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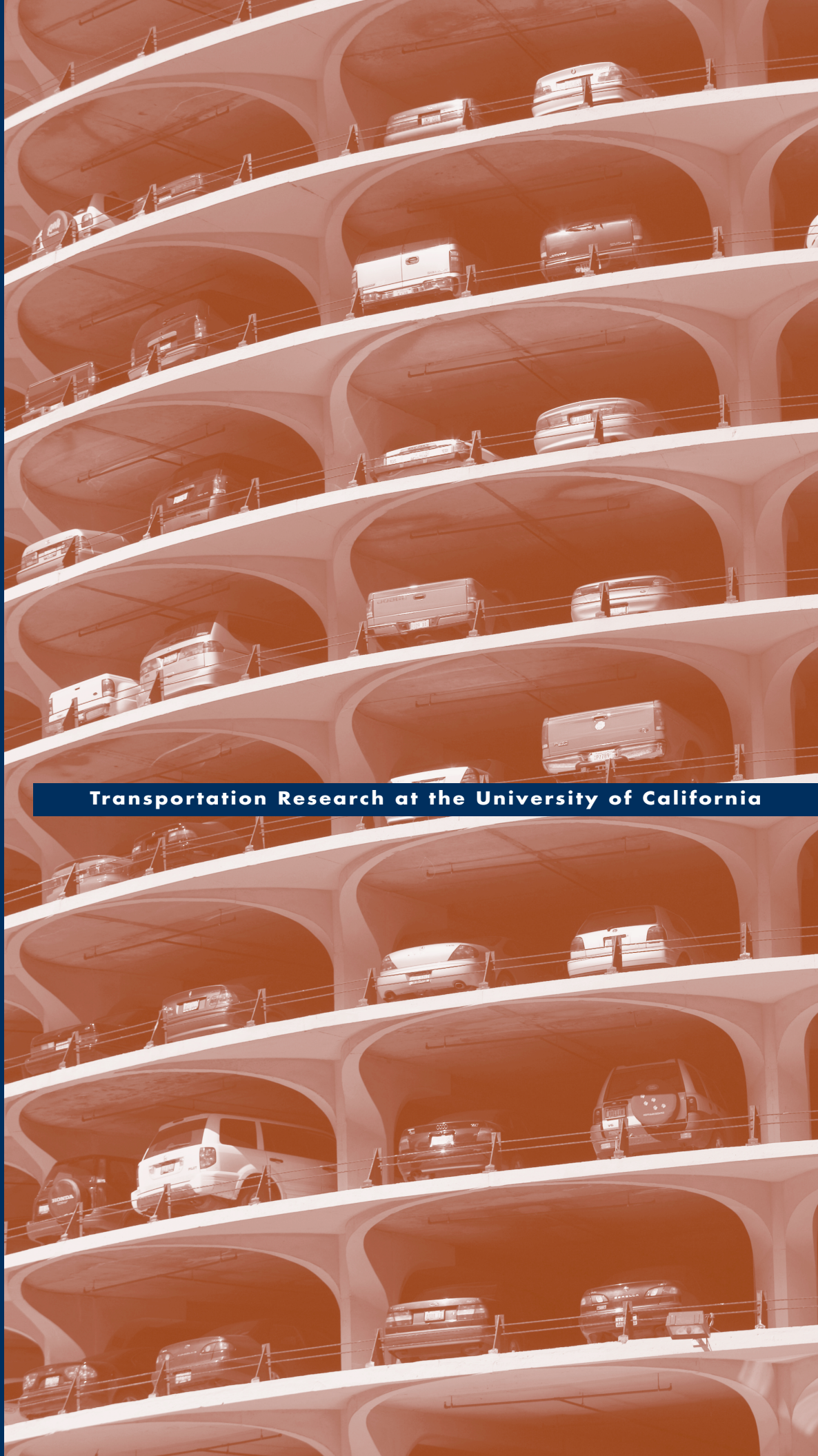
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Transportation Research at the University of California

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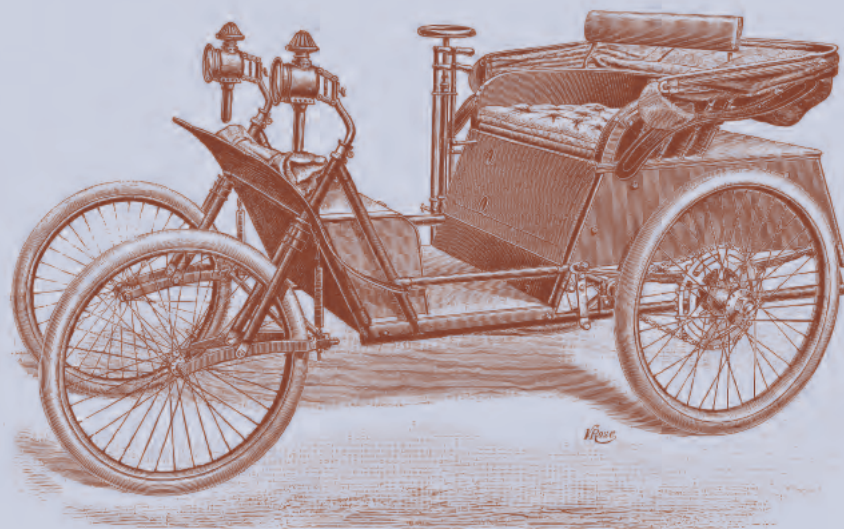
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Retrofitting the Suburbs to Increase Walking

MARLON G. BOARNET, KENNETH JOH, WALTER SIEMBAB,
WILLIAM FULTON, AND MAI THI NGUYEN

DURING THE LAST HALF OF THE 20TH CENTURY, cities and towns across America were built primarily for one transportation mode: the automobile. Much of this development occurred on the urban periphery, creating the suburbs that are now home to more Americans than either traditional central cities or small towns. Today, while federal transportation policies and urban planners have shifted toward promoting a more multimodal form of development, the legacy of the postwar era remains: thousands of suburban neighborhoods poorly served by any mode of transportation other than the automobile.

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Researchers have spilled much ink debating the feasibility of alternatives to car travel, but have focused less on how suburbs built for the car might be transformed to accommodate other modes. Seven years ago, communities in the South Bay area of Los Angeles County decided to focus on this question. They found that walking is the gateway mode for alternative transportation. The 2009 National Household Travel Survey shows that 10 percent of all trips in the US are taken on foot. Relatedly, an American Public Transportation Association analysis of over 150 on-board transit surveys from 2000 to 2005 showed that walking is the access mode for about 60 percent of all transit trips.

Walking travel and land use patterns vary substantially within the South Bay. Analyzing the correlates of walking in that area provides insight into ways to retrofit auto-oriented suburbs for more pedestrian travel.

