
Reduces or eliminates barrier	*Reduces or eliminates barrier*	*Reduces or eliminates barrier*	*Reduces or eliminates barrier*	*May eliminate or create barrier*

Telecommuting and flexible work hours can have many positive impacts on mitigating travel demand, especially if they reduce travel demand during peak hours which adds to traffic congestion. At the individual level, these work policies have the potential to save workers money and time that would have otherwise been spent commuting. Additionally, research shows that telecommuters earn wages that are at least equal to, and in some cases higher than, their fixed-schedule and fixed-location counterparts (Weeden, 2005). However, not all workers have access to flexible-location or flexible-schedule arrangements, as lower-wage and hourly workers typically have less access to flexible work schedules (Swanberg et al., 2005). For those with physiological limitations, telecommuting may ease the difficultly of commuting and ensure that they feel more comfortable during work hours with amenities they may only have access to at home. However, there are social benefits and drawbacks to telecommuting. One study showed that while remote working can improve organizational commitment, job satisfaction, and job-related well-being, remote workers work longer hours and at higher intensity than fixed-location workers (Felstead & Henseke, 2017). The recent rise of coworking spaces (i.e., shared workplaces used by different types of knowledge professionals) may provide an alternative workplace environment that is closer to home (and thus requires less travel), but it still retains social proximity and knowledge exchange advantages of working near others with similar interests (Gandini, 2015). However, more research is needed on coworking spaces and travel behavior.

6) Conventional Taxation

Conventional taxation measures include fuel taxes, which have existed for decades as one of the primary means to pay for transportation infrastructure in the US.

6.1 Fuel taxes
Fuel taxes are taxes applied per unit of fuel purchased.

Related STEPS Equity Framework Barriers:

Spatial	Economic
Exacerbates or creates barrier	*Exacerbates or creates barrier*

Fuel taxes are often viewed as regressive, especially when factoring in the association between income level and fuel-efficient vehicle ownership (Tovar Reaños & Sommerfeld, 2018). Fuel taxes also disproportionately burden drivers living in rural areas who may travel long distances or require light duty trucks as part of their employment, thus creating both spatial and economic barriers (Baker et al., 2011). Currently, studies have not examined the temporal, physiological, or social impacts of fuel taxes.

Expert Interview Synthesis

In this section, we summarize findings from 12 expert interviews with those who have past experience with equity considerations of congestion management approaches. The interview synthesis provides additional detail and fills some gaps in understanding missing from the current literature.

The purpose of the expert interviews is to better understand the social equity implications of a variety of congestion management strategies. In addition, interviewees were asked to identify gaps in understanding that are not currently present in the literature. The interview findings are organized into three main sections:

1) Experience with Congestion Management Strategies
2) Equity Considerations of Congestion Management Strategies
3) Gaps in Understanding and Next Steps

For all sections, we combined findings from the NGO/academic, private and public sector questionnaires to compare and contrast viewpoints for each topic.

Methods

Researchers at TSRC developed three expert interview questionnaires: one for the private sector, another for NGOs and academics, and a final one for the public sector. The public sector and NGO/academic questionnaires covered the following themes: experience with and understanding of congestion management strategies, opinions on what particular strategies are most effective, the equity implications of the strategies discussed, key future developments, and gaps in current understanding. The private sector questionnaire covered similar themes and focused on the organization's thoughts about current or future congestion management strategies or related policies around equity concerns.

Researchers contacted 21 potential interviewees from a list of experts representing private companies, universities, NGOs, and public agencies. The experts were identified based on their expertise and via past relationships with the TSRC and affiliation with organizations of interest. Of the 21 people contacted, one academic, three members of NGOs, seven public sector representatives, and one private sector representative agreed to our request for an interview. The interviews were completed June through August 2019 and lasted an average of about 45 minutes each.

