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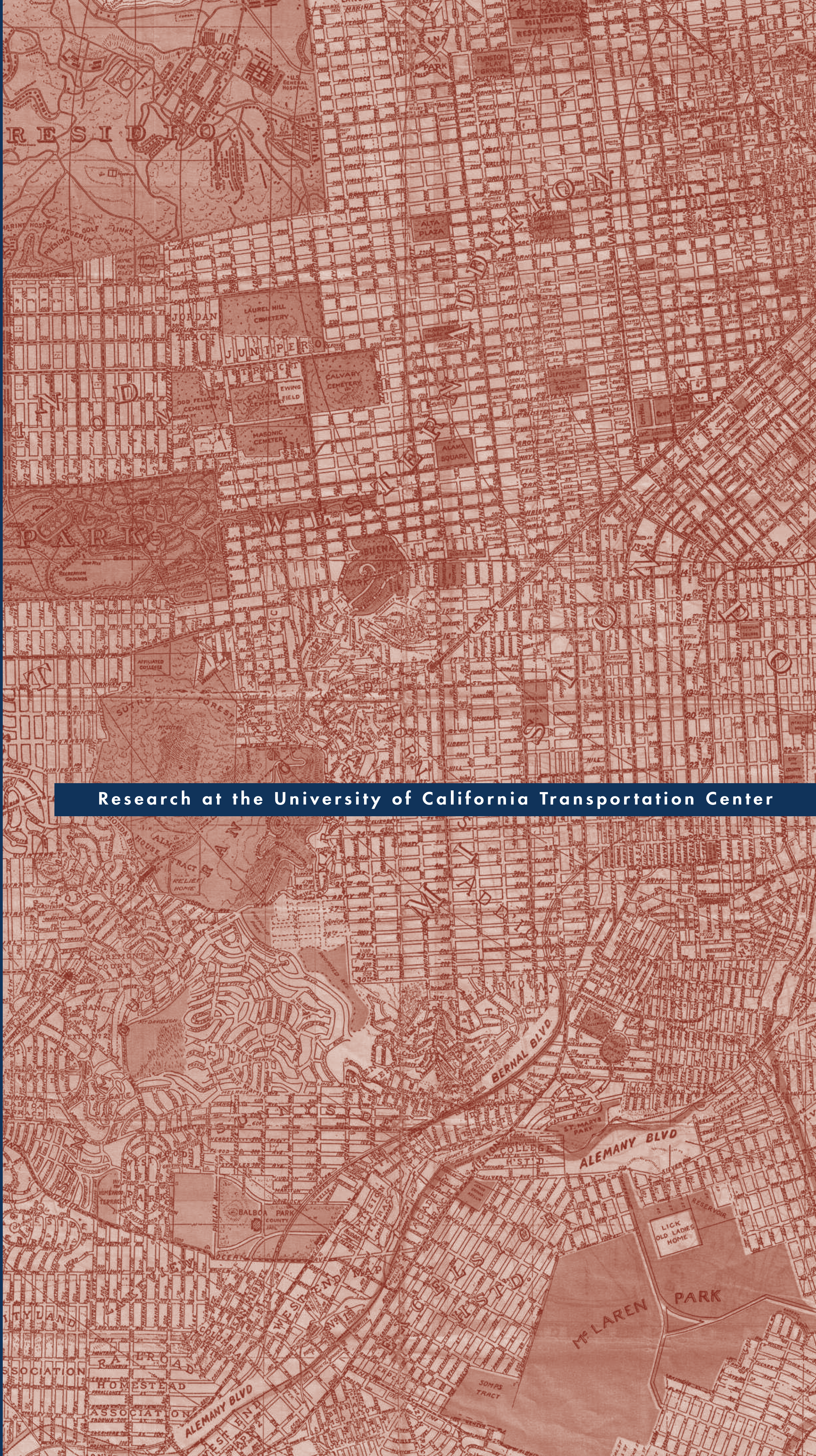

Research at the University of California Transportation Center

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ACCESS Magazine reports on research at the University of California Transportation Center. The goal is to translate academic research into readable prose that is useful for policymakers and practitioners. Articles in ACCESS are intended to catapult academic research into debates about public policy, and convert knowledge into action.

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"Writing—the hard part is making it look easy." E.B.White

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ACCESS is dedicated to the vital last step in transportation research: making information accessible. By connecting scholars with transportation planners and elected officials, *ACCESS* can catapult academic research into public debate and convert knowledge into action.

Donald Shoup
Editor of *ACCESS*

GOING MENTAL:
Everyday Travel and the Cognitive Map

ANDREW MONDSCHEIN, EVELYN BLUMENBERG, AND BRIAN D. TAYLOR

How do you get to work? Do you have a preferred route to your favorite restaurant? To the nearest hospital? To Disneyland? If you know—or think you know—the answers to any of these questions, then your cognitive map is at work. Humans rely on mental maps to store knowledge of places and routes in order to engage in travel and activities. People use their cognitive maps to decide where to go and how to get there. But accessibility research has largely ignored this essential aspect of travel behavior, despite the fact that a trip won't happen without prior knowledge of a destination and potential routes to it. As cities become larger and more dispersed, good information about opportunities and travel systems is more important than ever.

In our recent study, we found that cognitive maps and travel modes are linked in important ways that shape people's access to the many opportunities cities afford. We surveyed a diverse group of people in South Los Angeles and found significant differences between those who engaged in *cognitively-active* modes of travel, such as walking or driving, and those who engaged in *cognitively-passive* modes of travel, such as being a passenger in a car or on public transit. Those who engaged in cognitively-active modes of travel more accurately described the location of common destinations than did those who typically traveled by less cognitively demanding modes. Our results highlight the importance of providing meaningful wayfinding information to all travelers, especially those who rely on others for mobility. Our findings also highlight the critical role physical movement plays in cognitive development, and how travel experiences over the long-term can contribute to a better understanding of cities and access to their diverse destinations.

What to Remember about Cognitive Maps

Cognitive mapping research has long been a part of urban planning and design. Designer and planner Kevin Lynch introduced the concept in his 1960 book, *Image of the City*. Lynch showed that, as people interact with their surroundings, they interpret and encode them into mental maps. Lynch also established a typology of elements within a cognitive map that includes landmarks, routes, nodes, edges, and zones. This typology represents the city as an individual understands it. What psychologists call a cognitive map is not like the map one keeps in a glove compartment or views on a smartphone. Rather, it encompasses a wide variety of mental processes that humans use to store and recall spatial information. This, in turn, shapes how people live and travel. ➢

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A cognitive map encompasses a wide variety of mental processes that humans use to store and recall spatial information.

Lynch and subsequent researchers showed that cognitive maps are imperfect representations of the built environment and contain distortions that influence behavior. In addition, errors in cognitive maps vary not just from person to person but among groups as well. In the 1980s, Tridib Banerjee and William Baer found that low-income minorities had much more constrained perceptions of their surroundings than higher-income white residents of the same city. Similarly in the 1990s, Anastasia Loukaitou-Sideris and Liette Gilbert showed that different ethnicities utilized different elements of the built environment to describe the same downtown Los Angeles neighborhood.

While planners and designers use cognitive maps to show differences in how individuals perceive places, research rarely addresses why those differences exist and what to do about them. Psychologists and geographers describe cognitive maps as the end result of spatial learning, a developmental process that depends on navigation and wayfinding. In other words, how we travel significantly affects what we know about our surroundings. While physical and digital maps, and word of mouth, help extend our cognitive maps, the act of traveling has traditionally been the primary means by which we learn about destinations and how to get to them. This learning process requires one to actively wayfind in order to accrue knowledge about the surrounding environment. Wayfinding is such a central developmental function that its effect can be observed in the brain. For example, neurobiologists have found that London cab drivers develop distinctively large hippocampi by spending so much time navigating the mazelike streets of London, at least in the era prior to GPS. Though such findings demonstrate the importance of wayfinding in cognitive development, our understanding of how everyday travel modes affect spatial learning is quite limited.

On Foot, Behind the Wheel, or in the Passenger Seat

Given that travel experience plays such an important role in the spatial learning process, does traveling more by one mode, say by bus, shape a person's cognitive map differently than someone who usually travels by other means, like driving? If so, how and to what extent do these travel experiences shape people's knowledge of cities and accessibility? To test the hypothesis that different travel modes are associated with different types of knowledge about local and regional destinations, we surveyed two hundred individuals in South Los Angeles about how they usually travel and what they know about the location of and distance to key landmarks. We administered the survey in a shopping center near a transit station between Watts and Compton where residents are roughly half Latino and half African American. Respondents reported a wide range of modes for their daily travel, allowing us to compare spatial knowledge among modes such as driving, walking, and public transit.

Our initial results revealed a powerful pattern. For a wide range of spatial knowledge questions, responses were aligned by the level of wayfinding effort required of the traveler. Respondents who walked to the survey site exhibited spatial knowledge similar to auto drivers and less like auto passengers or transit users, despite the fact that walking and driving are dissimilar activities. Transit users were somewhat in between drivers and auto passengers on most questions, but more like passengers. For this research we defined travel modes based on the level of cognitively-active navigation required.

Here Be Dragons, and Job Opportunities

We observed significant spatial knowledge differences among cognitively-active and passive travelers, as well as for travelers who reported using a mix of active and passive modes [Table 1]. For example, when we asked respondents about the distance to Los Angeles City Hall, we expected they would have some idea, because it is readily accessible from our survey site by car and public transit. Absolute distance may be difficult to estimate if the respondent typically perceives travel in scales other than distance, such as in time or transfers (as transit users do). We therefore looked at other measures and controlled for a variety of factors known to influence travel, such as sex, ethnicity, employment status, and years spent living in the neighborhood. The absolute distance estimates showed an important result: cognitively-active travelers had significantly *more accurate* perceptions of distance than passive travelers. Mixed-mode travelers' results lay in between those of the active and passive travelers.

We also asked respondents to indicate which of two possible destinations they thought was closer in distance to the survey location. The destination pairs we used encompassed a wide range of employment, civic, shopping, and recreational destinations across the Los Angeles region. Again, active and passive travelers were different, with active travelers more likely to pick the closer of the two. These results build on the findings of labor researchers, suggesting that many job seekers lack information when seeking opportunities across a region. Active transportation may help overcome such deficits.

Finally, we looked at how spatial knowledge differences are embedded in the structure of the cognitive map. By asking respondents to describe their home and office or school locations in an open-ended way, we were able to capture the elements of the built environment that they found relevant to their everyday wayfinding and navigation. We compared cognitively-active and passive travelers by their relative reliance on landmarks, which past research has found to be the most rudimentary level of spatial knowledge. When asked to describe home locations, passive travelers were far more reliant on landmarks than active travelers, who were more likely to use streets and intersections. For work locations, active travelers had more success naming streets than passive travelers. Mixed-mode travelers' responses tend to resemble active travelers' in some instances and passive travelers' in other instances. ➢

TABLE 1

Differences in Spatial Knowledge among Active, Mixed, and Passive Travelers

SURVEY ITEM	MEASURE	RESPONSE BY LEVEL OF COGNITIVE EFFORT		
		Active	Mixed	Passive
"How far away is Los Angeles City Hall?"	Variability in responses for each group (standard deviations, higher number=less overall accuracy)	7.8	11.8	23.4
"Which is closer, Location A or Location B?"	Percentage of correct responses for five landmark pairs	60%	54%	52%
"Describe the location of your home."	Percentage using landmarks	12%	10%	21%
	Percentage using streets	86%	85%	82%
"Describe the location of your workplace."	Percentage using landmarks	30%	28%	29%
	Percentage using streets	80%	63%	66%

Implications, Short-Term and Long-Term

The ways that people travel affect their cognitive maps, resulting in significantly different knowledge of destinations and opportunities. The mental maps of cognitively-active travelers, like drivers and walkers, are similar, as are the maps of cognitively-passive travelers, who are generally car passengers and transit riders. Beyond being different, the maps of passive travelers are less accurate and more rudimentary than those of active travelers. Since our study, other scholars have found similar results elsewhere in the world. For example, in the Netherlands, transportation researchers found that college students who walked and biked had better knowledge of their campus and town than those who relied on public transportation.