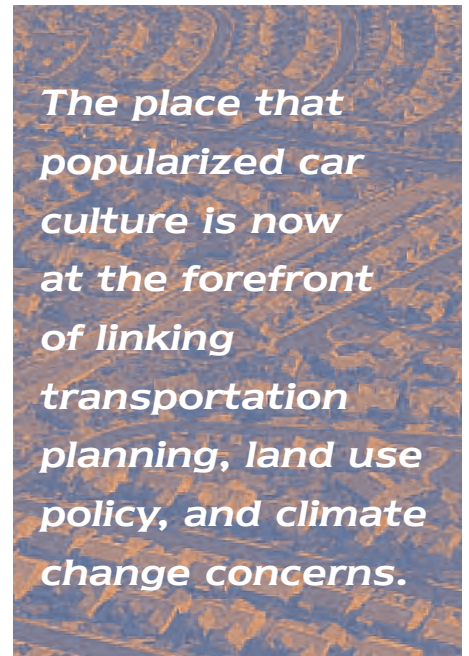
THE CALIFORNIA CONTEXT

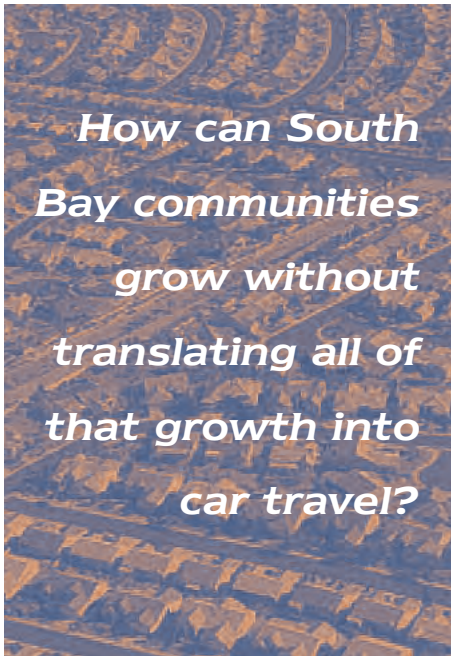
The opportunities for retrofitting suburbs to increase transit use and walking are especially golden in the Golden State. While the proliferation of auto-oriented suburbs has continued largely unabated in sprawling metropolitan areas such as Atlanta, Houston, and Phoenix, in California there are several reasons why suburbs will be retrofitting to increase walking. The first is geography: the major coastal metro areas (Los Angeles, San Diego, and San Francisco) are hemmed in by mountain ranges or desert, with little room for new development. While population density has declined in most US cities for over a century, Western cities, including greater Los Angeles, saw densities increase in recent decades. The second reason is economics: the collapse of the recent housing bubble dampened the market for new single-family residential units, particularly on the exurban fringe of California's metropolitan areas. The past few years have seen marked shifts in building from inland to coastal counties and from single-family to multi-family units. The state's planning and policy context is the third, and perhaps most important, reason why suburbs will be retrofitted to increase walking. The place that popularized car culture is now at the forefront of linking transportation planning, land use policy, and climate change concerns. California Senate Bill 375, passed in 2008, requires metropolitan planning organizations (MPOs) to develop "sustainable communities strategies," including infill development.

This combination of geography, market forces, and public policy will limit the expansion of California's urban areas, providing consistent pressure for infill development in the coastal counties. Adding more people to already congested places such as San Diego, the San Francisco Bay Area, and Los Angeles will increase the political pressure to reduce the resulting car traffic on arterial streets. Communities will look for relief valves—ways to move some of the traffic from infill development to alternate modes of travel. This context prompted the South Bay Cities Council of Governments to study how to accommodate growth in an area built for the car a half century ago.

THE SOUTH BAY STUDY

The South Bay area of Los Angeles County is a sociodemographically diverse collection of 16 cities between Los Angeles International Airport and Long Beach. Home to about a million people, these communities experienced their most rapid growth in the three decades after World War II. Car culture dominates in the South Bay, which has an arterial street grid dotted by strip malls and car-oriented developments. While the South Bay is built out and has almost no vacant land, the area is projected to add over 170,000 people between 2000 and 2025, providing substantial pressure for infill development. ➤





Infill development in built-out suburban communities is often a hot-button issue. Residents worry about traffic impacts, and not without cause. A lack of open land means few opportunities to widen streets, and the growth projected for the South Bay raises the possibility that roadways will congest further. California communities often have relatively high but uniform densities that provide few opportunities to concentrate trip origins and destinations to facilitate transit. This poses real obstacles to increasing population density without increasing traffic congestion. A traffic relief valve of some sort would be handy. How can South Bay communities grow without translating all of that growth into car travel? Can some trips be diverted to alternative modes? What role can walking play?

To answer those questions, we studied travel patterns in eight neighborhoods in the South Bay. The neighborhoods were of two types: pedestrian-oriented centers and auto-oriented corridors. Centers have an inwardly focused street geometry with a commercial core in the middle, while corridors have a linear commercial core along a major arterial street, with residential areas surrounding the commercial strip. While both center and corridor neighborhoods have residential and commercial uses in close proximity to each other, the center neighborhoods reflect older pedestrian- and transit-oriented street geometries that are characteristic of pre-WWII neighborhoods, as opposed to corridor neighborhoods that were built primarily in the automobile era. To understand the variation in walking travel within neighborhoods, we further divided these neighborhoods into inner and outer rings—roughly quarter-mile and half-mile buffers radiating from the neighborhood center or corridor, corresponding to census block group boundaries (Figure 1 shows the study areas).

Our primary source of travel behavior data was the South Bay Travel Survey. Participants in the survey completed a one-day travel diary that included questions about trip purpose, mode choice, and trip distance. We compared differences in travel behavior by mode (walking versus driving) across the eight center and corridor neighborhoods. People who live in the centered neighborhoods consistently walk more, and the centers capture a higher share of the center-based respondents' total trips. Table 1 shows the differences, which persisted in regression analyses that controlled for individual and household sociodemographic characteristics. The data also show that people living in the centered neighborhoods generally take shorter trips, and those shorter trips are more likely to be by walking. For some specific purposes (e.g., grocery shopping, other personal shopping, and entertainment) center residents take more trips than people living in corridors, presumably in part because shorter trip distances can encourage people to travel more.

TABLE 1
Walking and Driving in
South Bay Study Areas

	WALKING TRIPS PER PERSON PER DAY	DRIVING TRIPS PER PERSON PER DAY	% OF ALL TRIPS WITHIN CENTER OR CORRIDOR
Centers	0.19	2.00	38%
Corridors	0.07	2.30	27%

Source: Adapted from *Urban Studies*, "Retrofitting the Suburbs to Increase Walking: Evidence from a Land Use – Travel Study," by Boarnet, Joh, Siembab, Fulton, and Nguyen, 2011, Table 3, and reprinted with permission.

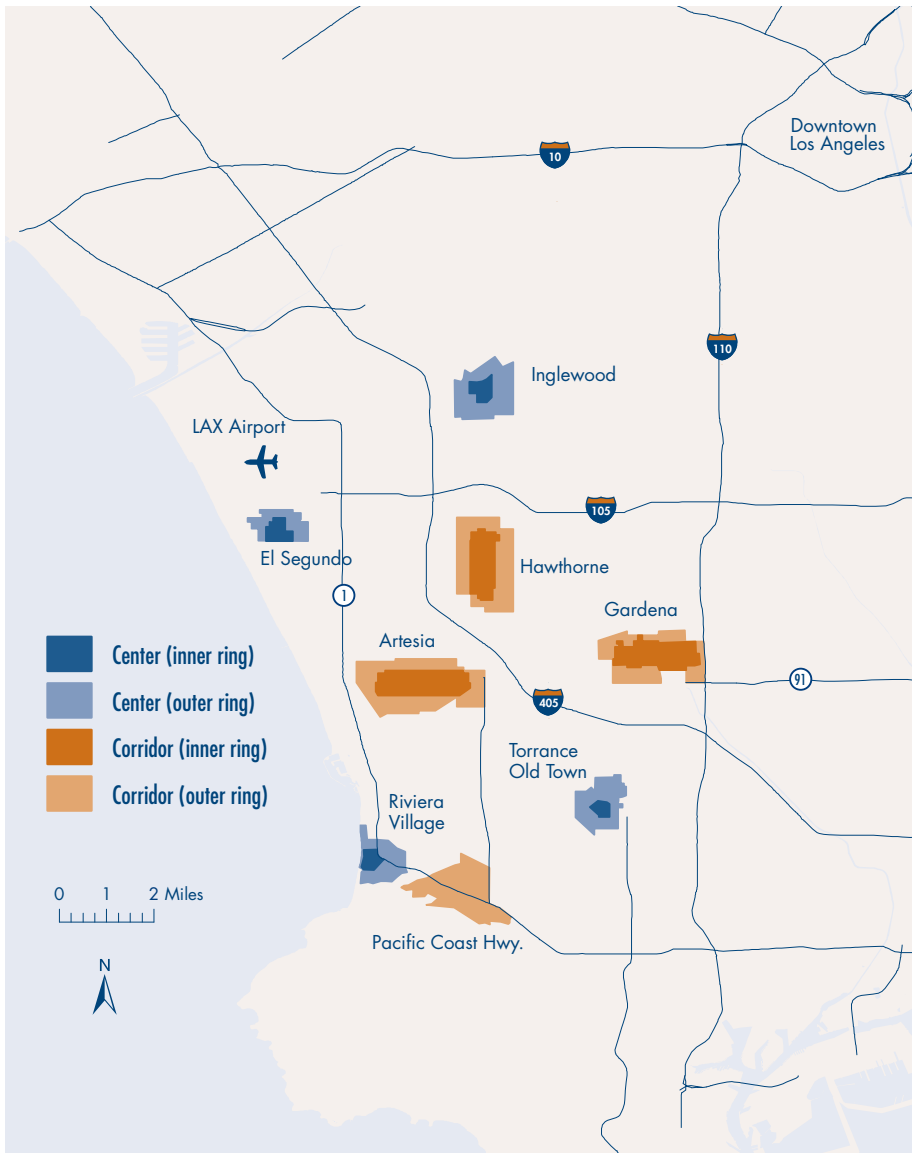


FIGURE 1
Map of South Bay
Study Areas

Reproduced with permission from *Urban Studies*, "Retrofitting the Suburbs to Increase Walking: Evidence from a Land Use – Travel Study," by Boarnet, Joh, Siembab, Fulton, and Nguyen, 2011.