Experience with Congestion Management Strategies

Interviewee Experience with Congestion Management Strategies

Interviewees that we spoke with had a wide range of experiences and expertise regarding a variety of different forms of congestion management strategies. Public sector representatives had experience both planning and implementing a number of congestion mitigation measures including: managed lanes (HOV, HOT, and express lanes), bus rapid transit (BRT) lanes, transportation demand management (TDM) programs with employers, public transit incentives for off-peak travel, and public outreach campaigns on alternative travel options. Some public sector respondents also had examined strategies under consideration including: cordon pricing, distance-based (VMT) pricing, dynamic congestion pricing, full-facility tolling, area pricing using geofencing, and taxation of shared mobility services. The private sector interviewee we spoke with had experience with shared mobility services and how they are regulated from a congestion management standpoint across various U.S. jurisdictions. The academic interviewee was experienced with congestion pricing as well as land use approaches. Interviewees from NGOs had experience with land use and transportation integration, smart growth policies, express lane implementation and policies, BRT, pedestrian and bicycle infrastructure improvements, public transit improvements, transit signal priority, curb space management, congestion pricing, and cordon pricing.

Congestion Management Strategies Developments of Interest

Many interviewees mentioned specific upcoming congestion management developments of interest in the US, both inside and outside of their particular jurisdictions including: New York City's approved and under development congestion charging program; potential plans for congestion charging programs in cities like San Francisco and Los Angeles; distance-based roadway pricing in states like California, Oregon, Washington, Colorado and Minnesota; dynamic and variable congestion pricing in Seattle and Portland; occupancy-based taxation for shared mobility services; transit oriented development centered around affordable housing; off-street parking policies; and regulations regarding congestion impact fees charged to developers.

Strategy Effectiveness and Key Considerations

After discussing interviewee experience with and thoughts on a number of congestion management strategies, we asked respondents about what specific strategies they believe are most effective at mitigating congestion. Most interviewees mentioned that no one strategy will solve congestion alone and that a variety of measures are necessary. For example, one public sector respondent claimed that both cordon and distance-based pricing will be important for addressing congestion and getting the traveling public used to usage-based road pricing in general. Those that had experience with express lane projects claimed that they had been effective at decreasing travel times and increasing speeds in the corridors where the lanes were implemented. Another representative from the public sector stated that cordon pricing is of most interest to their organization, but that area, distance-based, and time-based pricing could be explored as well if the technology used allows for these approaches. The academic interviewee highly favored dynamic congestion pricing, asserting that this strategy is the most effective congestion management strategy, while land use policies also play an important role. Another interviewee highlighted the need for incentives that reinforce and encourage sustainable transportation modes. While congestion pricing may discourage single-occupancy vehicle trips, financial incentives that reward individuals for choosing not to drive may also spur modal shift to more sustainable modes. Furthermore, these incentives could also create a more equitable system in which individuals who already use public transit or active transportation due to financial or legal barriers would be rewarded.

This respondent mentioned Milan, Italy as an example of a city that plans to pay individuals to bike to work.

Multiple public sector interviewees mentioned that the details of how exactly congestion management programs are implemented and enforced are crucially important for their success. Some strategies may be difficult to implement because the cost of enforcement may be higher than the revenue generated by the program itself. In this sense, the technology used in collecting fares and enforcement are critical for the financial sustainability of congestion management strategies. One public sector respondent said that they are assessing different technology options for distance and occupancy measurement. They are in the process of putting out a Request for Information (RFI) for technology to be used in roadway pricing programs, which may include cameras, smartphone tracking, or other proposed options. However, all interviewees that discussed enforcement methods also voiced concerns about road user privacy, noting that this is a very important consideration when implementing congestion management strategies.