Differences in cognitive maps have important implications for accessibility, transportation planning, and public policy. Sparse and inaccurate information about one's city is likely to reduce activity and travel in the empty spaces of the mental map. In reality, those empty spaces may be filled with jobs, services, or recreation opportunities. Even if passive travelling allows one to do other things, like texting a friend or relaxing, those with incomplete mental maps lose out on the opportunities from a more complete cognitive map. All else being equal, regular transit users and those who rely on others for mobility have more empty spaces in their mental maps than do drivers and walkers.

Our findings for Los Angeles do not diminish the importance of public transit. In transit-rich cities, it may be that transit and walking reveal more potential activities, while drivers miss out. For all cities, however, these findings suggest that providing compensatory information for passive travelers may be critical to building their mental maps. Opportunity and wayfinding information can be provided to transit users in multiple formats to reach a diverse populace with different levels of spatial understanding. In some ways, new information and communication technologies create unprecedented opportunities to provide better information about transit systems the cities they traverse. However, transit agencies and others focused on broad-based mobility need to be sure that these technologies are themselves accessible and provide relevant information to the entire urban population, not just to technophiles or transit veterans.

Our findings suggest that researchers and transportation planners need to make a greater effort to understand how transportation systems bring individuals into physical *and* cognitive contact with the city and its destinations. We looked at cognitive maps at a single point in time, but developing the knowledge and skills to engage with one's surroundings is a lifelong process. Does reliance on passive travel begin in childhood? Are children chauffeured to school today less spatially knowledgeable than their parents who rode bicycles to school? Can people learn to become better explorers, engaging more with their cities and the opportunities within them? Many of these questions underlie planners' concerns regarding livability and well-being, but so far we do not have theories and evidence to direct us to an optimum mobility system. Developing a better cognitive map may be one reason to encourage active travel and exploration, not just by car but by foot and bicycle as well.

A potential short-term solution for information deficits lies with technology, but we must also ask what effects technology might have in the long term on cognitive maps and spatial knowledge. Will information so easily acquired persist in the cognitive map? What if the digital information is wrong, incomplete, or biased? There may be tradeoffs between short-term benefits of smartphone navigation and long-term deficits of spatial knowledge. Regardless, cognitive mapping and spatial knowledge have been missing from our analyses of travel behavior and from transportation planning for accessibility. Cognitive mapping methods and concepts have evolved significantly since Lynch's study. They can help shed light not just on differences among travel modes, but also on a wide range of transportation issues that encompass what a person knows about destinations, routes, and the surrounding city. ◆

This article is adapted from "Accessibility and Cognition: The Effect of Transport Mode on Spatial Knowledge," originally published in *Urban Studies*.

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Driving Down Diesel Emissions

ROBERT HARLEY

It's official: exposure to diesel exhaust harms human health. In June 2012, the World Health Organization's International Agency for Research on Cancer (IARC) updated its rankings, shifting diesel exhaust from a probable to a known carcinogen. In addition to being a human carcinogen, diesel emissions contribute to both smog and climate change. Although gasoline engines remain the main on-road source of carbon dioxide (CO_2) emissions, diesel engines are now the dominant source of nitrogen oxides (NO_x) and particulate matter (PM) emissions [Figure 1].

While manufacturers now equip new diesel engines with advanced emission controls, many older engines will remain in service for at least another decade, limiting progress in reducing emissions. Continuing its longstanding role as a laboratory for testing innovative pollution-control strategies, California has recently mandated an accelerated schedule for retrofitting and replacing older diesel engines.

This article assesses the contribution of diesel engines to transportation-related air pollution and describes new emission-control technologies. Using recent fieldwork, we evaluate the effectiveness of an accelerated emission-control program for drayage trucks serving the Port of Oakland (drayage is the transport of goods over short distances). The results of early actions to reduce diesel emissions at the Port provide a preview of coming statewide efforts.

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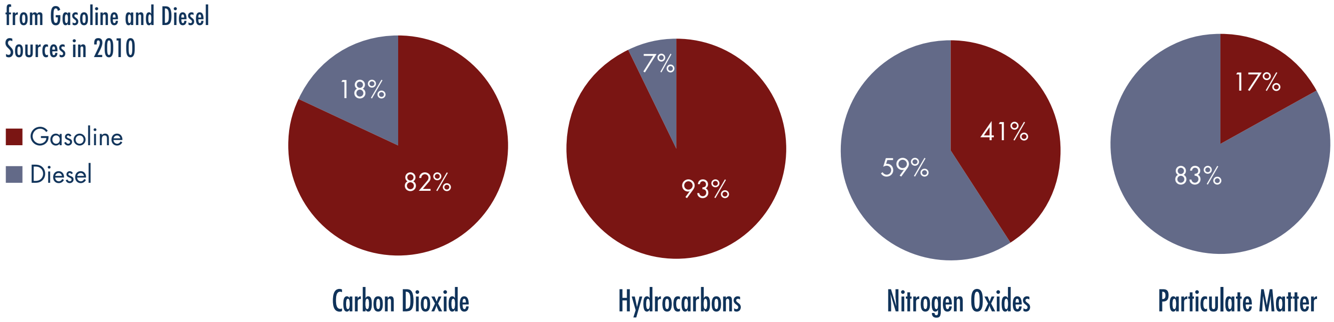
FIGURE 1

On-Road Pollution Emissions from Gasoline and Diesel Sources in 2010



Diesel Emissions and Controls: A Brief History

Over the last two decades, engine manufacturers have attempted to reduce PM and NO_x emissions from new diesel engines to comply with state and federal regulations [Figure 2]. Since 1990, engine manufacturers have reduced diesel PM emissions significantly. Initial efforts to control NO_x emissions, however, required adjustments to fuel injection timing, which actually increased fuel consumption. In response, many engine manufacturers in the 1990s programmed engines to meet NO_x emission standards during laboratory testing, but later reprogrammed them to increase fuel economy on the road. As a result, the expected reductions in diesel NO_x never materialized—a major setback for air pollution control efforts.

The most stringent standards for diesel emissions took effect in 2007, and vehicle operators now typically equip trucks with filters to control PM and catalytic converters to reduce NO_x. Particle filters installed as replacement mufflers can serve as a retrofit for older heavy-duty trucks still in service. In contrast, diesel catalytic converters are generally impractical for retrofitting on older engines, and they also require the periodic addition of diesel exhaust fluid (DEF), a NO_x-reducing reagent that costs about $500 to $1,000 per year. While truck drivers appreciate saving fuel, they may also resent paying for DEF.

Another challenge to diesel emission control efforts has been the slow turnover rate of the heavy-duty truck fleet. In response, the California Air Resources Board adopted rules that require accelerated retrofitting or replacement of in-use engines over the next decade. This approach goes beyond national emissions standards that apply only to new engines. The state is focusing its early actions on drayage trucks serving ports and rail yards; by 2013, all these trucks must meet the stringent 2007 federal PM emission standards shown in Figure 2. ➢

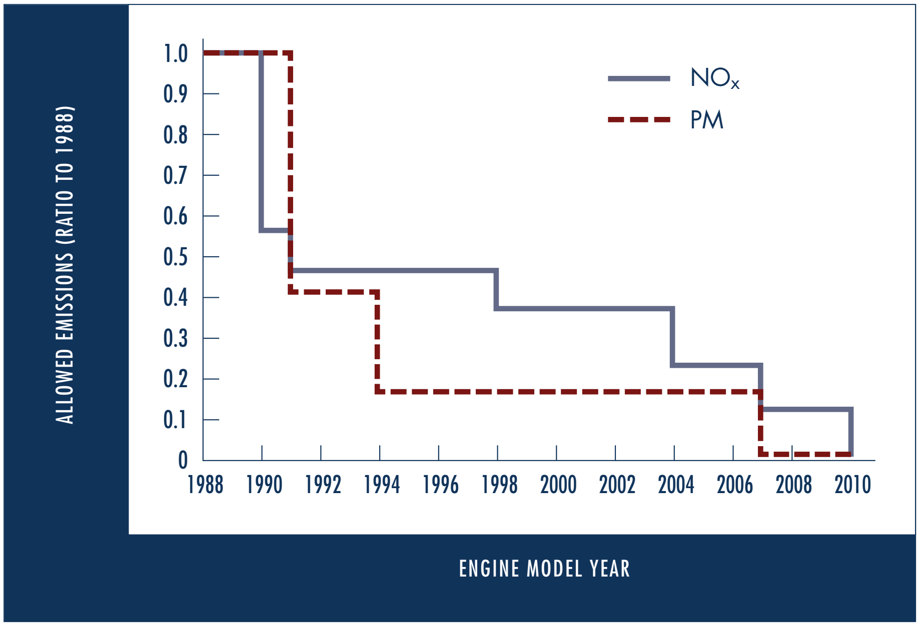


FIGURE 2

US Standards for Exhaust Emissions from New Diesel Truck Engines

Effects of Early Actions at the Port of Oakland

With support from the Bay Area Air Quality Management District, our team assessed emissions from hundreds of port trucks in two field-sampling campaigns during November 2009 and June 2010. To measure the concentrations of CO_2, NO_x, and PM, we set up a mobile laboratory on a bridge near the Port of Oakland. We used the data to calculate pollution emissions from individual trucks driving by.

After our first sampling, the Port of Oakland banned the oldest (pre-1994) port trucks and required operators of middle-age (1994–2003) trucks to either retrofit their vehicles with diesel particle filters or buy newer trucks. Grant programs helped many truckers pay for particle filter retrofits, funded by the Air Resources Board, the Bay Area Air Quality Management District, the Environmental Protection Agency, and the Port of Oakland. Some operators, however, chose to buy newer trucks instead of retrofitting older equipment.

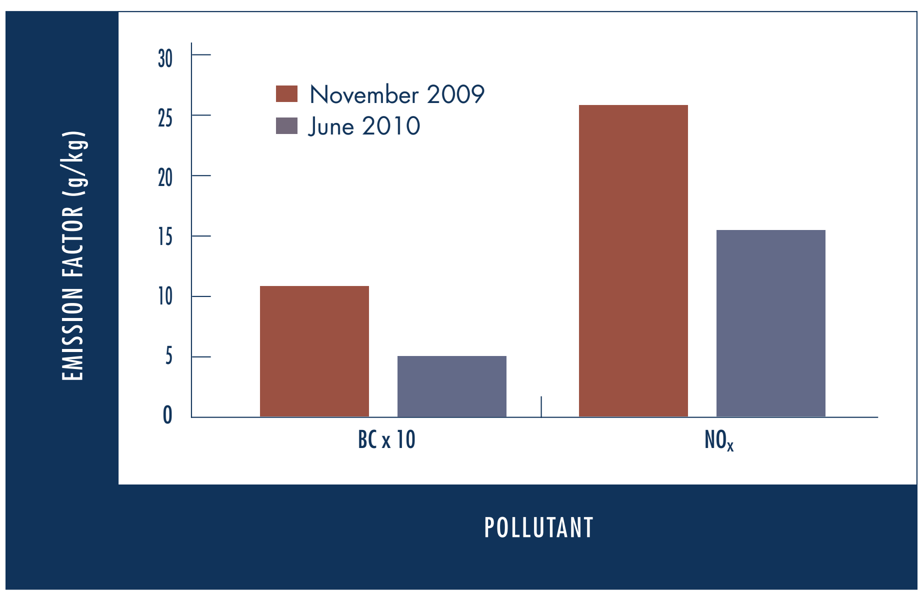
Figure 3 shows that, in less than one year, emission rates from port trucks decreased by about 54 percent for black carbon (BC) particles and about 41 percent for NO_x. Without enforced turnover of the truck fleet, it would have taken about ten years to achieve the same emissions reductions.