But why do people who live in centers walk more? To explore this, we regressed the number of walking and driving trips per person on individual and household characteristics and land use variables. These included population density, attributes of the street network including grid-orientedness and block size, and measures of local business activity (the number of commercial establishments per acre, employees per acre, sales per acre, and the ratio of businesses in the inner ring divided by the outer ring).

Our results show that the number of businesses per acre is the single most robust indicator of whether people are likely to walk in their neighborhood. We find that people living in neighborhoods with more business establishments per acre conduct more of their travel within their neighborhood and are more likely to travel by walking.

This suggests that walkable neighborhoods are often places where there are many nearby destinations. Measures that might correlate with large establishments—retail employment >

An aerial photograph of a city grid, showing streets and buildings. The text is overlaid in white, italicized font.

Pedestrian-oriented centers require a concentration of business activity larger than the local residents can support.

or sales—did not predict walking travel nearly as reliably as the *number* of businesses per acre, suggesting that the key is not simply sales but a large number and variety of businesses in a relatively small area.

But is the association between businesses per acre and walking causal? Could it be that business density does not cause walking but that there is a self-selection phenomenon where people who like to walk choose to live near a higher concentration of retail and service destinations?

We addressed this issue by studying variations in travel behavior within one small study area: the Artesia Boulevard corridor. The Artesia corridor is a mile-long commercial strip demarcated by intersections with major arterial streets at each endpoint and intersected by a smaller arterial street roughly at the corridor midpoint. We selected Artesia because businesses are not distributed smoothly along the commercial corridor but are concentrated in the middle. We compared walking trips for survey respondents living within a quarter mile of either corridor endpoint with walking trips for people living within a quarter mile of the middle intersection. If residential location choice largely determines the study area where people live but not where along the corridor residents live, travel behavior differences within the Artesia corridor can be attributed to direct effects of differences in the built environment and business concentration, and not residential preferences.

Our results show that, compared to other residents in the corridor, people living near the midpoint of the Artesia corridor take more walking trips and fewer driving trips, take a larger fraction of their total trips within the corridor, and are more likely to walk when traveling to the businesses along Artesia Boulevard. The differences are statistically significant and striking in magnitude. Survey respondents living within a quarter-mile of the midpoint took five times as many daily walking trips and 30 percent fewer driving trips than others in the corridor.

Looking further, we compared actual retail sales with estimates of local retail demand for both the resident and employee populations of the area to assess whether walkable neighborhoods have commercial concentrations that serve the local population or whether those neighborhoods must also import customers from other places. We find that retail sales in the two centers with the most walking are approximately three to four times as large as what could be supported by the residents and employees in those centers, suggesting that pedestrian-oriented centers require a concentration of business activity larger than the local residents can support. Thus people must drive from outside of the neighborhood to support the commercial activity that in turn encourages local residents to walk more. Therefore, business densities that reduce driving within the neighborhood also require some driving from outside of the neighborhood, implying that policy must focus not just on small and dense village centers but on knitting these together in larger transportation networks.

POLICY RECOMMENDATIONS AND CONCLUSION

While traditional urban design elements such as inwardly focused street geometry may encourage walking, our results suggest that a more critical factor is the concentration of business activity in a compact commercial center. The tricky part is that the business concentration needed to encourage walking appears to be larger than most neighborhood residential populations can support. Given that, suburban regions should focus both on fostering pedestrian centers and on knitting those centers together with transportation networks, though such networks need not accommodate only cars.



We suggest both a land use approach and a mobility approach, and coordination between the two. A land use approach would focus on identifying and promoting walkable centers. Even auto-oriented areas such as the Artesia corridor can enjoy concentrations of pedestrian activity if there are retail businesses nearby. Planners can develop pedestrian-oriented centers through densification and infill development, for example by offering density bonuses. Planners might reduce or remove minimum parking requirements or even limit parking.

A mobility approach would promote transit service, tailored to the context of the suburbs. Rather than the common approach of running underutilized central-city style buses, in a region like the South Bay transit might include high-frequency shuttle bus service between neighborhood centers. A more ambitious but possibly more appropriate approach would promote the use of small, fuel-efficient vehicles (such as neighborhood electric cars) and through carshare programs. The South Bay Cities Council of Governments is already experimenting with a neighborhood electric vehicle demonstration program. The advantage of neighborhood vehicles is that they are small, allowing more efficient use of limited streets and parking with a lighter environmental footprint. While neighborhood electric vehicles are not designed for travel speeds over 25 miles per hour, they may be ideal for relatively dense, auto-oriented suburbs like the South Bay, where an overwhelming number of local non-work trips are shorter than three miles.

Overall, the first step would be to develop walkable nodes of neighborhood businesses that would then be connected through regional mobility networks. Implementing such a strategy is a political and planning challenge but, as the regulatory and market pressures now seen in California become more prevalent throughout the US, we believe that the policies that support suburban walking will become more common. Adapting auto-oriented suburbs to promote alternative travel modes will be increasingly central to the realities of transportation planning in the future, and it all starts by focusing on the walk from home to the store. ♦

FURTHER READING

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Beyond Rationality in Travel Demand Models

JOAN L. WALKER

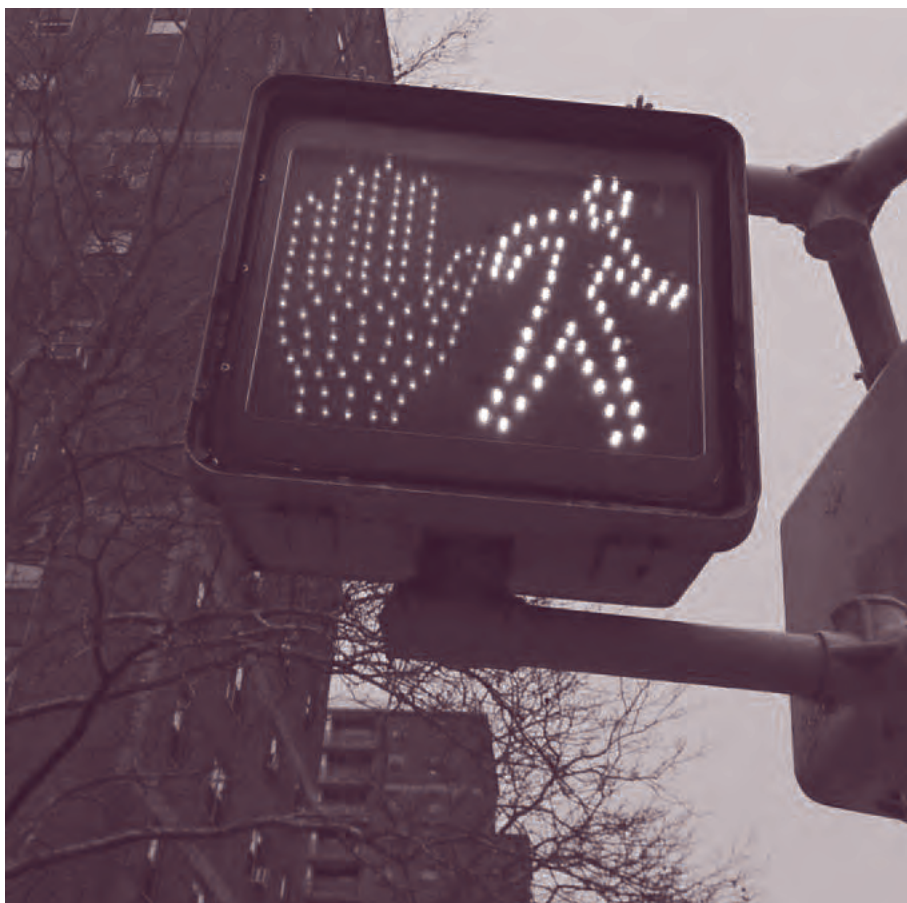
THE EFFECTIVENESS OF TRANSPORTATION POLICIES will depend on how users respond to them. Therefore, we must understand how to predict and influence behavior over the long term, which is the realm of travel demand modeling.