Some respondents also elucidated important differences between travel modes that must be considered under certain congestion mitigation measures. For example, cordon pricing alone may not alleviate congestion within a certain zone if a significant portion of trips are made entirely within the zone itself. Therefore, area pricing that considers circling in a particular area might need to be considered in some cases. This is especially important if many intra-zone trips are made by TNC or delivery vehicles that may circle around downtown areas more often than other travel modes. Another respondent mentioned the need to include curbside management strategies that account for TNCs and delivery vehicles, since these services are becoming more prominent in U.S cities today and can greatly increase congestion if not carefully regulated and managed. This respondent also discussed the importance of reforming both on-street and off-street parking policies to reduce circling. Additionally, the respondent highlighted the need to make robust public transit improvements so that travel times are competitive with private vehicle use. This may lead to greater modal shift which could greatly reduce overall congestion levels.

Because congestion is dynamic and variable with time, some respondents voiced that flat-rate distance-based pricing would not be effective at mitigating congestion, but see this strategy as a replacement for the gas tax. Instead, they believe that dynamic congestion pricing would be more effective at changing travel behavior and reducing congestion, and this strategy could be layered on top of distance-based pricing. These respondents were also opposed to adding road capacity as a way to reduce congestion, and instead see the need to use our current capacity more efficiently. This would include not only reducing the overall number of vehicles on the road, but also increasing the number of passengers per vehicle.

Many respondents mentioned that public and stakeholder outreach are key to implementing successful congestion management projects. Without proper messaging and publicly available information, fees that are part of a new congestion management measure will likely be negatively received by the public. However, if the benefits of a program are clearly communicated and equity issues are appropriately addressed, communities are more likely to be supportive and understanding of congestion management programs and the advantages they intend to bring. We discussed the equity considerations of various congestion management strategies with interviewees, and our findings are presented in the next section.

Equity Considerations of Congestion Management Strategies

Equity Implications of Congestion Management Strategies

The interviewees we spoke with listed a number of equity concerns related to various congestion management strategies. Equity implications tended to differ depending on each particular strategy discussed, and depended on the region in context, since regions have various existing conditions affecting current personal vehicle dependence across income levels.

A number of interviewees expressed concern around who would be able to use express lanes and who will ultimately benefit from the installation of HOT lanes. While some of the public sector respondents we spoke with referred to express lanes that constituted additional lanes, which they believed did not have negative equity impacts since they did not adversely affect the throughput of existing lanes in the short term, others we talked with were concerned about the equity impacts of converting existing lanes to HOT lanes. Depending on how they are implemented, express lanes may be prohibitively expensive for low-income populations and travel times for non-express lanes may increase, which raises important equity considerations. It is important to note, however, that this respondent concern refers to the conversion of existing lanes to priced lanes of which there are few examples of in the U.S. Research has shown that all income groups use tolled lanes, although higher-income groups tend to use these lanes more frequently than lower-income groups (Income-Based Equity Impacts of Congestion Pricing, 2008). Although these prices may still be burdensome for low-income drivers, travel time reliability may be a more important factor than price for individuals who choose to pay the toll anyway. The concern then may be that these individuals pay a higher proportion of their income on transportation because this may be their only option due to individual time constraints (e.g., childcare, employment). Some work has been done to address these concerns, and respondents mentioned LA Metro's toll equity program which offers free transponders and monthly maintenance fee waivers for households that make under certain income thresholds (LA Metro, 2012). However, another public sector interviewee mentioned that they had explored income qualifications for reduced express lane rates but had not received much support from the legislature. The respondent cited high costs for program implementation that would likely not be offset by the revenue generated from the express lanes. Addressing funding barriers is a challenge for equity programs to be successful.

Respondents also brought up equity implications for cordon and area pricing strategies. A public sector interviewee mentioned that a planned cordon tolling project had equity implications for existing low-income residents living inside the proposed toll area. Since the area is preparing for considerable redevelopment efforts, existing residents feel it is not fair to impose a new toll that did not exist previously. While still in the planning process, the public sector interviewee claimed that their organization is considering a number of mitigatory options, including discounts and public transit incentives.