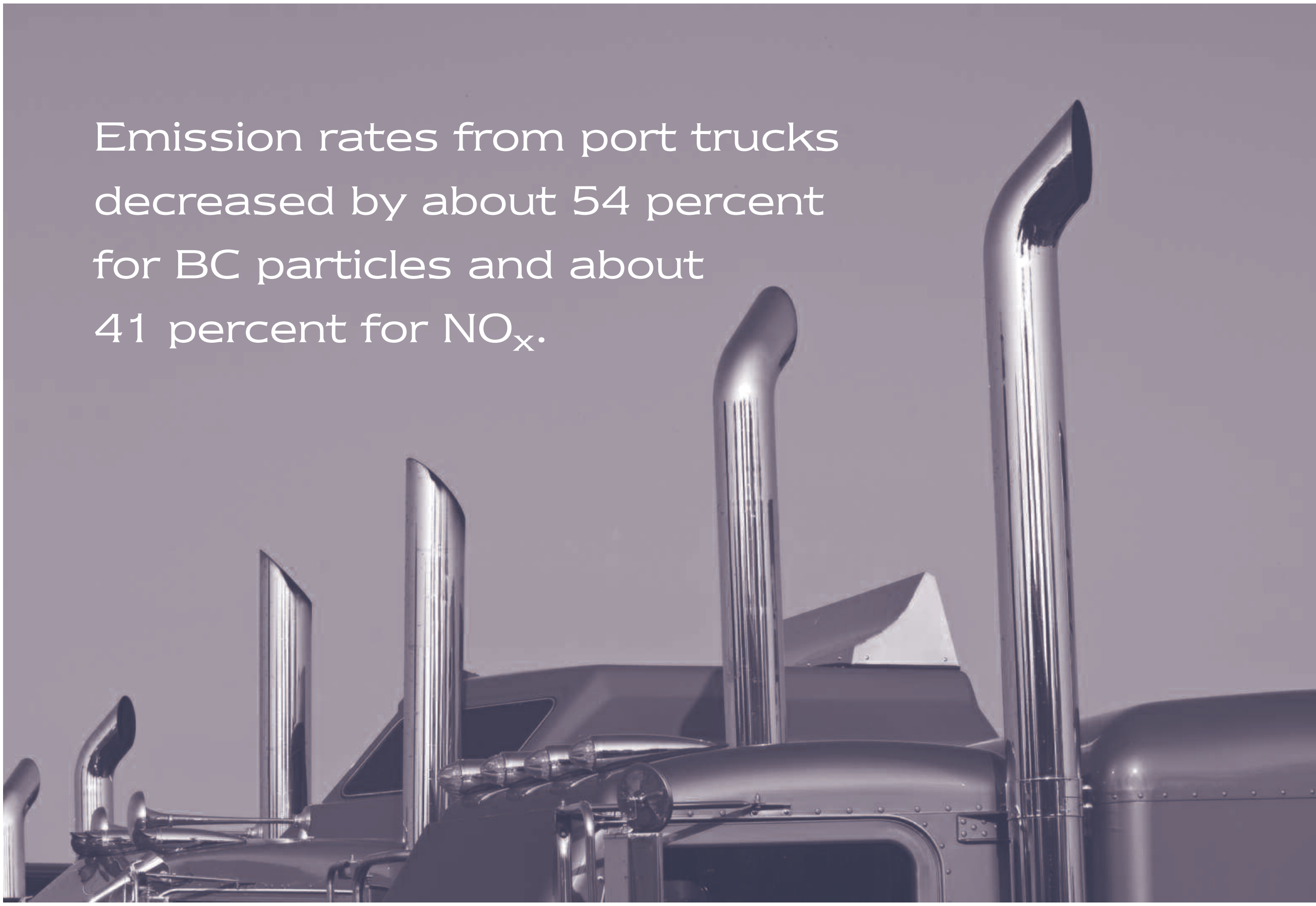
The large reduction of NO_x surprised us because we expected diesel particle filters to reduce PM emissions, not NO_x emissions. After examining the shift in age distribution of trucks between sampling periods, however, we saw the importance of replacing the oldest and middle-aged trucks with newer, cleaner ones. This shift was the main driver for reducing NO_x and also contributed to reducing PM. Retrofits of particle filters on older trucks also helped to reduce PM emissions.

These actions to clean up port truck emissions in Oakland serve as a case study for future requirements that will apply to diesel trucks statewide, including out-of-state trucks that operate in California.

FIGURE 3

Emission Rates from Heavy-Duty Diesel Trucks at the Port of Oakland (grams of emissions per kilogram of diesel fuel burned)





Emission rates from port trucks decreased by about 54 percent for BC particles and about 41 percent for NO_x.

Moving Forward with Cleaner Trucks

Truck owners will face decisions about whether to retrofit or replace equipment, depending on engine model year and gross vehicle weight. By 2023, the state will require nearly all diesel trucks above 14,000 pounds gross vehicle weight to be 2010 or newer models. We expect to see at least a 50 percent reduction in on-road diesel PM and NO_x emissions in California.

Although other factors are involved, California's diesel control program is likely to increase sales of new and used heavy-duty trucks over the coming decade. For example, at the Port of Los Angeles, wholesale replacement of the drayage truck fleet occurred over a short time period. Because of this example and others, we will likely see a short-term increase in demand for used trucks with 2007–2009 engines equipped with diesel particle filters, and a longer-term increase in prices for used trucks with 2010 and newer engines. We also expect to see increased sales of new trucks in California and an increase in imports of used trucks, especially 2010 and newer models, from other states. ➢

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In contrast, diesel control rules will likely increase exports of older trucks from California to other states or other countries. Federal and state governments should consider adopting measures to encourage scrapping rather than exporting the oldest and most polluting trucks, which simply moves the negative health and environmental impacts to another location. They should also consider their own programs that require accelerated truck retrofit or replacement, removing the incentive for California trucking companies to export their old equipment.

As trucking companies feel squeezed by the added cost of particle filters and catalytic converters, gasoline and natural gas may begin to compete with diesel. Engines running on gasoline and natural gas can meet emission standards using less expensive catalytic converters without an exhaust particle filter. The reduction in fuel economy caused by switching from diesel to gasoline may not be large enough to matter, especially for medium-sized trucks that drive fewer miles per year. If the availability of natural gas and fueling infrastructure increases, natural gas may also compete effectively with diesel in terms of fuel cost per mile.

Our measurements at the Port of Oakland indicate that banning the oldest trucks, requiring particle filters on middle-age trucks, and encouraging purchases of newer trucks roughly *halved* PM and NO_x emission rates from drayage. Because of registration requirements and port checkpoints, these regulations were relatively easy to implement and enforce. To ensure similar success at the statewide level, officials must vigorously enforce the more broadly targeted diesel emission control rules.

The durability of diesel particle filter systems is another key factor that will affect future emissions and air quality. To date, the number of heavy-duty trucks that have 2010 or newer engines is relatively small. We will need to track the durability and reliability over the next 10 to 20 years to ensure the real-world effectiveness of the NO_x control equipment installed on these engines. Ongoing evaluation is critical if we are to improve air quality in California, the US, and worldwide. ◆

This article is adapted from "Effects of Diesel Particle Filter Retrofits and Accelerated Fleet Turnover on Drayage Truck Emissions at the Port of Oakland," originally published in *Environmental Science & Technology*.

From Fuel Taxes to Mileage Fees

PAUL SORENSEN

For much of the past century, federal and state taxes on gasoline and diesel have provided the majority of funding for US highway construction and maintenance. Fuel taxes perform well in this role: they distribute the tax burden among drivers in rough proportion to their use of the road network, are inexpensive to administer, and offer a modest incentive to buy and drive fuel-efficient vehicles.

Because the federal government and most states tax fuel on a cents-per-gallon basis, the tax rates must be periodically hiked to keep pace with inflation and increased fuel economy, a difficult political task in recent decades. Consequently, fuel tax rates have stagnated, leading to reductions in real (inflation-adjusted) revenue per vehicle mile of travel (VMT).

More stringent fuel economy standards and increased use of alternative fuels are expected to accelerate the erosion of fuel tax revenue in the coming years. Figure 1 traces the trajectory of federal fuel tax revenue if current tax rates, last increased in the early 1990s, are left unchanged through 2035. In short, nominal fuel tax revenue (unadjusted for inflation) will flatten, real fuel tax revenue will decline by over 40 percent, and real fuel tax revenue per VMT will decline by almost 60 percent.

This same concern applies to state fuel taxes. Together, federal and state fuel taxes currently provide around $70 billion in highway funding each year, accounting for about half of the nation's budget for road expenditures. A 40 percent decline in real revenue thus translates to tens of billions of dollars per year. ➢

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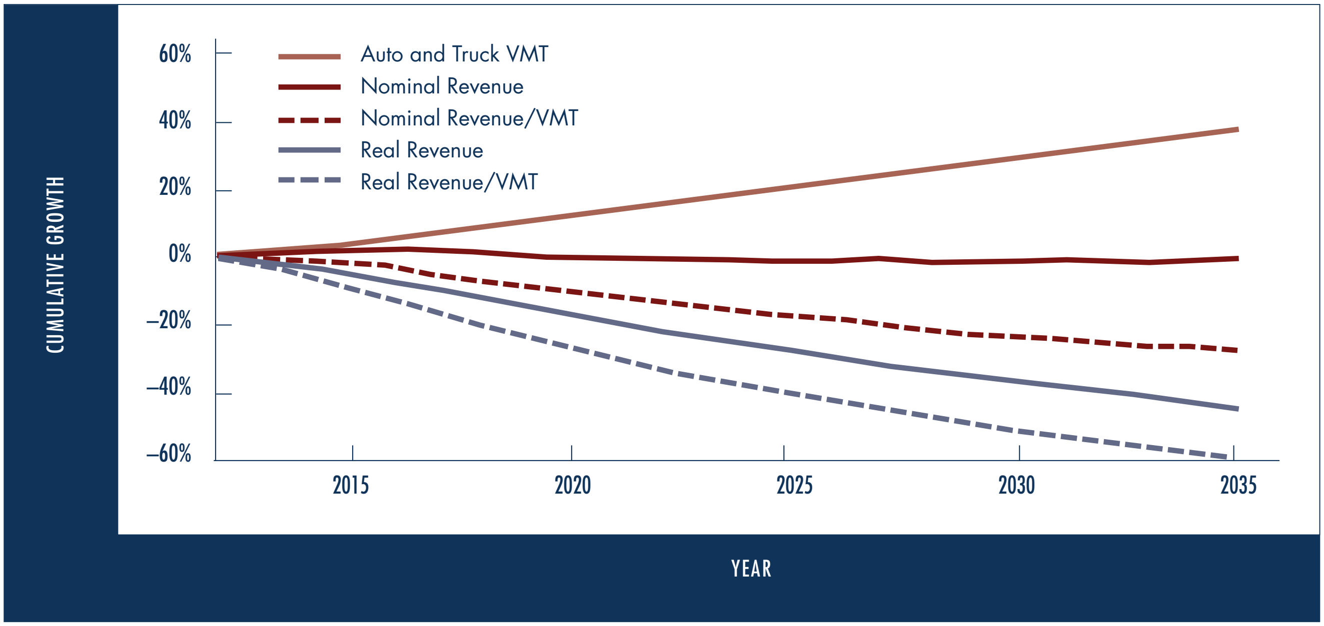

Based on the Energy Information Administration's 2012 *Annual Energy Outlook*, with assumed inflation of 2.5 percent per year.