Relevant decisions made by individuals include where to live and work; the type and quantity of vehicles and transit passes to own; the types, locations and scheduling of activities; and by what modes and routes one travels to those activities. This article explores ways to improve travel demand models to reflect actual behavior, whether it is “rational” or not.

The statistical models used for predicting transport-related behaviors are predominantly rooted in the microeconomic paradigm of rationality, which assumes that people can accurately calculate and compare the value of options and then follow the best possible course of action. But are people rational when it comes to making transportation decisions? Are *you* aware of all of your transportation alternatives? Do you understand and weigh travel times, monetary costs and reliability by mode? Do you choose the alternative with the minimum generalized cost calculated solely from travel times and monetary costs? Or are there other factors that influence your decision such as comfort, convenience, habits, values, or peer influences?

Behavioral science researchers have a long history of raising serious questions about the rationality assumption. Their research has often succeeded in pointing out seemingly inconsistent and non-sensible choices. For example, an experiment in the 1970s conducted by behavioral economists Daniel Kahneman and Amos Tversky found that, while most people would travel an extra 15 minutes to save \$7 on a new pen, most people would *not* travel an extra 15 minutes to save \$7 on a new suit. An assumption of rationality would suggest that \$7 should equal \$7 regardless of context. While this behavior is perhaps irrational by some definitions, it is bias in a predictable and measureable direction if what matters is the magnitude of the savings relative to the cost of the item.

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Are people rational when it comes to making transportation decisions? Are you aware of all of your transportation alternatives?

Instead of assuming that people make *mistakes* when they act outside of what a narrowly defined theory of rationality would predict, behavioral modeling incorporates intricacies of the decision-making process, such as hidden but systematic rules that govern behavior. If these are not accounted for, it may appear that people are making irrational transport choices.

Early transportation planners employed the behavioral assumption that people choose the alternative with the minimum generalized cost, with cost narrowly defined as a function of travel time, the value of that time, and monetary costs. When it was realized that such a deterministic rule was often violated, probabilistic models of behavior became the dominant form. Such models introduce error terms to the preference equations, which is a first step in capturing so-called irrationalities.

Probabilistic techniques, such as logit and probit, are still the dominant form in travel demand modeling, and are becoming more behaviorally realistic. It is important to note that rationality is not a fundamental assumption in these models, as “irrational” processes (as long as they are predictable) can be incorporated.

In this article I emphasize three different themes based on research I conducted with my students. The first has to do with how people make trade-offs between time, money, and other factors such as environmental impacts. The second has to do with the roles that social influences play in travel and activity behavior. The third is focused on the heterogeneity of travel-related behavior. In all cases the methods underlying the findings discussed involve observing choices that people make (either in a hypothetical or real >

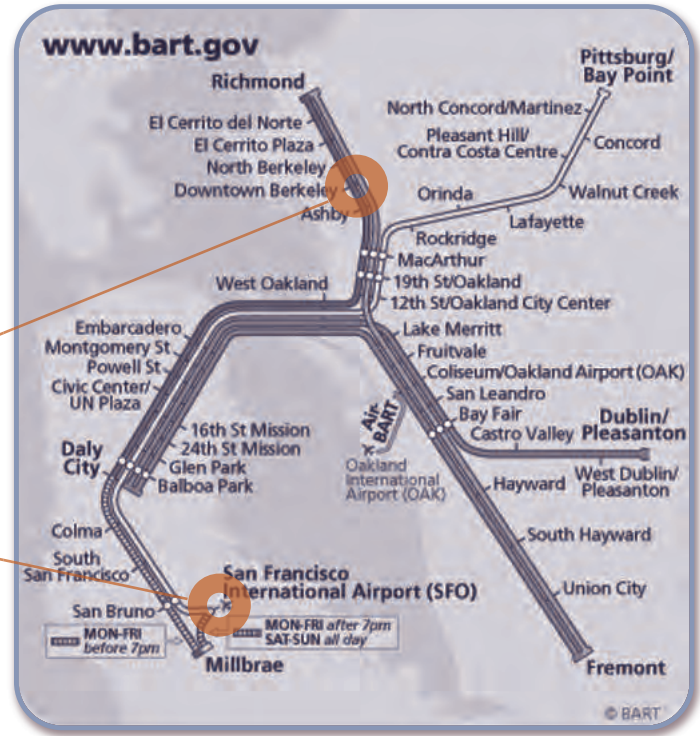
FIGURE 1

Example of Emissions Information Reported on the BART Website

Downtown Berkeley Station
2160 Shattuck Avenue, Berkeley, CA 94704
Connecting Transit, Neighborhood Map and more...

San Francisco Int'l Airport Station
International Terminal, Level 3, San Francisco Int'l Airport, CA 94128
Connecting Transit, Neighborhood Map and more...

CO₂ emissions saved by this BART trip: **23.3 pounds.**



setting). From these observations, we make inferences regarding the underlying preferences. The overriding objective is to develop travel demand models that better reflect actual behavior.

TRADING OFF TIME, COST, AND ENVIRONMENTAL FACTORS

Decision making essentially involves trade-offs. Travelers weigh different levels of attributes—time, monetary cost, reliability, comfort, convenience, safety, and so forth—across travel alternatives. A single alternative rarely fares best in each of these dimensions, and therefore a traveler has to weigh the importance and relative value of each attribute and choose the alternative that provides the greatest utility. The most important behavioral trade-off in transportation is between the time cost and monetary cost. One's value of time is expected to be on the order of one's wage rate and it represents the amount of money that one is willing to spend to save a certain amount of time. This impacts whether one chooses a relatively fast yet expensive alternative (such as a car) or a relatively slower yet cheaper alternative (such as a bus).

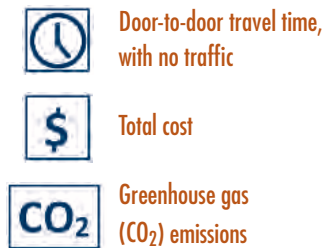
While time and cost are critical, travel modes have other important attributes. Reliability of travel time has been emphasized in the literature. Comfort and convenience have also been studied. However, the typical transport model is still fairly sparse in terms of representing the attributes of alternatives.

One attribute that has been appearing more frequently on transportation websites is the environmental impact of travel decisions. For example, Figure 1 shows a screen



FIGURE 2

Example Screen from the Mode Choice Experiment



capture from the Bay Area Rapid Transit’s website that reports a savings of 23 pounds of CO₂ if one takes BART instead of driving from Berkeley to the San Francisco airport. However, little seems to be known regarding what impact, if any, such information has on transport decisions.

To study the potential impact of providing environmental information to system users, we designed a behavioral choice experiment and used UC Berkeley undergraduates as subjects. We presented them with hypothetical scenarios and offered them auto ownership, mode choice, and route choice decisions. The decisions all involved making trade-offs between attributes such as travel time, monetary cost, reliability, safety, and greenhouse gas emissions. An example screen from the mode choice experiment is shown in Figure 2, where we used a mock-up of an iPhone traveler information app to display information to students about possible travel choices. Given the particular context of the trip (such as a commute trip) and the travel information provided on the phone, subjects were asked which mode they would choose. Different subjects were provided different alternatives and values of the attributes. The auto ownership and route choice experiments had a similar design.