How taxation rates are implemented was also discussed by some respondents. A public sector respondent mentioned that discounts could be given for HOV lanes and even mentioned that they had implemented free park and ride lots for those who elect to carpool (and use the HOV lanes). Similarly, some jurisdictions currently tax or are considering taxing shared mobility services like TNCs and microtransit. One respondent opined that shared rides (like Lyft Shared rides or uberPOOL) should be taxed at a lower rate than private rides, since shared rides encourage higher vehicle occupancies. Some cities, like New York City, account for this difference but others, like Chicago, do not at present. Occupancy-based pricing considerations could possibly improve equitable outcomes by encouraging shared rides and further reducing the cost to those who either share rides already or who may be incentivized to do so.

One public sector respondent we spoke with mentioned that regardless of the predicted equity impacts of a particular project, if significant construction efforts (such as building a new lane) occur in disadvantaged areas, it is important for possible adverse health and equity impacts to be considered and mitigated for as part of the planning and environmental impact report (EIR) processes.

Some respondents discussed the potential positive social equity implications of congestion management strategies as well. A couple respondents voiced that although congestion pricing is a regressive charge and may be burdensome to low-income drivers, congested roads and highways lead to poor air quality within their vicinity, and households that live near freeways tend to be of lower incomes. As a result, congestion management strategies can increase equity by enhancing air quality near low-income communities, who also tend to drive less than higher income communities. Another respondent also highlighted the fact that the cost of driving is often embedded in property development which artificially lowers the cost of driving while increasing the cost of housing. This in turn can be unfair for low-income residents who may not drive at all. Another positive implication that was mentioned was regarding increased use of public transit and active transportation. This respondent mentioned that if congestion management strategies lead to increased use of active transportation (walking and biking), this can enhance roadway safety due to the "safety in numbers" effect. In general, respondents stated that the current system of unpriced roads is not equitable and that having an intentional focus on social equity from the beginning of any congestion mitigation program would help to produce equitable outcomes.

Current and Future Policy Developments

Although many congestion management strategies are still under development in the US, there are some current and upcoming policy developments related to equity considerations of these strategies. Interviewees mentioned a few existing policies and processes that aim to provide equity benefits related to congestion mitigation measures. These include: the LA Metro toll equity program as previously mentioned, co-creation workshops that help solicit and include disadvantaged community feedback into program development, bus fare maximums that must be less than the cost of an express lane, and fund allocation to projects in lower-income areas from congestion management program revenues.

In terms of future developments, policies and plans related to the approved but under development New York City congestion pricing were discussed by multiple interviewees. While the cordon fees will not go into effect until 2021, the exact details of the program are currently being examined. Some respondents we spoke with emphasized that revenue from such a program should be directed toward funding and improving high quality public transit options which could help foster equitable program outcomes. One interviewee mentioned that a portion of the planned New York City congestion fee will go toward funding public transit improvements in outer borough neighborhoods, in hopes of increasing accessibility in lower-income areas. Another respondent stated that while using congestion fee revenue for public transit is a good option, it does not help those who need to travel outside of transit service routes or who need to use their vehicle as part of their employment. This respondent stated that rebates or discounts should be incorporated into programs for low-income individuals who cannot replace driving with public transit.

Several public sector interviewees stated their belief that outreach and workshops are one of the most important pieces to achieving equitable outcomes, in order to receive and incorporate input directly from the communities that could be adversely impacted and to ensure that citizens are comfortable with the plan that is ultimately produced. Interviewees also mentioned that future policies related to congestion management strategies should consider subsidies or exemptions for disadvantaged users, although some mentioned that additional work is needed to determine the appropriate details of such efforts.

Key Metrics for Evaluation

Those that we spoke with mentioned a variety of metrics that should be measured and analyzed to adequately evaluate the equity impacts of various congestion management strategies. High quality and periodic data collection were mentioned by multiple interviewees as being critical to the accurate measurement of social equity impacts. A few public sector respondents emphasized the importance of measuring mode share and modal shift by income level and race/ethnicity, in order to evaluate equity impacts of a particular strategy. If use of a particular facility or program is balanced among a representative income distribution, then planners would be able to verify that certain equity goals are being met. With these data, planners could take into consideration who uses a particular facility and if the makeup of those that are benefiting has shifted over time. For example, by measuring mode share by income along a corridor being considered for congestion management measures, one could determine how many low-income drivers might be negatively affected versus how many low-income public transit users might be positively affected. Through longitudinal studies, modal shift can be analyzed to determine whether the effects of a particular strategy are being fairly distributed among different communities.