FIGURE 1

Potential Erosion of Federal Fuel Tax Revenue

The Allure of Mileage Fees

Current and projected revenue challenges have prompted growing interest in a transition from taxing fuel to taxing miles of travel. Mileage fees, also known as mileage-based user fees or VMT fees, promise more stable revenue than fuel taxes and allocate the tax burden in proportion to travel with greater precision. Tied to travel rather than fuel consumption, the revenue stream is immune to changes in fuel economy or even fuel type. Mileage fees must still be increased periodically to account for inflation, but the increases need not be as frequent or as large as with fuel taxes. Alternatively, mileage fees can be indexed for inflation when the program is first established.

Fuel taxes can be indexed as well, though the indexing should account for both inflation and fuel economy improvements. With much more stringent federal fuel economy standards planned in the coming years, however, the distribution of the fuel-tax burden will become increasingly regressive; owners of newer vehicles with higher fuel economy will pay much less per mile, while owners of older and less efficient vehicles will pay more. The introduction of alternative fuels further complicates matters. Already, electric vehicles and natural gas vehicles can be recharged or refueled at home, and the same may be true of hydrogen fuel-cell vehicles at some point. Unless the fuel-tax collection regime can be extended to cover at-home refueling, a far more complicated task than collecting gasoline and diesel taxes at the wholesale level, such vehicles will be subject to no fuel taxes whatsoever.

In addition to more stable revenue and more precise allocation of the tax burden in proportion to travel, a mileage-fee system can be designed to provide a range of compelling advantages.

Value-added motorist services. One option for implementing mileage fees involves the use of in-vehicle devices with GPS and wireless communications. This equipment can also host a range of apps offering drivers greater convenience, safety, and opportunities to

save money. Obvious examples include pay-as-you-drive insurance, automated payment of parking fees and tolls, real-time routing assistance, and alerts to safety hazards.

Better data for planning and operations. A system of mileage fees can also generate a steady stream of detailed (and anonymized) travel data, including traffic volumes and speed across all links of the network. Transportation departments can use these data to manage the transportation system in real time and to allocate additional investments where they are most needed.

Greater efficiency. Per-mile fees can be structured to vary according to time, location, and vehicle emissions class and weight, incentivizing travel decisions and vehicle choices that reduce traffic congestion, air pollution, and excessive road wear. For many observers, this represents the most persuasive argument for shifting to mileage fees. One form of variable fees—congestion pricing—has proven highly effective at reducing congestion. At present, however, congestion pricing applications involve significant technology development efforts and are limited to specific facilities or to small urban cores surrounded by a cordon ring of enforcement gantries. Under a mileage-fee system, with no additional expense, congestion pricing can be easily extended to cover all congested routes within a region, with the per-mile price potentially varying by both time and specific route to optimize overall traffic flow.

That said, the ability to implement congestion pricing, or any other form of variable fee, is not generally viewed as a selling point for building public acceptance. Most planning efforts have therefore assumed that a mileage-fee system will begin with a flat per-mile rate. Once the system is in place, local jurisdictions will then have the option of altering the fee structure to implement various forms of congestion tolls or other forms of pricing.

Other revenue mechanisms such as sales taxes, general fund transfers, fuel tax increases, or facility tolls are also viable for increasing funding for transportation. Only mileage fees, however, offer all of the benefits outlined above. ➢

Increasing Interest in Mileage Fees

Mileage fees have attracted great interest abroad, leading to studies, trials, and fully implemented programs. Several European countries have established weight-distance tolls for commercial trucks, a variation on mileage fees that incorporates truck weight or axle weight in the fee structure. New Zealand instituted mileage fees for diesel-fueled trucks and passenger cars. The Netherlands conducted extensive planning for a kilometer-based road use charge that would apply to all vehicles, though a change in government stalled implementation.

Though mileage fees have yet to be implemented in the United States, interest is accelerating. Trials have been conducted in Oregon, Minnesota, and the Puget Sound region, while the University of Iowa staged trials involving participants in 12 cities across the country. Colorado, Nevada, Texas, Washington, and member states in the I-95 Corridor Coalition have studied the concept or are considering their own trials. New York City's planned DriveSmart initiative envisions the deployment of sophisticated in-vehicle equipment that would initially focus on value-added services and could later be used to levy mileage fees. Oregon and New York have also conducted trials or studies looking at the automation of existing weight-distance truck tolls.

Just as Oregon was the first state to levy motor fuel taxes to fund highways in the early 20th century, it is now poised to lead the nation in implementing mileage fees. The Oregon Department of Transportation recently tested a fully-functional mileage-fee system in late 2012. Based on the results, state legislators passed legislation in the summer of 2013 that will allow up to 5,000 Oregon drivers, on a voluntary basis, to pay a 1.5 cents per-mile fee in place of the state's 30 cents per-gallon fuel tax beginning in 2015. If successful, the switch to mileage fees may eventually become mandatory for all vehicles.

Lessons from the Front Lines

Programs in Europe and New Zealand demonstrate the technical feasibility of mileage-based taxation. Evidence from these programs suggests that drivers will modify their travel choices in response to the incentives in the per-mile pricing structure. In the German TollCollect program, for example, the newest and least polluting trucks qualify for a 50 percent discount on the per-kilometer rate. This has led to an extremely rapid turnover among truck fleets.

At the same time, experience from recent US trials make it clear that mileage fees involve a range of challenges and uncertainties:

System requirements. Policymakers must decide what functions mileage fee systems should support, such as varying fees by location and time of travel, providing value added motorist services, or offering various forms of privacy protection.

Technical design. A mileage-fee system must provide mechanisms to meter mileage, collect fees, prevent evasion, and protect privacy. There are numerous technical design options, each with different functionalities, levels of privacy protection, and costs of implementation and administration. For example, mileage fees based on annual odometer readings eliminate the cost of in-vehicle equipment and reduce privacy concerns, but might entail higher labor costs to conduct the readings. Mileage fees based on sophisticated in-vehicle equipment can enable location-based mobility apps, but may engender privacy concerns and increase the system's capital costs. If different states choose different technical options, the systems should be interoperable—that is, able to collect and apportion fees for interstate travel.

Institutional structure. Appropriate institutional roles for government agencies and the private sector also need to be defined. Should the private sector be viewed solely as the source for technology procurement or should it also have a role in managing accounts and collecting revenue on behalf of the government?

The Core Challenges of Cost and Public Acceptance

Many of the issues and uncertainties above can be resolved with thoughtful planning and engineering. Two fundamental obstacles, however, bring into question the wisdom and viability of replacing fuel taxes with mileage fees: cost and public acceptance.

Fuel taxes are collected from fewer than 2,000 fuel wholesalers around the country and passed along to consumers in the retail price of gasoline and diesel. They are cheap to administer, typically costing about 1 percent of revenue. Mileage fees, by contrast, involve collecting taxes from millions of drivers, a much more complicated endeavor. This raises a legitimate concern that the advantages of mileage fees will be outweighed by the increased cost of collecting them. Recent evidence and modeling suggests that costs as a share of revenue could be around 5 or 6 percent, though earlier estimates have been even higher. Yet even with higher administrative costs, mileage fees are likely to yield far more net revenue over the coming decades than fuel taxes, given shifts toward higher fuel economy and alternative fuels.

Polls, however, indicate that current support for the concept of mileage fees is dismal. In fairness, other revenue options such as increasing fuel taxes also poll poorly. But mileage fees pose additional public acceptance challenges, such as fears of privacy invasion and low public trust in government.

When people hear about mileage fees, especially in conjunction with GPS-based metering, many think, "The government will be able to track where and when I drive, and I don't like it." New taxes and fees of any type are always a difficult political sell and it will be critical to assure the public that mileage-metering devices will be fair and secure. ➢

Drivers will modify their travel choices in response to the incentives in the per-mile pricing structure.

Addressing Public Concerns

Planners and elected officials interested in mileage fees are well aware of the significant hurdles posed by high system costs and low public support, and have responded with considerable ingenuity. Earlier trials focused on demonstrating the technical feasibility of alternate mileage-fee implementation mechanisms. More recent efforts, in contrast, have explored innovative strategies aimed at overcoming cost and public acceptance challenges. Taking stock of recent trials and initiatives in the US, several broad themes emerge.

Proactively building support. Support for mileage fees appears to rise with greater familiarity and understanding. In the University of Iowa trials, the share of participants who viewed mileage fees favorably increased from 40 percent before the trials to 70 percent afterwards. Recent polling by the Mineta Transportation Institute indicates that support for mileage fees also increases when voters understand how the revenue will be allocated.

Building on the recognition that greater familiarity with mileage fees often translates to greater support, both Oregon and Minnesota included elected officials as participants in their recent mileage-fee trials. Another way to build support is to convene a diverse stakeholder taskforce to identify concerns and provide input on design principles and policy decisions. Minnesota, for example, included a member of the American Civil Liberties Union on its exploratory mileage-fee taskforce to help ensure that privacy concerns are properly addressed.

Providing drivers with choices. Recognizing that personal preferences vary, mileage-fee planners in Oregon have designed the system to allow drivers to choose among different options for metering mileage, paying fees, and protecting privacy. Drivers with strong privacy concerns, for example, can opt for a simple metering device that tallies only total mileage. Other drivers may prefer a GPS-equipped device that supports a greater range of value-added services and exempts fees for miles traveled out of state or on private roads. For those who remain steadfastly opposed to mileage fees, however metered, Oregon plans to provide drivers with an additional option of paying a fixed annual fee instead of paying by the mile. To avoid adverse selection, the fixed fee assumes high annual mileage.

The Minnesota trials also provided participants with the option of metering total miles based on odometer readings or miles by time and location using a GPS-equipped smartphone app. Drivers using the smartphone app qualified for discounts on the per-mile fees for travel in rural areas or during off-peak hours, and paid no fees for out-of-state travel.

Fostering private sector competition and ingenuity. There are also several potential advantages to designing a system under which multiple firms are licensed to collect fees and provide metering devices. Much like smart phones, in-vehicle metering devices can support a range of mobility apps. Some of these, such as pay-as-you-drive insurance or automated parking fee payment, create additional revenue flowing through the system.

Competition among firms can drive down costs and stimulate innovation in value-added services, while the revenue from additional paid services will reduce the cost borne by the public sector for collecting mileage fees.

Because many firms already provide in-vehicle equipment that offers all manner of motorist services, it isn't necessary to reinvent the wheel. Oregon has developed open standards so that firms can modify existing devices and have them certified for metering and assessing mileage fees.

Starting small. Switching from fuel taxes to mileage fees will be enormously challenging, so recent planning efforts have started small and moved slowly. Oregon, for example, initially planned to levy mileage fees for any vehicle rated at 55 miles per gallon equivalent or higher, most of which are battery and plug-in hybrid vehicles. Texas also considered legislation to levy mileage fees on electric vehicles. Based on focus-group research, the notion that all drivers should pay their fair share resonates, and there aren't enough electric vehicle owners to mount strong opposition. Some are concerned that this approach will slow sales of electric vehicles, but current government tax credits and subsidies for electric vehicle purchases greatly exceed what one might expect to pay in mileage fees.

Another approach is to establish a system in which drivers can voluntarily switch to mileage fees. The intent, however, is not to increase revenue in the near term; rather, it is to demonstrate through the engagement of *willing* drivers that the system works before transitioning to mileage fees for all vehicles. Oregon adopted this approach, and New York City's planned DriveSmart initiative embodies this concept as well.