We found that our subjects were willing to reduce emissions at the cost of time and/or money. They exhibited an average willingness to pay for emissions reduction, or what we call the *value of green*, of 15 cents per pound (\$300 per ton) of CO₂ saved. This estimate was consistent across choice context (such as whether the CO₂ savings were achieved through vehicle choice, mode choice, or route choice) and presentation (for example, whether >



the information was presented in tons or pounds). We also found significant heterogeneity in the value of green, with most values ranging between 0 and 70 cents per pound of CO₂ saved.

These results are influenced by the particular demographic of our sample, UC Berkeley undergraduates. Relative to the population at large, our subject group is highly educated, young, idealistic, and part of a community that is regularly recognized as being a national leader on environmental issues. It is also influenced by the fact that these are decisions made in the lab rather than a real market. The significance of our results lies not in the estimate of \$0.15/pound, but rather in the consistency of the estimated average value of green for this particular population across choice tasks. The results indicate that our subjects can evaluate the rather abstract notion of pounds of CO₂ and exhibit intentions to modify their behavior as a result. This suggests the importance of attitudes and value systems in making transport choices that go beyond issues of time and monetary cost.

SOCIAL INFLUENCES

Social influences are another source of perceived irrationality. Psychologists and behavioral economists emphasize that we are social beings who are influenced by those

around us. However, the statistical framework used to model travel demand is conventionally grounded in individual choice, assuming that choices are made independent of others' decisions.

But when we explored the role of social influences in transport behavior, we typically found them to be important. For example, in the experiments described above we also tested for the strength of social influences on transportation choices. Subjects in the auto ownership experiment were provided with a home and a work context and the commute times by mode. We then asked them whether they would purchase a conventional car (described as having a specific purchase price, annual cost, and annual greenhouse gas emissions), purchase a hybrid car (with the same set of attributes), or choose not to own a car. We also told some subjects in the experiment what their peers in the lab had chosen. We found that the peer information significantly swayed their choices. Subjects were more likely to choose a hybrid car if we told them that a large portion of their peers chose a hybrid car.

In the same experiment, we also explored pedestrian safety behavior, namely how different pieces of information influence obedience at traffic signals. We included different types of information aimed at influencing pedestrian jaywalking behavior, including information based on the law, on accident and citation rates, and on the behavior of peers. We then presented subjects with only one of these pieces of information, and asked whether they felt that in the coming week they would cross against red lights more frequently, less frequently, or the same as the previous week. We found that information on the law, citation rates, and accident statistics had no effect. The only piece of information that had a significant effect was the information on peer compliance with pedestrian laws. Unfortunately, telling students that others at Berkeley walk against the traffic signal 28 percent of the time (a statistic based on an informal survey at local intersections) led them to report that they were *more* likely to cross against red lights in the coming week.

We have done other work to incorporate theories of social network effects into travel demand modeling. Using a household travel diary from the Netherlands, we developed a mode choice model that incorporates social influences from peers. We defined peers to be those in the decision maker's residential neighborhood and socio-economic strata. Then we included as explanatory variables the mode shares of these peer groups. We found these factors to be significant. Modes that were used by one's social reference groups had an extra level of attractiveness beyond what would be suggested by travel times and travel costs. Note that this effect remains after employing instrumental variables to control for self-selection, similarities in tastes within socio-economic groups, and similarities in transport service within neighborhoods.

These social influences have important implications in transport behavior because they suggest a feedback loop between decision makers that can be self-reinforcing over time. This is often referred to as a social-multiplier effect, a bandwagon effect, or herd behavior. For example, with the introduction of a new transportation mode, such as bike-sharing or carsharing, a feedback effect between members of a social group can propel the adoption of the new mode over time. The reinforcement may be either in a desirable direction (toward more sustainable or safer behavior) or, as illustrated by the pedestrian case, in an undesirable direction. The many new forms of social networking make this role of reinforcement even more important. >

Subjects were more likely to choose a hybrid car if we told them that a large portion of their peers chose a hybrid car.

ATTITUDES AND VALUE SYSTEMS

Another important source of perceived irrationality is the fact that individual preferences vary widely in terms of attitudes towards modes (for example, car lovers versus car haters) and urban environments (for example, suburban lovers versus urban lovers). Such deep-rooted orientations lead to differences in preferences for travel and location. While the concept of heterogeneity is well established in travel behavior research, typically such segmentation is inferred based on socio-economic classifications, observed behaviors, or responses to attitudinal surveys.

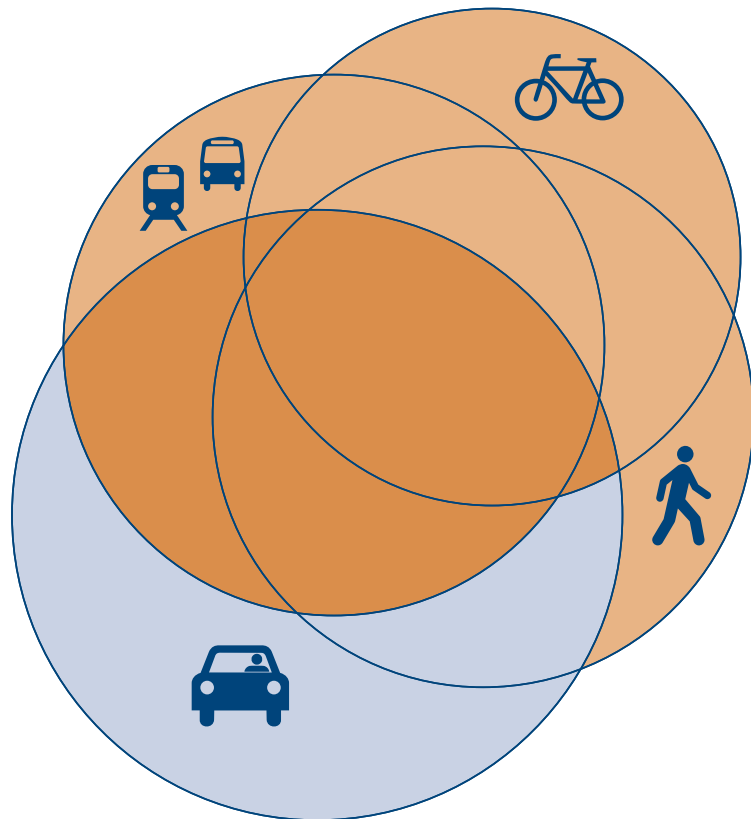
We have been studying the issue of segmentation using modeling techniques in which the segmentation is determined by the underlying *preferences* that affect the behavior. The idea is that there are distinct segments (or classes) in the population and each class exhibits distinctly different preferences or, in other words, each class has a different model specification. The modeling method results in an estimate of the number of distinct segments, the preferences of each segment (the choice model), and the socio-demographics that tend to be associated with each segment.

We studied residential housing choices using a stated preference survey conducted by Portland Metro. Subjects selected from a set of hypothetical housing options, each described by attributes of the price, the structure, the lot, the neighborhood, and accessibility to stores and to one's work. We found three groups of people, each with distinctly different housing environment preferences. One group consisted of those drawn to suburban living, with a preference for larger lots and houses, auto use, and good schools.

FIGURE 3

Distinct Modal Orientations Suggested by Analysis of the MobiDRIVE Data

- Auto Oriented (34%)
- Green (26%)
- Multimodal (40%)



These tended to be more affluent families with older children. Another group was the opposite: its orientation was toward urban settings with higher density and more urban activity. Members of this group tended to be professionals and households without children. The third group was primarily focused on transit accessibility, but also on good schools and less dense environments. Members of this group tended to be less-affluent, younger families. The models we used not only provide information on the different segments (or classes) of behavior, but also the size of each segment. In the case of the Portland sample, the division was 43 percent suburban oriented, 27 percent urban oriented, and 30 percent transit oriented. These results suggest that people have strong modal preferences.