A baseline equity metric discussed by one respondent was the availability of transportation choices. This respondent stressed the need to identify whether there are alternatives to driving. This is an important factor to consider when planning any congestion pricing implementation where mode shift away from driving is a desired outcome. A lack of convenient and affordable alternatives can greatly impede modal shifts. Similarly, another respondent stated that one of the most important metrics to measure is the travel time difference between commuters using public transit and those using personal vehicles. Better equity within transportation systems would improve public transit such that travel times are better than or similar to commuting via personal vehicle. Research has shown that drivers often value travel time reliability over travel time, with reliability often valued higher during morning commutes and total travel time valued during evening commutes (Brent & Gross, 2018). Additionally, those with inflexible work schedules are more sensitive to changes in travel time reliability, and this may influence mode choice for these travelers more drastically (Bhat & Sardesai, 2006). Both the value of total time and travel time reliability should be considered when defining equity metrics between modes.

One respondent stated that it is important to measure change in congestion on both the priced highways or lanes, as well as on adjacent city streets. Their concern was whether a highway pricing program would divert traffic from highways to city streets. This may ultimately increase travel times on highways, but could simply divert the congestion and emissions problems elsewhere.

However, measuring behavioral change due to a particular congestion management implementation can be difficult. One public sector respondent stated that before and after surveys are ideal to assess modal shift and other behavior changes, but that recruiting the appropriate respondents can sometimes be tricky. Analyzing the use of a particular facility may be easier than assessing an entire cordon zone because the users may be easier to identify and reach out to. For example, one respondent mentioned a past express lane study that mailed surveys to drivers based on license plate camera detection. Surveys that target those who travel in a downtown area may be slightly more difficult to deploy, although not impossible. For any survey effort, measures must be taken to ensure disadvantaged populations are being reached in these types of assessments.

One respondent discussed the need for metrics around how discounts or exemptions are allocated. While some programs set income qualifications, thresholds may become more difficult to measure if considering other factors like race/ethnicity or household location. The interviewee mentioned that public transit accessibility metrics could possibly be used as part of determining qualifications for discounts or exemptions, with those in low accessibility areas receiving more subsidy than those in higher accessibility areas, for example. Additionally, one respondent expressed the need to quantify the use of discount programs, stating that this could measure whether information about the program was delivered properly and if it is indeed providing the benefits intended. Multiple interviewees emphasized the importance of involving stakeholders in the development of performance measures and metrics.

Gaps in Understanding and Next Steps

Current Gaps in Understanding

Most interviewees agreed that there are still many outstanding questions regarding the equity impacts of congestion management strategies. Although there have been some studies that recommend steps to ensuring equity throughout planning processes, there are very few studies that empirically assess the equity impacts of active congestion mitigation measures. This is partly due to the fact that congestion management programs are largely still under development in the US. Many respondents did not focus on the lack of empirical knowledge regarding the equity implications of congestion management strategies, and instead highlighted the fact that these implications are highly location dependent. One respondent stated that an important gap in understanding is the lack of city-level data analysis regarding the current trends of income levels and personal vehicle use. Some cities, such as New York, Seattle, and Portland, have performed analyses that can serve as examples for other cities when planning for congestion management strategies. In addition, some respondents claimed that there are gaps in knowledge around whether social equity programs decrease overall travel times as part of certain strategies. For example, there is little knowledge around whether subsidies for an express lane would increase or decrease overall throughput in the corridor.