Developing a multi-jurisdictional system. A final idea being pursued in Oregon, and also explored by the I-95 Corridor coalition and in the University of Iowa trials, is to create a system that can accommodate multi-jurisdictional mileage fees. This enables either a multi-state or a national system, and it also allows localities to levy their own fees on top of state or federal fees. The net effect is to apportion fixed system costs across a larger number of drivers and increase total revenue flowing through the system, in turn reducing administrative costs as a share of revenue.

What Comes Next?

The prospect of a broad transition to mileage fees in the United States remains uncertain. Many of the efforts described here are still ongoing, and it is too early to evaluate their cost and effectiveness. As fuel tax revenue continues to decline, however, interest in a more stable source of highway funding is increasing. With the shortfalls in transportation funding, the success of distance-based road pricing in other countries, and the advances in supporting technologies, future prospects for mileage fees are surely greater than what current public opinion polls suggest. ◆

This article is adapted from *Mileage-Based User Fees for Transportation Funding: A Primer for State and Local Decisionmakers*, originally published by the RAND Corporation.

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SF*park*: Pricing Parking by Demand

GREGORY PIERCE AND DONALD SHOUP

In 2011, San Francisco adopted the biggest price reform for on-street parking since the invention of the parking meter in 1935. Most cities' parking meters charge the same price all day, and some cities charge the same price everywhere. San Francisco's meters, however, now vary the price of curb parking by location and time of day.

SF*park*, San Francisco's new pricing program, aims to solve the problems created by charging too much or too little for curb parking. If the price is too high and many curb spaces remain open, nearby stores lose customers, employees lose jobs, and governments lose tax revenue. If the price is too low and no curb spaces are open, drivers who cruise to find an open space waste time and fuel, congest traffic, and pollute the air.

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In seven pilot zones, San Francisco installed sensors that report the occupancy of each curb space on every block, and parking meters that charge variable prices according to the time of day. In response to the observed occupancy rates, the city adjusts parking prices about every two months.

Consider the prices of curb parking on a weekday at Fisherman's Wharf, a tourist and retail destination [Figure 1]. Before SF*park* began in August 2011, the price was $3 an hour at all times. Now each block has different prices during three periods of the day—before noon, from noon to 3 pm, and after 3 pm. By May 2012, prices on almost every block had decreased for the period before noon and increased between noon and 3 pm. Most prices after 3 pm were lower than during mid-day, but higher than in the morning. ➢

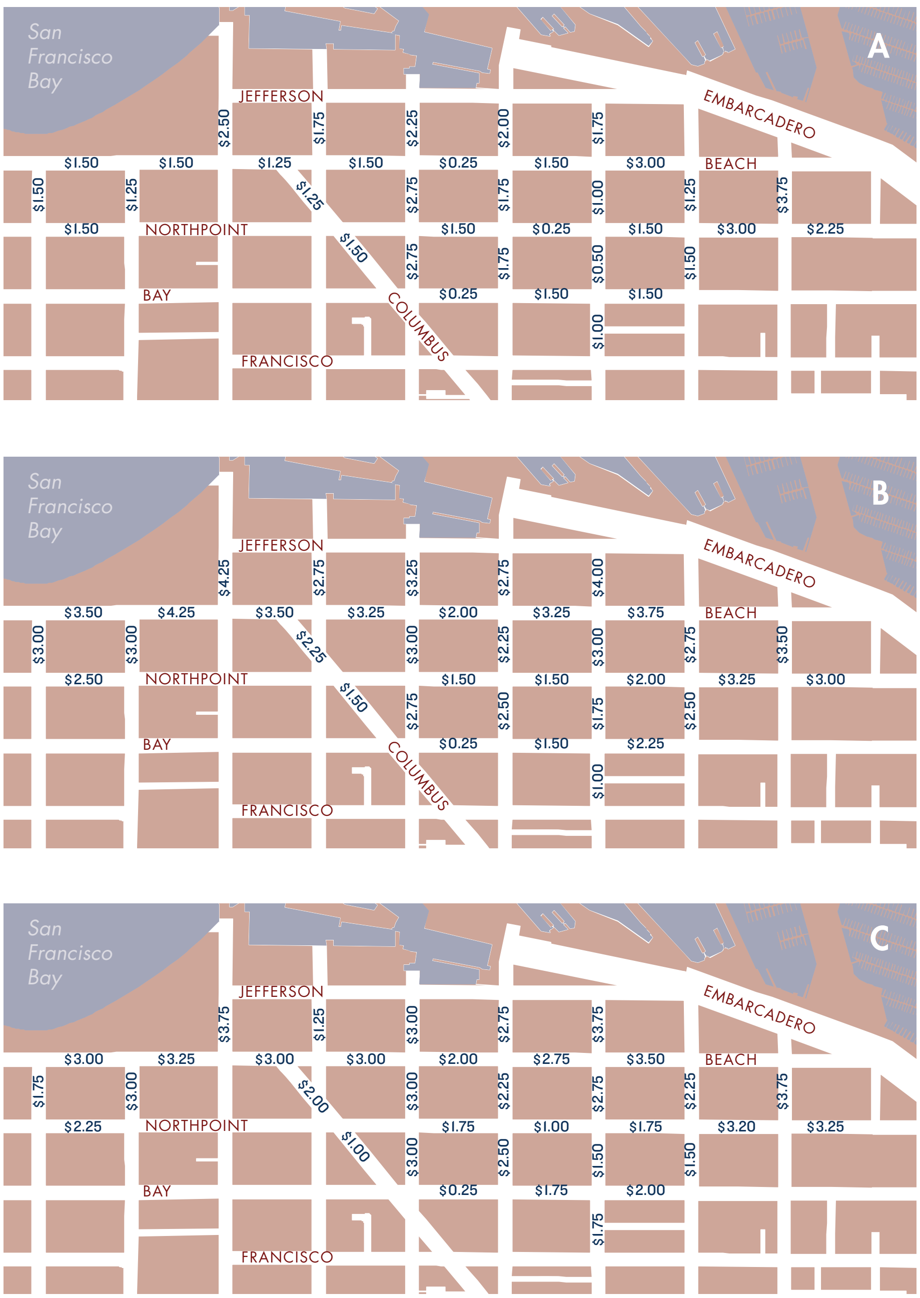


FIGURE 1

Weekday Parking Prices at Fisherman's Wharf, May 2012

(A) Before Noon
(B) Noon to 3pm
(C) After 3pm

SF*park* bases these price adjustments purely on observed occupancy. Planners cannot reliably predict the right price for parking on every block at every time of day, but they can use a simple trial-and-error process to adjust prices in response to occupancy rates. This process of adjusting prices based on occupancy is often called performance pricing. Figure 2 illustrates how nudging prices up on crowded Block A and down on under-occupied Block B can shift a single car to improve the performance of both blocks.

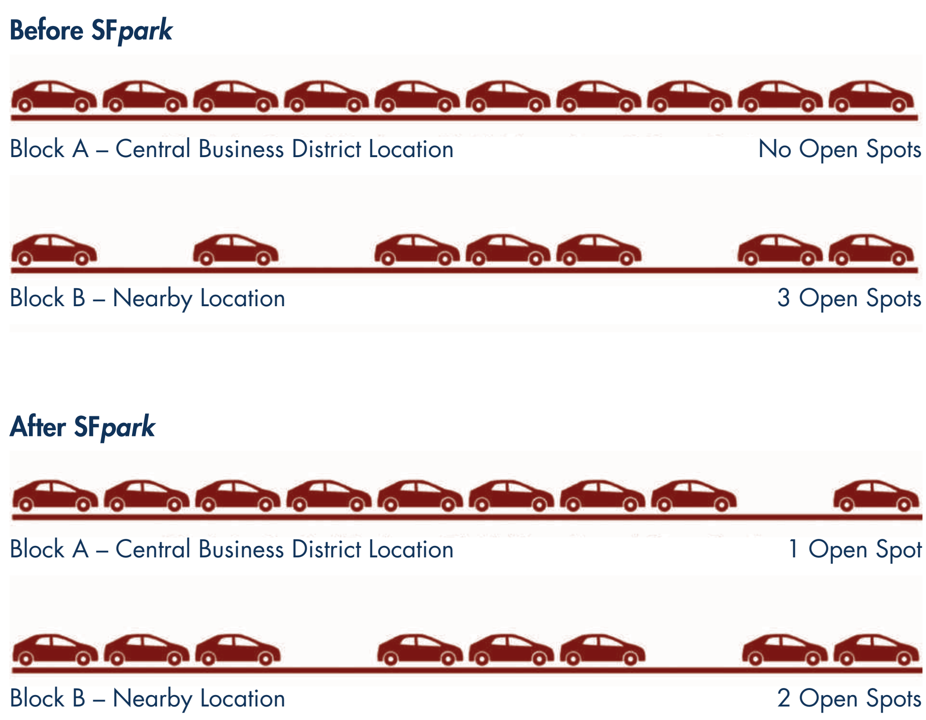
Beyond managing the on-street supply, SF*park* helps to depoliticize parking by setting a clear pricing policy. San Francisco charges the lowest prices possible without creating a parking shortage. Transparent, data-based pricing rules can bypass the usual politics of parking. Because demand dictates the prices, politicians cannot simply raise them to gain more revenue.

Did SF*park* Move Parking Occupancy in the Right Direction?

After several years of planning, the San Francisco Municipal Transportation Authority (SFMTA) launched SF*park* in April 2011 by installing new parking meters and extending or removing the time limits on curb spaces. The pilot program covers seven zones that contain 7,000 metered curb spaces. The initial prices in each zone were simply carried over from the previous, uniform pricing scheme. Under the new SF*park* program, most meters operate daily from 9 am to 6 pm, with prices that vary by the time of day and between weekdays and weekends. SFMTA established the desired target occupancy rate at between 60 and 80 percent for each block. If the average occupancy on a block for a given period falls in this range, the price will not change in the following period. San Francisco's pricing policy is thus data-driven and transparent, while most other cities' pricing policies are political and opaque.

FIGURE 2

Performance Prices Balance Occupancy on Every Block



In setting a target occupancy rate, SF*park* has two goals: to make curb parking readily available, and to ensure that curb parking accommodates as many customers as possible for the adjacent businesses. These two goals conflict because when meter rates increase to encourage one or two open spots per block, the higher prices also reduce average occupancy.

For example, large groups gathering at a restaurant may generate exceptionally high parking demand on a block on some days, so cities cannot aim for a consistently high occupancy rate of 80 to 90 percent without often reaching 100 percent occupancy, which produces unwanted cruising. A lower average occupancy, however, means fewer customers. San Francisco set the target occupancy rate at between 60 and 80 percent to cope with the random variation in parking demand and to balance the competing goals of reliable availability and high occupancy. If SF*park* works as intended, prices will move occupancy rates toward this target range.

During its first two years, SF*park* adjusted prices 11 times on each block for three different periods during the day. Prices increased in 31 percent of the cases, declined in 30 percent, and remained the same in 39 percent. On average, prices declined in the morning and increased in the midday and afternoon. The average price fell 4 percent, which means SF*park* adjusted prices up and down according to demand without increasing prices overall.

Because occupancy rates have moved toward the target goals, the share of blocks needing no price adjustment has slowly increased since the program began. By August 2013, after the program had been operating for two years, 62 percent of blocks were in the target range. Altogether, a third of all the blocks that had been over- or under-occupied at the beginning of SF*park* had shifted into the target occupancy range.