To study this issue further, we used a six-week household travel and activity diary from Germany (*MobiDRIVE*). The duration of this survey allows us to observe modal patterns and preferences that are difficult to detect in a typical one- to two-day survey. The model results indicate three groups distinguishable by their modal preferences. These are depicted in Figure 3. We use a Venn diagram to demonstrate where individuals fall in terms of orientation toward different modes. Each circle corresponds to one of four main modes: auto, transit, bike, and walk. The first group consists of people strongly oriented toward the auto. These individuals tend to walk when they don't drive. The second group appears on the opposite side and consists of "green" travelers who prefer not to drive. The third group consists of travelers who have more balanced preferences that include the auto along with transit and/or biking. Note that membership in these groups is based on *preferences*, after controlling for the modal alternatives available for any given trip. The division of the sample was 34 percent auto oriented, 26 percent green, and 40 percent multimodal. These splits are based on the German context we analyzed and would likely be different in the US.

In both the residential choice analysis and the mode choice analysis, the models that explicitly allow for distinct market segments provide a better fit to the data than other approaches for capturing heterogeneity. More importantly, the behavioral underpinning of unobserved heterogeneity provides a richer and more robust framework for tailoring different policies to different groups. Further, the structure of the model helps explain behaviors that may appear irrational, such as why people drive even when there are alternatives that appear more attractive.

CONCLUSION

Predicting behavior is critical for transport policy making, system design, and operations. It is essential to anticipate the actions of users in order to effectively design and manage transportation systems and to analyze the potential of policies designed to change behavior. Predicting behavior is challenging—humans have varying preferences, motivations, experiences, and decision-making processes. Indeed, forecasting demand has proven elusive, with a long history of poor predictions. However, ignoring the demand side due to its complexity is not the answer. We must enrich our models by incorporating important explanatory variables such as environmental factors, social influences, and heterogeneous attitudes and values. If such factors are not taken into account, it will appear that people are making irrational transport choices and modeling will fail to guide public policy to the best possible outcomes. ♦

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The Davis Bicycle Studies

Why do I bicycle but my neighbor doesn't?

SUSAN L. HANDY

Pick a city, any city in the US, and then pick a house within that city. Open the door of its garage and you're likely to find a bicycle. Chances are good that it is covered with dust or has a flat tire. If not, and if its owner has in fact used it any time recently, odds are the purpose was exercise or recreation. Compare this to a garage, any garage, in Davis, California. Inside you're likely to find several bicycles—more bicycles, perhaps, than people living in that house. In all probability, one or more of those bicycles is used at least weekly, not for exercise or recreation but for transportation—to get the rider to work, school, the store, a restaurant, or another destination in town. Davis is one of the few places in the US where bicycling is a substantial mode of transportation. With the goal of helping other communities in their efforts to promote this low-cost, low-polluting, health-promoting mode, my students and I have undertaken a series of studies over the last five years to understand bicycling in Davis.

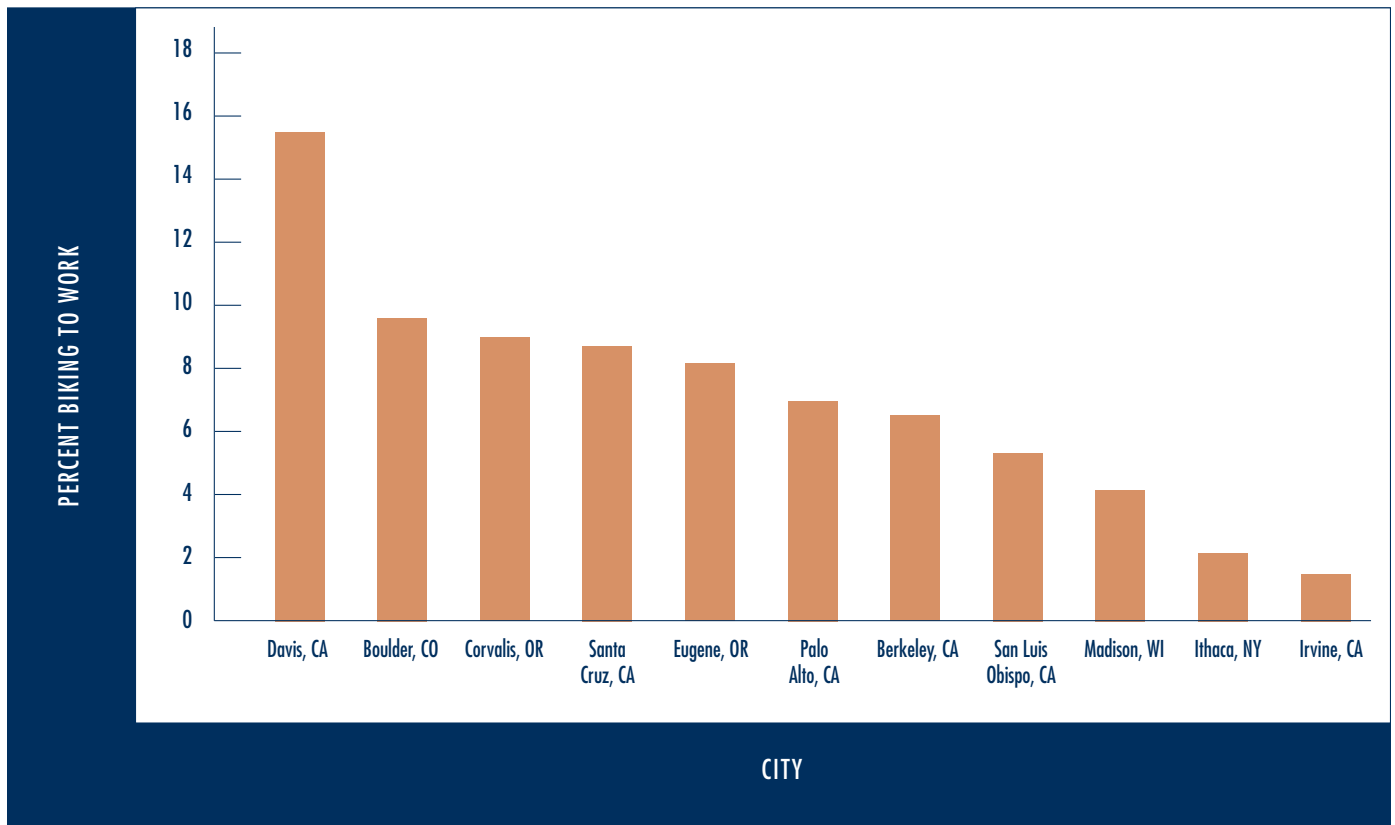


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Davis gained a reputation as a bicycle-friendly town as early as the 1950s. The city has many natural advantages for bicycling: it is flat, compact, and has favorable weather for much of the year. But its bicycle friendliness also reflects concerted policy efforts. Plans for an expanded University of California campus in Davis in the late 1950s featured extensive bicycle paths. A few years later, a Davis family returning from a year in the Netherlands inspired city officials to embrace bicycling. In 1967, the city striped the first bicycle lanes in the US. In the years that followed, city staff experimented with a variety of designs for bicycle facilities and for accommodating bicycles at traffic signals. Meanwhile, the university invented the bicycle roundabout, now used at other schools, to handle the large number of bicyclists on campus. Today, Davis has over 50 miles of on-street bike lanes and over 50 miles of off-street bike paths in an area of less than ten square miles, with 25 dedicated bike bridges and tunnels.

This infrastructure supports a substantial amount of bicycling. According to the latest American Community Survey data, over 15 percent of Davis workers usually commute to work by bicycle. Our own surveys provide even more impressive numbers. According to the 2010–11 Campus Travel Survey for UC Davis, 46 percent of faculty and 40 percent of staff who live in Davis commute to campus by bicycle, as do 47 percent of undergraduates and 55 percent of graduate students. Our 2006 survey of adults in Davis and five comparison cities showed that 53 percent of Davis residents bicycled at least once in the previous week. Of those who biked, over half did so for transportation rather than recreation. In 2009, we surveyed students at Davis High School and found that just over one third usually bicycle to school. The same year, counts of bicycles in the racks at elementary >

FIGURE 1
Percent of Workers Usually Bicycling to Work



Perhaps even more interesting than the fact that so many people in Davis bicycle is the fact that so many more don't.

schools in the city found that the share of students bicycling to some schools is as high as 25 percent. When we surveyed parents at Saturday morning soccer games in 2006, nearly 20 percent reported that their children had bicycled to the game. In comparison, less than 1 percent of daily trips in the US are by bicycle.