One public sector respondent mentioned that the State Route 91 Express Lane project in southern California had some of the most robust evaluation since it is one of the oldest express lane projects in the state. A study from 2009 measured sociodemographics among express lane users over time and found that users are likely to be in their early 50s, male, and with some college education. The average annual household income of users was just over $100,000 in 2009, an increase compared to previous years (Insights Worldwide Research, 2009). Although this particular study assesses sociodemographics of facility users over time, it did not assess a particular program aimed at equity outcomes.

A couple public sector respondents mentioned that they would like to see statistics on the portion of people that qualify who take advantage of a particular discount program to determine how popular a program is and how effective the outreach has been. Additionally, the equity impacts of cordon and area pricing strategies will need to be carefully assessed as New York City and potentially more U.S. cities enact these types of strategies. Additional studies and analyses that gauge modal shift and reasons for using or not using a particular facility or program will be needed to fill these gaps in understanding.

Several respondents stated that a major gap in understanding from both planners and policy makers is the failure to recognize the inequity of the current transportation system, namely that of unpriced roads. There is also an understanding gap regarding the ability to differentiate between generally progressive policies and policies that can mitigate a particular negative impact. One respondent stated the importance of using revenue to specifically alleviate any harm caused by pricing programs. This may include discount and rebate programs to ensure that travel behavior change is distributed fairly among all income levels and racial backgrounds.

Recommendations for Further Research and Next Steps

The interviews concluded with a discussion of recommendations and next steps for further research that could address these gaps in understanding. Multiple public sector respondents believed that more work could be done in the near term to determine sociodemographic distributions and travel behavior motivations of existing users of congestion management facilities and programs. One interviewee claimed that reasons why different populations use particular facilities are not well understood, at present. For example, high- and low-income users may pay for express lanes for different reasons. For example, the SR-91 express lanes in Southern California are used by all income levels, a common trend of tolled facilities has led to the rejection of the "Lexus lane" concept. However, when the price of the SR-91 toll rose, moderate-income drivers reduced their travel, but the lowest income group did not (Income-Based Equity Impacts of Congestion Pricing, 2008). While more research is needed, it is possible that low-income drivers must make tradeoffs between meeting other time-constrained responsibilities and the relatively high monetary costs of priced lanes. Trip purpose and traveler motivations should be researched further to better understand potential equity implications. For programs that have not been implemented at scale in the US, like cordon pricing, a few interviewees claimed that those involved should look to international examples like London, Stockholm, and Singapore to better understand potential equity impacts of certain approaches.

A couple respondents claimed that lack of funding, especially for public transit services that could provide a good alternative to private vehicles, is a serious problem in the U.S. especially as compared to many European countries. Ultimately, appropriate levels of funding must be in place not only to implement congestion management strategies themselves, but also to enact equity programs and provide high quality public transit alternatives.

Supplementary Metrics for Equity Analysis

Although best practices for the process of examining equity impacts of congestion management strategies are still under development, our literature review and expert interviews uncovered a number of key metrics that should be collected and analyzed in order to assess equity impacts. We note that metrics collected may differ depending on the particular strategy being studied or the broader sociodemographic context. Additional and more detailed metrics may be necessary in some situations. However, this list aims to provide a baseline of metrics that researchers should consider compiling when analyzing the social equity impacts of congestion management strategies.

The first metric that should be examined is whether equity considerations and outreach were integrated into the planning process itself. This can be assessed by ensuring that community meetings are held in affected disadvantaged areas, communications through appropriate media outlets and in various languages are conducted, if necessary, and community-based organizations (CBOs) are active in planning process (Cohen and Hoffman 2019). Other than examining whether appropriate participants are brought to the planning table, there are also measurable metrics that should be collected and analyzed to determine equity outcomes and impacts. There are many ways to group equity metrics. For example, Caltrans (2010) divides transportation system equity performance measures by the: 1) equitable distribution of impacts on low-income, minority, disabled, youth, and elderly populations relative to impacts on population as a whole and 2) equitable distribution of access and mobility through comparison of travel times and costs by income groups and by minority and non-minority groups for work/school and other trips. For the purposes of this document, we use the STEPS framework to organize this list of metrics. These include before, during, and after implementation measurements of the following metrics:

Spatial Metrics

- Scale of people affected
  - Aggregate measures of households and travelers affected
  - Spatial distribution of households and travelers affected
- Spatial distribution of infrastructure projects
  - Mapping of congestion management projects in given spatial area
  - If applicable, identification of spatially overlapping projects (or planned projects) to determine possible synergistic effects

Temporal Metrics

- Travel time and reliability considerations
  - Changes in average travel times among different populations due to strategy implementation
  - Travel time comparison across driving, public transit, and other modes
  - Travel time reliability comparison across driving, public transit, and other modes
  - Number of jobs, schools, and healthcare facilities accessible by driving and public transit within key travel time thresholds

Economic Metrics

- Cost considerations
  - Changes in travel cost due to strategy implementation among different populations
  - Changes in percentage of household income spent on transportation among different populations due to strategy implementation
  - Discounts or subsidies, if applicable, for tolls or public transit alternatives
  - Cost comparison between driving, public transit, and other modes on the affected facility
- Funding allocation
  - How revenue from measure was spent and whether at least a portion was allocated with an equity focus

Physiological Metrics

- Disability considerations
  - List of mitigatory project measures to ensure disabled persons accessibility
  - Americans with Disabilities Act (ADA) facility features
- Health and safety considerations
  - Health and safety impacts including changes in particulate matter, changes in collisions, and bicycle and pedestrian safety

Social Metrics

- Sociodemographic factors
  - Sociodemographic distributions (e.g., age, gender, race/ethnicity, education, income) of those potentially affected by strategy implementation
  - Sociodemographic distributions of users of a particular facility
- Administration and outreach
  - Number of participants in equity programs and the total number that are eligible
  - Number of disadvantaged travelers reached through targeted marketing or outreach programs
  - Administration barriers addressed for unbanked users, transponder subsidies, etc.
  - Availability of materials in multiple languages

Other Metrics

  - Mode use and modal shift on affected facility(s) after implementation
  - Changes in property values in areas affected by strategy implementation

The above set of metrics represent a generalized set of data to gather in order to assess equity impacts at a baseline level. While there are likely additional metrics that could be used to measure equity outcomes of congestion management strategies, the list above provides a basic breakdown of metrics to consider collecting when assessing social equity effects.

Conclusion

The social equity impacts of congestion management strategies vary widely depending on the particular strategy, land-use and societal context, implementation details, and many other factors. Due to the myriad of considerations that can affect equity outcomes of congestion mitigation measures, impacts can be positive or negative for different populations. In addition, more empirical research is needed that examines the equity impacts of specific congestion management strategy implementations. Findings from this white paper clarify current knowledge and gaps in understanding through an in-depth literature review and a series of expert interviews.

We find that assessing the details of how congestion management strategies are implemented and who will ultimately benefit from installation are critically important for the success of a project in terms of equitable outcomes. Timely and regular outreach to the public and all stakeholders involved is key and must begin in the early planning stages. While we cover many different strategies that could reduce congestion, including parking policies, infrastructure changes, and shared mobility, pricing strategies were most often cited in the literature and among experts in discussing congestion mitigation measures. The current system of unpriced roads throughout most of the U.S. negatively impacts disadvantaged communities, as fuel taxes are generally perceived as regressive. While various forms of road pricing may be effective at reducing congestion and generating public-sector revenue, alternative transportation options, like public transit, must be available for congestion reduction and equity benefits to be realized. Spatial and economic barriers could be created due to certain types of road pricing, and lower-income populations could be adversely affected, if costs and travel times increase for those that commute long distances. If thoughtfully implemented, means-based pricing schemes could help mitigate some of these unintended negative equity impacts. As a growing number of cities, regions, and states across the U.S. consider and begin implementing congestion management strategies, high quality and periodic data collection will be critical to ensure the accurate measurement of social equity impacts.

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