We can use an example of parking prices and occupancy rates on Chestnut and Lombard Streets in the Marina District to show the effects of SF*park*. In July 2011, these parallel streets had the same meter rate ($2 an hour) but very different occupancy rates. All five blocks of Chestnut were over-occupied (above 80 percent); of the five blocks on Lombard, two were under-occupied (below 60 percent), and three were in the target range (60 to 80 percent). What would it take to shift a few cars from the over-occupied blocks on Chestnut to the under-occupied blocks on Lombard? ➢

Figure 3 shows the path of average prices and occupancy on the five blocks of Chestnut and Lombard Streets from 3 pm until 6 pm. In response to the over- and under-occupancy, SF*park* began to increase the prices on Chestnut and reduce them on Lombard. After 10 price changes in two years, the average price on Chestnut had climbed by 75 percent to $3.50 an hour; on Lombard it had fallen by 50 percent to $1.00 an hour. As prices diverged, occupancy rates converged within the target range.

Figure 4 shows the parking prices on each block in April 2013. Between Pierce and Scott Streets, for example, the price on Chestnut was $3.50 an hour, and just a block away the price on Lombard was only 50 cents an hour, yet both blocks were in the target occupancy range. Parking spaces so close together would seem close substitutes for each other, but the huge price differences reflect very different local demand patterns.

FIGURE 3

Average Parking Prices and Occupancy Rates on Chestnut and Lombard Streets, 3 pm to 6 pm

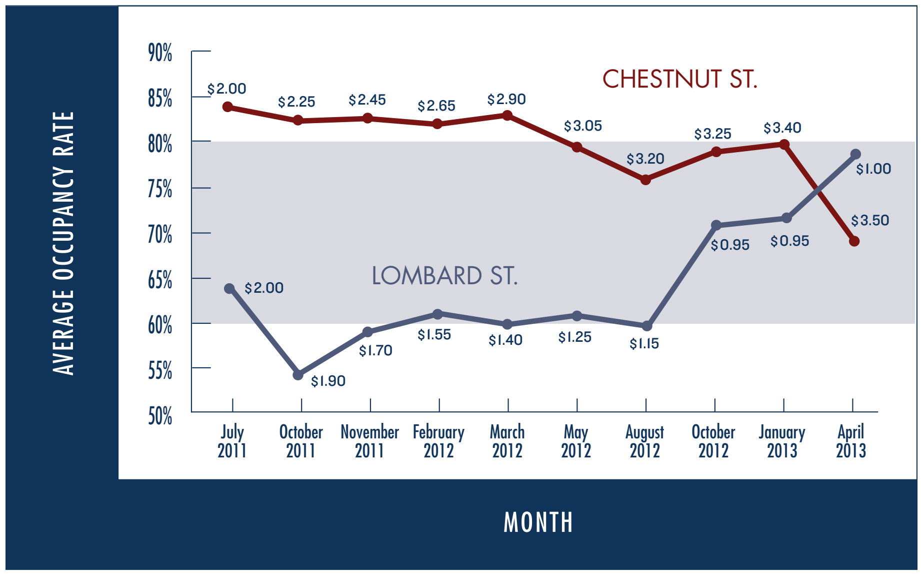
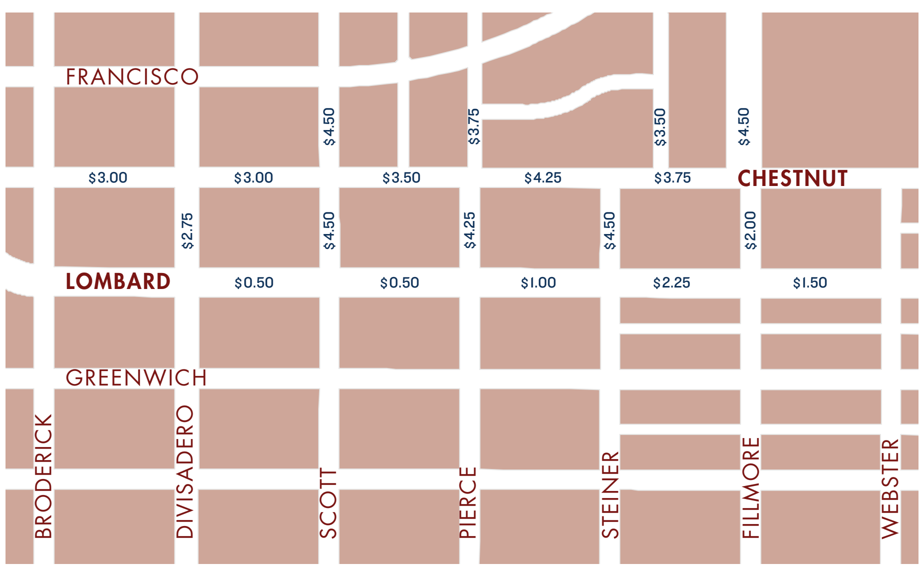


FIGURE 4

Parking Prices on Chestnut and Lombard Streets, April 2013, 3 pm to 6 pm



PRICE ELASTICITY OF DEMAND

Before each price change, SF*park* publishes data on the occupancy and prices for all curb spaces in the pilot zones. The price elasticity of demand measures how these price changes affected occupancy rates. Economists define price elasticity as the percent change in the occupancy rate (the quantity of parking demanded) divided by the percent change in the meter price. For example, if a 10 percent price increase leads to a 5 percent fall in occupancy, the price elasticity of demand is –0.5 (–5% ÷ 10%).

We calculated the elasticity of demand revealed by all the price changes during SF*park*'s first year. For each price change, we compared the old price and average occupancy to the new price and average occupancy during the following period. We thus have 5,294 elasticity measurements, one for each price change during the year at each time of day at each location.

The *average* price elasticity of demand was –0.4, but when we plot the elasticity for *individual* price changes at the block level, we find astonishing variety. Figure 5 shows the distribution of the price elasticities calculated for 5,294 individual price and occupancy changes on 1,492 city blocks.

The wide range of price elasticities suggests that many variables other than price affect parking demand. Higher prices should reduce occupancy, and lower prices should increase occupancy. In many cases, however, occupancy either rose after prices rose or fell after prices fell. Higher prices do not cause higher occupancy, and lower prices do not cause lower occupancy, so other factors must have overwhelmed the effects of prices on occupancy in the cases of positive price elasticity.

The wide range of elasticity at the block level also suggests that the circumstances on individual blocks vary so greatly that planners will never be able to estimate an accurate elasticity to predict the prices needed to achieve the target occupancy for every block. Instead, the best way to achieve target occupancy is to do what SF*park* does: adjust prices in response to the observed occupancy. This trial-and-error method mirrors how other markets establish prices, so it should work in the market for on-street parking. ➢

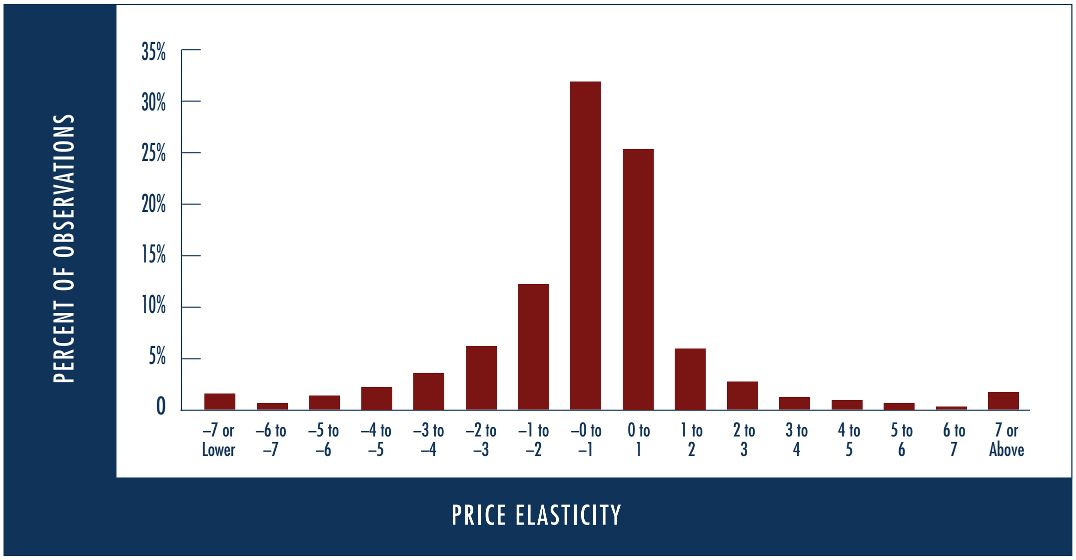


FIGURE 5

Distribution of Elasticities for 5,294 Price Changes

Equity in Performance Pricing

While it is clear that performance parking prices can improve transportation efficiency, are they fair? In San Francisco, 30 percent of households do not own a car, so they don't pay anything for curb parking. How the city spends its parking revenue also affects the equity implications of charging for parking. San Francisco uses all its parking meter revenue to subsidize public transit, so automobile owners subsidize transit riders. SF*park* will further aid bus riders by reducing traffic caused by drivers cruising for underpriced curb parking.

Performance pricing is not price discrimination because all drivers who park on the same block at the same time pay the same price. Performance pricing is also not the same as maximizing revenue. Because demand was, on average, inelastic, the city could increase revenue by charging higher prices. However, SF*park*'s goal is to optimize occupancy, not to maximize revenue, and the average price of parking fell by 4 percent during SF*park*'s first two years.

Three Suggested Improvements

Our findings suggest three ways to improve SF*park*: (1) refine the periods of operation, (2) shift from reaction to prediction in setting prices, and (3) end the abuse of disabled placards.

Refine the time periods

Most meters stop operating at 6 pm, so anyone who arrives at 5 pm and pays for one hour can park all night. Drivers who park during the evening thus have an incentive to arrive during the last hour of meter operation while a few open spaces are still available. Since SF*park* sets the price to achieve an average target occupancy for the period from 3 to 6 pm, a price can be too high at 4 pm (and occupancy too low) but too low at 5 pm (and occupancy too high).

One way to solve this problem is to operate the meters in the evening for as long as they are needed to achieve the optimal occupancy. Free parking after 6 pm is a holdover from the days when meters had one- or two-hour time limits to increase turnover during the daytime. Most businesses closed by 6 pm, so parking turnover was not needed in the evening. Today many businesses remain open after 6 pm, so the old rationale for free parking in the evening no longer applies. The purpose of metering in the evening is to prevent shortages, not to create turnover.

Because the occupancy sensors and parking meters are already in place for the pilot program, it seems unwise to cease operating at 6 pm simply because the old meters did. If, during the day, SF*park* reduces cruising, congestion, traffic accidents, energy waste, air pollution, and greenhouse gases, San Francisco can incrementally extend metering to additional evening hours when it will provide similar benefits. SF*park* has not increased curb parking prices overall, so the major benefit is better parking management, not more revenue from the existing meters. Nevertheless, more revenue can come from installing more meters and extending meter hours. In 2013, for example, the city extended meter operation to include Sundays, so SF*park* increased meter revenue without increasing the average meter rates.

Taking this process to its logical end, SF*park* can refine its pricing strategy to fit the demand on specific blocks at different times of the day across different days of the week. Narrowing the pricing windows to meet varying demand will increase the program's efficiency.

SF*park*'s goal is to optimize occupancy, not to maximize revenue.

Shift from reaction to prediction

The wide range of occupancy changes after each price change shows that many factors other than prices affect parking demand. Therefore, basing the next period's parking prices only on the previous period's occupancy rates will not reliably achieve occupancy goals. For example, SF*park* should not increase prices in January because occupancy rates were high during the Christmas shopping season. Seasonal adjustments based on occupancy rates in previous years may greatly improve the program's performance.

By shifting from reaction to prediction when adjusting prices, SF*park* may be able to get closer to target parking occupancy rates. Like hockey players who skate to where the puck will be, SF*park* can price parking based on future demand, not simply on past occupancy.