But perhaps even more interesting than the fact that so many people in Davis bicycle is the fact that so many more don't, despite the favorable conditions. Nearly half of adults had not bicycled in the previous week, over half of students arrived at the high school by car, and over three quarters of soccer players were driven to their games. So why do some Davis residents bicycle but others don't?

The obvious answer is distance. Because neighboring cities are separated from Davis by 10 miles of agricultural land, most residents who do not work in Davis face commute distances beyond what they would consider feasible for bicycling. In our survey, 47 percent of residents who work in Davis commute by bicycle, compared to less than 4 percent of residents who work outside of Davis. Among campus employees, only about 2 percent of those who live outside of Davis commute by bicycle. But distance doesn't explain everything. Most UC Davis faculty and staff who live in Davis do not bicycle to campus even though they live less than three miles away. So what else, besides distance, explains why some Davis residents bicycle but others don't?

For adults, the answer has much to do with individual attitudes. In analyzing the data from our 2006 survey, we found that comfort with bicycling was one of the most important factors differentiating residents who regularly bicycle for transportation from those who don't. Another one of the most important factors was agreement with the statement "I like riding a bike." Those who "strongly agreed" with this statement were far more likely to bicycle regularly even than those who just "agreed."

The pattern holds within Davis and each of the other cities. How people feel about bicycling influences how often they bicycle, although it is also possible that how often people bicycle over time influences how they feel about bicycling. Not surprisingly, given how frequently they bicycle, Davis residents are generally more comfortable bicycling and like bicycling more than residents of other cities. Nearly two thirds of Davis residents said they were comfortable bicycling on a four-lane street with bicycle lanes, compared to just over half of the residents of Turlock, CA, another Central Valley city of about the same size as Davis but lacking its bicycling infrastructure and culture (Table 1). Thirty-two percent of Davis residents strongly agreed that they "like riding a bike" but only 13

TABLE 1
Bicycling and Attitudes

	Davis, CA	Boulder, CO	Eugene, OR	Chico, CA	Woodland, CA	Turlock, CA
Percent bicycling at least once per week	53%	50%	38%	37%	20%	12%
Percent comfortable bicycling on 4-lane street with bicycle lane	66%	53%	58%	61%	54%	53%
Percent strongly agreeing that "I like riding a bike"	32%	34%	30%	18%	16%	13%

percent of Turlock residents felt this way. Perhaps Davis residents bicycle more not only because the good bicycling conditions here may change how people feel about bicycling, but also because Davis attracts residents who feel comfortable with and like bicycling. Indeed, Davis residents said that a community’s orientation toward bicycling was an important factor in deciding where to live much more often than residents of the other cities did, and those who assigned the most importance to this factor were also the ones who were most likely to be bicycling.

For children, whether one bicycles also has a lot to do with attitudes, but the attitudes of parents are as important as the attitudes of the children themselves. Distance from home to the soccer field was of course an important factor in whether or not families bicycled to games, as was the ability of the child to bicycle. But equally important was whether the parent regularly bicycled more than once per week and whether the player bicycled to school (Figure 2).

In other words, some families are simply more bicycle oriented than others. We saw this same effect in our study of bicycling to high school: distance to school was important, but students with parents who were willing to chauffeur them places and did not encourage bicycling were far less likely to bicycle to school. Teens’ having a driver’s license and access to a car—conditions over which parents have a significant influence—also reduced bicycling. The students’ attitudes—including liking to bicycle and confidence in bicycling—mattered as well, but much less so than parental encouragement. Surprisingly, friends’ opinions seemed to have no influence at all. >

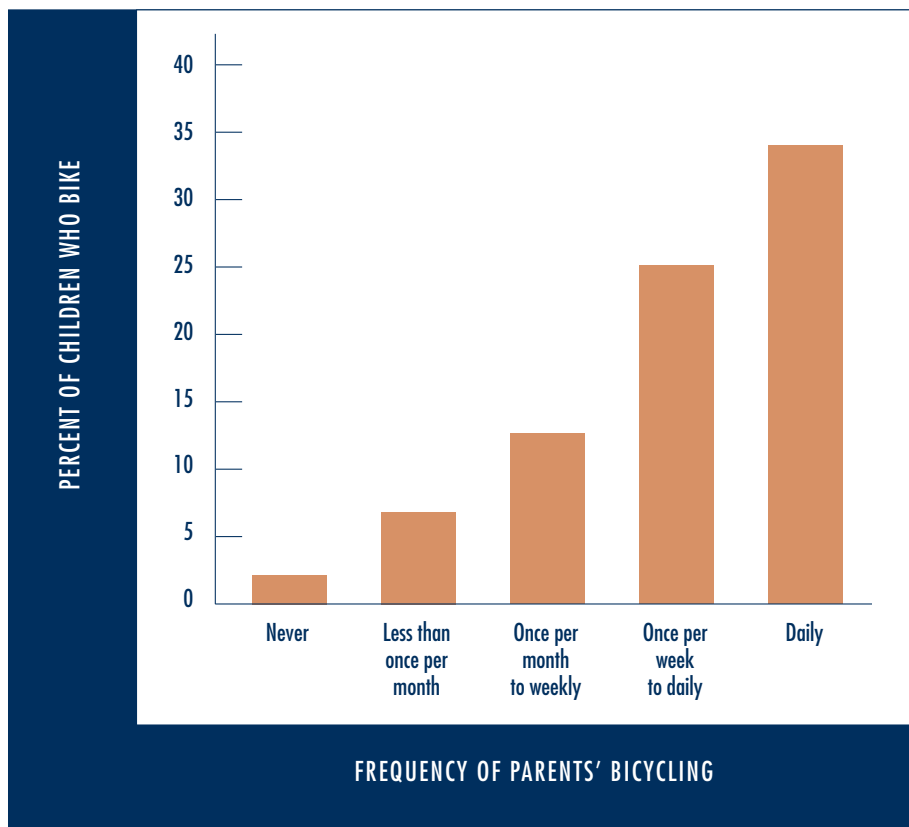


FIGURE 2

Percent of Davis Children Who Bike to Soccer Games by Frequency of Parents’ Bicycling



In all these studies, gender differences play an important role: women are less likely to bicycle regularly or to commute by bicycle, and girls are less likely to bicycle to soccer games or to school. In our 2006 survey, women expressed greater concern for safety than men, since they are more likely to fear both being in a collision and being attacked. They reported feeling less comfortable bicycling and they liked bicycling less than men. Among students, faculty, and staff at UC Davis, under 60 percent of women said that they are “very confident” riding a bicycle, compared to over 80 percent of men. For high school students, we found similar differences: girls liked bicycling less and felt less confident bicycling. These differences in attitudes between men and women clearly contribute to their differences in bicycling (Table 2).

A consistent message thus emerges from our Davis bicycle studies: while good infrastructure is necessary to get many people bicycling, it is not sufficient for getting most people bicycling. In our studies, the effect of infrastructure on bicycling appears to be as much indirect as direct, since good infrastructure attracts bicycling-inclined residents to the area by increasing bicycling comfort and enjoyment. But, as Davis demonstrates, even with good infrastructure cities hoping to increase bicycling will need to find ways to change attitudes. For example, training programs for children and adults can help to increase confidence in bicycling ability, while promotional events may help to increase liking to bicycle. Such activities encourage more residents to take advantage of the opportunity to bicycle that good infrastructure provides.