End the abuse of disabled placards

Abuse of disabled parking placards helps explain why occupancy does not reliably respond to price changes. Because California allows all cars with disabled placards to park free for an unlimited time at parking meters, higher prices for curb parking increase the temptation to misuse disabled placards to save money. Higher prices at meters may therefore drive out paying parkers and make more spaces available for placard abusers. If so, disabled placard abuse will reduce the price elasticity of demand for curb parking.

Placard abuse is already rampant in California. A survey of several blocks in downtown Los Angeles in 2010, for example, found that cars with disabled placards occupied most of the curb spaces most of the time. For five hours of the day, cars with placards occupied all the spaces on one block. The meter rate was $4 an hour, but the ➢

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meters earned an average of only 28 cents an hour because cars with placards consumed 80 percent of the meter time. Drivers using disabled placards were often seen carrying heavy loads between their cars and the adjacent businesses.

Reforms in other states show how California can prevent placard abuse at parking meters. In 1995, Michigan adopted a two-tier placard system that takes into account different levels of disability. Drivers with severe disabilities receive special placards allowing them to park free at meters. Drivers with less severe disabilities receive ordinary placards and must pay at meters. Before this reform, Michigan had issued 500,000 disabled parking placards allowing all users to park free at meters. After the two-tier reform, only 10,000 people (2 percent of the previous placard holders) applied for the special placards that allow free parking at meters. Enforcement is simple because any able-bodied driver who misuses the distinctive severely-disabled placard is conspicuously violating the law. Illinois adopted a similar two-tier placard law in 2013.

How will ending placard abuse affect SF*park*? If reform reduces placard abuse at meters, more spaces will open up for paying parkers. SF*park* will then reduce prices to increase occupancy, but all the new parkers will pay for the spaces they occupy, so parking revenue will probably increase. The lower prices, higher revenue, and greater availability of curb spaces will benefit almost everyone except placard abusers.

Conclusion: A Promising Pilot Program

SF*park* is a pilot program to examine the feasibility of adjusting prices to manage parking occupancy, and it appears largely successful. Los Angeles has already adopted a similar program called LA Express Park, and other cities are watching the results. After drivers see that prices can decline as well as increase, they may appreciate the availability of open curb spaces and learn to use the pricing information to optimize their parking choices for each trip. What seemed unthinkable in the past may become indispensable in the future.

With performance parking prices, drivers will find places to park their cars just as easily as they find places to buy gasoline. But drivers will also have to think about the price of parking just as they now think about the prices of fuel, tires, insurance, registration, repairs, and car purchases. Parking will become a part of the market economy, and prices will help manage the demand for cars and driving.

If SF*park* succeeds in setting prices to achieve the right occupancy for curb parking, almost everyone will benefit. Other cities can then adopt their own versions of performance parking prices. Getting the prices right for curb parking can do a world of good. ◆

This article is adapted from "Getting the Prices Right: An Evaluation of Pricing Parking by Demand," originally published in the *Journal of the American Planning Association*.

Parking Reform Made Easy

RICHARD WILLSON

Parking requirements in zoning ordinances create one of the most wasteful elements of transportation and land use systems: unoccupied parking spaces. Each space requires over 300 square feet of valuable land or building area, yet many sit empty. Minimum parking requirements at shopping malls, for example, often lead to sprawling developments surrounded by large, underused parking lots. Spaces for workplaces may be well-used during the day but remain unoccupied in the evening because they are not shared with other land uses. Sometimes, the parking required is greater than the amount of parking *ever* used.

Parking is overbuilt and underutilized for two reasons: 1) zoning requires an excessive parking supply, and 2) it prevents efficient sharing of parking among different land uses. Both reasons reflect a legacy of single-use zoning and an automobile-first approach to planning. Minimum parking requirements prevent private developers from responding to market conditions, and lessen developers' interest in sharing parking or developing sites that are accessible without driving. Planners sometimes claim that developers would build the same amount of parking regardless of regulations, but if that's true, then why impose minimum parking requirements in the first place?

Parking requirements should be framed as a *means* of providing access, not an end. Parking requirements are only one of several ways to ensure storage for private automobiles. Private auto transportation, in turn, is only one of several ways to provide access. To carry out parking reform, we must counteract the decades-old practice of thinking about access in terms of roadways and parking. In my recent book, *Parking Reform Made Easy*, I examine the origins of parking requirements, the impediments to change, and how we can reform these antiquated laws. ➢

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Why Parking Requirements?

Early zoning ordinances did not have parking requirements. Zoning sought to manage the external impacts of properties, such as when a new building represented a fire hazard to the structure next door. In the mid-20th century, parking requirements were added to address surface street congestion caused by patrons driving in search of parking. Planners didn't foresee that minimum parking requirements would favor private vehicle travel, lower overall density, and increase traffic.

In 1995 and again in 2013, I surveyed Southern California local planners about parking requirements and found a tautological justification for minimum parking requirements: planners wished to "ensure an adequate number of parking spaces." This response reflects a lack of critical thinking about fundamental public objectives, such as accessibility, economic development, and sustainability. The response also reflects an outdated vision of separated land uses, unrestricted auto-mobility, and plentiful free parking. Thus, many parking requirements are relics that undermine current land use and transportation goals.

Why Change is Difficult

Some regional and state policy makers recognize that existing parking requirements are excessive, but most have neglected the issue because parking is a responsibility of local governments. Yet parking requirements are crucial to accomplishing federal, state, and regional objectives in transportation, land use, and the environment. There are recent indications that if local governments do not carry out reforms, states may do it for them. In 2012, a proposal in the California legislature (AB 904) sought to override local parking requirements in transit-rich areas. Legislators subsequently tabled the proposal, however, showing the power of local governments to resist state interference in parking policies.

Many local planners know the parking requirement status quo is wrong. They have observed wasted land, turned away restaurant proposals in historic districts, and seen affordable housing not pencil out. Despite these undesirable outcomes, planners have not made changes. Why? Some may feel powerless to change ossified regulations, sensing weak political support and lacking technical expertise to justify changes. Others may want the negotiating leverage that excessive parking requirements provide to extract public benefits from developers. Furthermore, planners know that parking is a key point in NIMBY resistance to development, so avoiding parking controversy can help ensure economic development. In effect, cities are addicted to parking requirements. The addiction is analogous to smoking, where immediate gratification overwhelms future costs.

Change means freeing ourselves of parking dogma, habits, and golden rules. The old reality dictated fixed parking requirement ratios and exhibited an unwillingness to deviate from standard practice, even when it made sense to do so. This approach emphasized precision and uniformity. It undervalues important considerations of local variability, policy relationships, environmental capacity, and human behavior. All the land-use plans, design reviews, and streetscape renderings in the world will not produce desired outcomes if we do not reform parking requirements.

Why Not Eliminate Parking Requirements?

Deregulating off-street parking would allow markets to determine parking supply levels and provoke a fresh debate about justifications for public regulations and subsidies for *all* transportation modes. Currently, minimum requirements compel the provision of access for driving and parking, whereas zoning codes seldom impose equivalent requirements for bus, bicycle, or pedestrian facilities. When they do, those requirements have been added more recently and are at a lower investment level.

Under minimum requirements, even those who do not drive share in paying the cost of parking. Parking costs are embedded in higher retail prices, lower workplace salaries, higher rents, and the like. In these ways, most minimum requirements tend to prioritize private vehicles. Eliminating minimum requirements would begin to level the playing field for all travel modes.

Cities such as Philadelphia, Portland, and Seattle have recently reformed their parking requirements and adopted limited deregulation. Deregulation shifts the approach from automatically requiring parking to not supplying it until it is economically justified. It is a big change from standard practice and should be coupled with programs for shared parking and parking management. Still, the idea of eliminating minimum parking requirements hasn't gained traction in many places. Local officials are often buffeted by demands from residents, storeowners, and employees for *more* parking, not less.

Approaches to parking reform will vary from community to community. Accordingly, Table 1 shows the range of reform options, including the traditional approach in which the minimum requirements exceed expected use. At the other end of the spectrum is deregulation, with no minimum or maximum parking requirements. In many cities and towns, the best approach is somewhere in between, with deregulation in central business districts and transit-oriented developments, and reduced minimum requirements in other areas.

In effect, cities are addicted to parking requirements.

Moving Toward Reason and Action: 12 Steps

In my book, I explain how planners can use a 12-step toolkit to inform reasoned decisions about minimum parking requirements. The process begins with measured parking utilization rates and moves through a series of adjustments that consider local context and policy goals.

Step 1. Measure the existing parking utilization, which varies from place to place. This utilization is expressed as a rate, such as spaces occupied per 1,000 square feet of occupied building area or per residential unit. Planners assemble a sample of these measurements to provide an accurate assessment for a land use. The current utilization rates do not directly suggest future requirements, however, since perpetuating the existing levels can preserve undesirable conditions: underpriced and oversupplied parking, separated and low-density land uses, and automobile-first design.

Step 2. Consider future parking utilization. Despite regional transportation plans that must account for development 20 years into the future, parking requirements are often stuck in the past. For example, planners commonly use the Institute of Transportation Engineers *Parking Generation* handbook, which includes parking utilization ➢

APPROACH	MINIMUM REQUIREMENT	MAXIMUM REQUIREMENT	DEVELOPER RESPONSE
Traditional	> Utilization	None	Rarely builds more than the requirement
Moderate reform	= Utilization	None	Assesses market for project, may exceed the minimum
Big city approach	< Utilization	A fixed ratio or percentage of minimum	Makes market decision whether to supply the minimum or build to the maximum
Partial deregulation	None	A fixed ratio	Makes market decision whether to supply any parking or build to the maximum
Deregulation	None	None	Makes the market decision whether/how much to build

TABLE 1

Developer Response to Parking Requirements

measurements from decades ago. Since buildings last decades, or even centuries, parking requirements should consider how regional trends will affect future parking utilization levels. Most trends suggest a decrease in parking use per unit of development; the Step 1 rate is adjusted to account for expected increases or decreases in the parking utilization rate over the time period selected.

Step 3. Begin moving from utilization rates to prospective parking requirements. There is a policy choice about whether parking requirements should be based on the expected average use or other values such as 33rd or 85th percentile use levels, as drawn from sample data. Choosing an 85th percentile level means requiring *every* development build as much parking as sites with close to the highest observed utilization, while the 33rd percentile means requiring less than the average observed utilization, allowing developers to decide whether to build any more than that. Decisions about this "basis for the rate" depend on community goals and shared parking opportunities. The appropriate Step 2 utilization rate (average or percentile) is used as a prospective parking requirement based on this policy decision.

Step 4. Adjust the prospective parking requirement to account for particular characteristics of the project or land use category, as well as area land use and transportation conditions. For example, cities should require less parking near transit stops than near freeway off ramps. These project and context adjustments are applied as an adjustment to the Step 3 prospective parking requirement.

Step 5. Account for market conditions and policies regarding parking pricing, unbundling of parking costs from rents, or parking cash-out programs. These pricing policies generally reduce parking demand, so cities should reduce the parking requirements for developments with these policies.

Step 6. Consider plans for facilities and programs to increase transit and shuttle services, bicycling, and walking. Planned improvements to these travel modes may reduce parking use levels and justify a downward adjustment to the Step 5 prospective parking requirement.

Step 7. Assess the impact of local practices and policies that affect how efficiently spaces are used. For example, if spaces are designated for specific individuals in a development, an upward adjustment to the Step 6 prospective parking requirement may be made because efficient internal sharing of parking spaces cannot occur. Similarly, designating a vacancy goal such as 5 to 10 percent to ease the process of finding a space would also suggest an upward adjustment to the prospective parking requirement.

Step 8. Recognize that community parking resources, either on-street or in other off-street facilities, may justify a reduction in the parking requirement for new development. It involves measuring excess parking supply in the area and assessing its availability. If community parking resources are credited toward new development, the portion credited is subtracted from the Step 7 prospective parking requirement.

Step 9. Conduct a shared-parking analysis, which applies when parking requirements are being developed for mixed-use zoning categories or blended requirements (requirements that apply to a broader range of land uses in a district). The Step 8 prospective parking requirements for each land use being considered are entered into a shared-parking model that considers peak demand times for each use, the opportunity for multiple land uses to share parking spaces, and calculates an overall parking requirement for the land use mix.

Step 10. Evaluate the prospective parking requirement, as adjusted through Step 9, and consider whether it supports community goals and plans. These goals are found in comprehensive plans and vary among communities. They often address transportation, design, urban form, economic development, environmental sustainability, and social equity. For example, a community with aggressive goals for transit and non-motorized transportation may decide to adopt lower parking requirements, or to eliminate them. ➢

A community with strong economic goals may embrace parking deregulation because it can reduce development cost. An iteration of Steps 3 through 9 may be considered to align parking requirements with community goals.

Step 11. Address regulations about the minimum size of parking spaces to allow an efficient yield of spaces per square foot of parking area. Jurisdictions may choose to adopt smaller dimensional requirements to more efficiently use land and building area. The decision considers the effects of use type, vehicle mix, and parking space turnover on desired dimensions.

Step 12. Consider regulations allowing tandem parking (one car behind another), valet parking, and automated parking. Each measure can increase the yield of parking spaces per square foot of parking area. Policies allowing these measures are differentiated by land use category and local conditions.

This twelve-step process is an alternative to setting a parking requirement based on a neighboring city's requirement or a national average. It can be used to establish parking requirements for a land use category, for a district, or for a particular project. Ideally, local governments will reform requirements based on a clear sense of the benefits. If they don't, regional or state agencies can use this process to recommend or mandate parking ratios for local governments. Regional agencies, for example, could develop suggested parking requirements that vary by context features, such as transit accessibility, mixed-land uses, and density. They can also integrate parking reform with regional planning and modeling activities. For example, in King County, Washington, the Metro Transit's web-based GIS tool provides data on parking utilization for multifamily housing and tests alternative parking ratios in terms of costs and impacts.

In Praise of Incrementalism

In the past decade, many cities initiated comprehensive zoning code reform, and others are planning such efforts. Comprehensive reform efforts allow planners to rethink parking requirements while they consider the basic organization and functioning of the zoning code. These efforts also allow planners to bypass the complexity of older codes that have undergone countless revisions. Ideally, planners will amass enough political clout and financial resources before undertaking the daunting task of comprehensive zoning code revision.

There are many situations, however, where financial resources and political capital are not sufficient for comprehensive parking reform. In these cases, an incremental approach can produce good results. It makes sense to start where there is support, either from elected officials or from community or district stakeholders. Code reformers can work with these stakeholders and produce parking requirement reforms, parking overlay zones, or partial deregulation without creating opposition that might emerge in a citywide effort. These early successes often build support for larger, more comprehensive efforts. Rather than viewing pilot projects or experiments as somehow inferior to comprehensive parking reform, we should see them as effective ways of producing valuable information, testing innovative ideas, and ultimately generating change.

Small victories enable learning and create momentum. Let the reform begin! ◆

The article is adapted from *Parking Reform Made Easy*, published by Island Press.

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Vehicular ad hoc Networks: Storms on the Horizon

AMELIA REGAN

Researchers and policy makers have long anticipated fully connected vehicular networks that will help prevent accidents, facilitate eco-friendly driving, and provide more accurate real-time traffic information. Today, vehicular ad hoc networks (VANETs) offer a promising way to achieve this goal. Using advances in wireless communications, computing, and vehicular technologies, VANETs rely on real-time communication not only with roadside sensors but also among vehicles and pedestrians. While there are still communication problems to solve within these complex systems, concerns about privacy, liability, and security are the chief obstacles that prevent progress towards large-scale implementation.

What are VANETs?

Computers extensively control modern passenger vehicles, from anti-lock braking systems and electronic fuel-injection, to cruise control and self-parking mechanisms. Yet, these vehicles are also an oddity in today's interconnected world; cars are unable to communicate with each other, or for the most part, with the outside world. Even when vehicles communicate with external gadgets, such as for electronic toll collection, these vehicular networks rely heavily on roadside sensors. VANETs, however, are unique in that they turn participating cars into wireless routers or nodes, allowing cars close to each other to form a network. With the addition of smart phone technology, VANETs can incorporate three different communication pathways:

- **Vehicle-to-Vehicle (V2V):** messages are transmitted between neighboring vehicles. This includes "single-hop" and "multi-hop" messaging scenarios in which vehicles communicate either directly with other vehicles or through intermediary vehicles.

- **Vehicle-to-Infrastructure (V2I):** messages are transmitted between vehicles and road-side units located on nearby arterial road intersections or highway on-ramps. ➢

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- **Vehicle-to-Pedestrian (V2P):** messages are transmitted between vehicles and pedestrians who send and receive messages via their phones or other wireless devices.

With vehicles and pedestrians contributing to the network, VANETs are highly mobile. The more vehicles participating in the network, the more predictable speed and traffic patterns become. And because the network is created using the computers already installed in vehicles and carried by pedestrians, there are few power constraints or storage limitations.

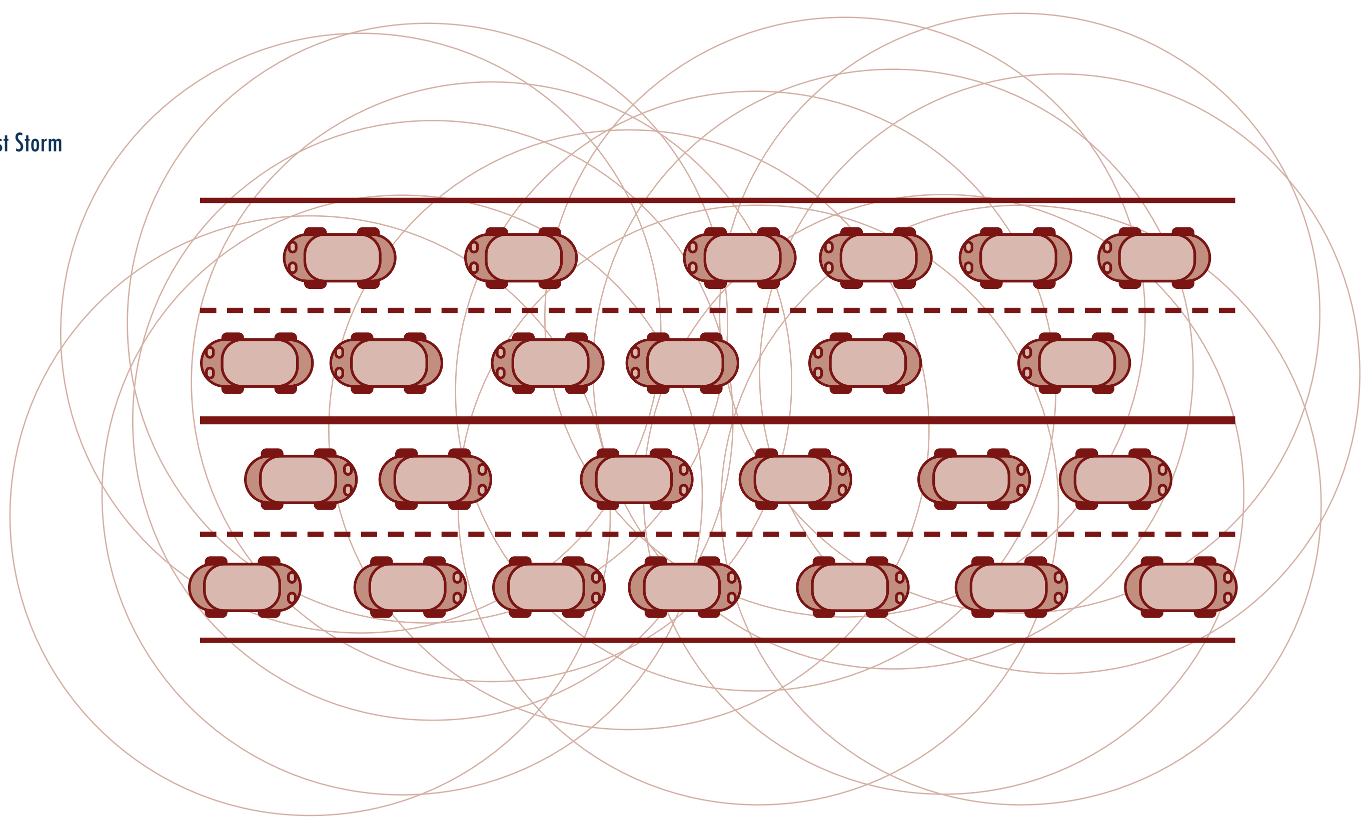
VANETS have many applications. For example, V2V and V2I systems use information on acceleration and braking behaviors of nearby vehicles to track dangers beyond a driver's line of sight, helping to prevent collisions. When vehicles communicate with each other, "platooning" is possible, allowing multiple vehicles to accelerate or brake simultaneously as one unit. Platooning reduces the distance between vehicles and aerodynamic drag, helping to improve fuel efficiency. V2P systems both improve the safety of pedestrians crossing at intersections, and facilitate carpooling and ridesharing by providing people with real-time information. A vehicular network can also provide useful information, such as route guidance, or entertainment content to passengers and drivers.

Challenges

For safety purposes, vehicles must periodically broadcast their location and speed profiles to neighboring vehicles. But when the vehicle network is highly congested, these single-hop messages may create a broadcast storm, overloading the VANET system and delaying message transmission [Figure 1].

FIGURE 1

The Broadcast Storm



Broadcast storms are worse in cities and on congested highways during rush hour. This causes problems because high communication reliability and fast dissemination of information among vehicles, pedestrians, and transportation infrastructure are essential for safety-based applications.

In addition to the communication challenges posed by broadcast storms, the success of a large-scale VANET hinges on solving the issues of privacy, liability, and security. While people may willingly share personal information on social networks, they strongly oppose its being shared without their consent. The privacy requirement, however, is in direct conflict with the need for integrity, authentication, and non-repudiation in a VANET. Many potential participants, therefore, will opt out because they do not want their location broadcast at all times to unknown parties.

Liability concerns have also delayed, and even prevented, the deployment of many VANET technologies. If the system fails and one vehicle crashes into another, who is at fault? Determining liability in a technology-induced collision involves many stakeholders, which is not a simple matter in our litigious society.

Finally, the most important issues are security and safety. VANETs require extremely fast message authentication and processing. Conversely, VANET messages must have strong protection against hacking and extremely high reliability, which significantly increases message size, and thus processing time. Therefore, as the number and speed of messages on a VANET increase, safety applications become more vulnerable to tampering.

An August 2013 *New York Times* article points out how easily automotive computers can be tampered with. Imagine that a safety message requiring immediate braking is falsely disseminated in a congested network. Forget about one vehicle crashing into another. What about dozens of vehicles crashing into each other? Hundreds? Unfortunately, the communication resources needed to ensure message integrity, sender authentication, and extremely fast dissemination are simply unavailable for safety applications at this time.

If the primary challenges related to privacy, liability, and security can be overcome, VANETs, and intelligent, connected vehicles in general, present amazing opportunities to improve transportation safety, increase traffic flows, and reduce environmental harm. ◆

This article draws on "Broadcasting Safety Information in Vehicular Networks: Issues and Approaches," published by the *IEEE Network*.

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