Many cities in Europe have combined such programs with infrastructure investments—and with disincentives for driving—to good effect. My favorite example is Odense, Denmark, a city about three times the size of Davis where one quarter of all

	WOMEN	MEN	EVERYONE
Bicycled in the last 7 days – adults	50%	56%	53%
Usually bicycled to work – adults	31%	36%	33%
Bicycled to campus on given day – faculty and staff	42%	54%	48%
Bicycled to campus on given day – undergrad and grad students	48%	54%	52%
Usually bicycled to high school – students	30%	43%	37%
Bicycled to soccer game – children	14%	22%	18%

TABLE 2
Bicycling and Gender

trips are by bicycle. Densities and distances are similar to Davis, but the quality of the bicycle infrastructure puts Davis to shame. On my stay there several years ago, I was particularly impressed with the bicycle signage, parking facilities, and “green wave” signals (a sequence of traffic signals timed for the speed of bicycles rather than cars). The live bicycle counts publicly displayed on an electronic sign in the city center were especially fun. The city has implemented many creative programs in its efforts to increase bicycling, including giving bicycles to domestic workers, taking senior citizens on guided bicycle rides, and lending bicycle trailers to parents of young children. The city’s efforts produced an 80 percent increase in bicycle trips between 1984 and 2002.

Personally, I find it frustrating that bicycling in Davis is not more pervasive. I moved to Davis for my job rather than for the bicycling, but I naturally embraced bicycling as my primary mode of travel once I got here. Sure, I believe in the importance of minimizing my driving, but I also simply enjoy getting on my bike more than I enjoy getting into the car. This may have something to do with all the time I spent getting around by bicycle from the age of four or five through my high school years. Now I can’t imagine going back to a car-dependent lifestyle. And that is exactly what my research team and I are trying to understand in our next study: where do attitudes toward bicycling come from and why do some people enjoy bicycling so much more than others? We’ll see. ♦

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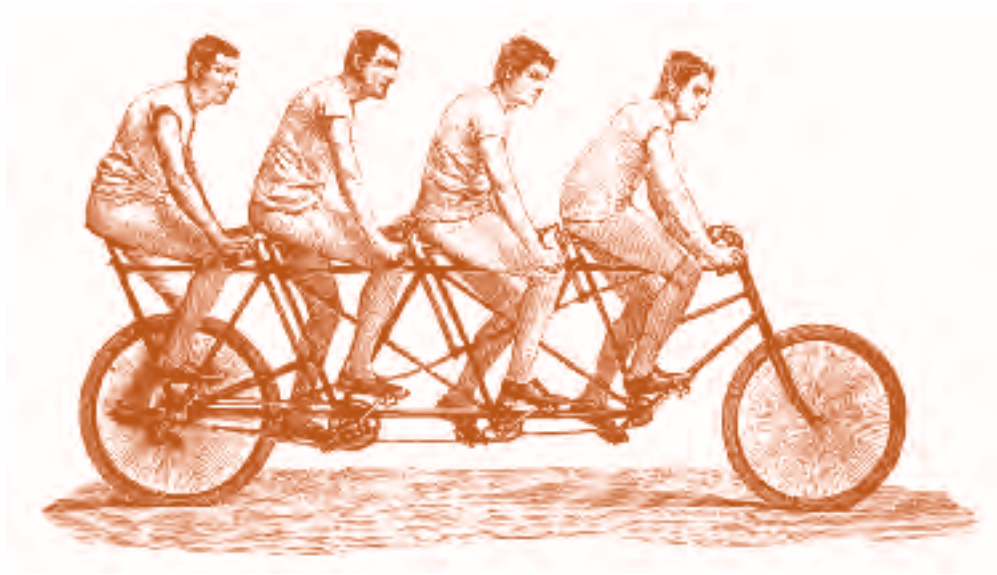
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Worldwide Bikesharing

SUSAN SHAHEEN AND STACEY GUZMAN



Bikesharing has evolved greatly since the first program was launched in the Netherlands in the mid-1960s. As of May 2011, there were an estimated 136 bikesharing programs in 165 cities around the world, with 237,000 bikes on the streets. In the Americas, bikesharing activity has spread to Canada, Mexico, the US, Argentina, Brazil, and Chile. Asia, which represents the fastest-growing bikesharing market today, has programs in China, South Korea, and Taiwan.

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BIKESHARING HISTORY

Bikesharing has passed through three distinct generations. First-generation bike-sharing, or White Bikes, began in Amsterdam in 1965. Fifty bicycles were painted white, left permanently unlocked, and placed throughout the inner city for the public to use freely. Providing the bicycle was the main component in this free bike system. Because users often stole or damaged the bikes, this initiative failed soon after its launch. Despite Amsterdam's disappointing experience, the bikesharing concept caught on.

Problems with first-generation bikesharing led Copenhagen to launch an improved bikesharing model in 1995. This led to the second bikesharing generation, known as coin-deposit systems. The main components of this generation are: 1) bicycles distinguished by color and special design; 2) designated docking stations in which bikes can be locked, borrowed, and returned; and 3) small deposits to unlock bikes. By designating specific bicycle station locations and adding coin-deposit locks, second-generation systems are much more reliable, as users have a defined and secure space to access available bicycles. However, theft is still a major problem with coin-deposit systems largely due to customer anonymity.

Building upon previous experience, third-generation bikesharing is gaining more widespread popularity by incorporating advanced information technologies (IT) for bicycle reservations, pick-up, drop-off, and information tracking. Third-generation bikesharing has four main components. First, program bicycles are distinguished by special designs or advertising displays on the bikes. Second, each program employs docking stations. There are two types of docking station—fixed and flex. The majority of bikesharing programs use fixed stations, which are designated stations with multiple bicycle docks and a kiosk. Flex stations use mobile phone technology and street furniture (i.e., a stop sign post) for bicycle pick up and drop off. Users of flex stations receive a code on their mobile phone to unlock bicycles. They leave bikes at major intersections and inform the program where the bicycle is locked. This approach makes bicycles available throughout an entire city, and it minimizes the amount of infrastructure needed to operate a program. A third major component is the user interface necessary for check-ins and check-outs at the kiosks. Finally, advanced technology (e.g., mobile phones, magnetic stripe cards, and smartcards) allows users to locate, reserve, and access bicycles. Today, most bikesharing programs are third-generation systems.

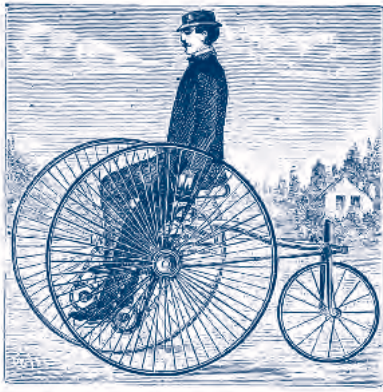
Vélo à la Carte, launched in 1998 in Rennes, France, was the first IT-based system. Today, the most widely known IT-based system is Vélib' in Paris. To date, Vélib' operates with 20,600 bicycles and 1,451 bike stations, which are available every 300 meters throughout the city center. In its first year of operation, Vélib' reported 20 million trips made.

In the Americas, Washington, DC was the first to implement an IT-based system. Today, the largest third-generation program in North America is BIXI in Montreal. Launched in May 2009, Montreal's BIXI operates with 5,000 bicycles and 400 stations. The program has expanded into Toronto and the Ottawa-Gatineau area.

The bikesharing program in Hangzhou, China currently operates with 61,000 bicycles and over 2,400 bike stations. As the largest bikesharing program in the world, the Hangzhou experience provides unique insight into bikesharing (more below). ➤

TABLE 1
Worldwide Bikesharing Programs

COUNTRY	PROGRAMS	BICYCLES	STATIONS
Argentina	1	560	15
Australia	2	2,600	200
Austria	3	1,500	82
Belgium	1	2,500	180
Brazil	2	452	43
Canada	1	6,100	490
Chile	1	150	15
China	19	123,172	4,422
Czech Republic	1	30	16
Denmark	3	2,650	187
France	29	36,830	3,141
Germany	5	13,330	811
Ireland	1	550	44
Italy	19	3,763	362
Japan	1	150	15
Luxembourg	2	400	64
Mexico	1	1,200	90
Monaco	1	10	2
Norway	1	1,660	154
Poland	1	155	13
Romania	1	300	3
Slovenia	1	300	31
South Korea	2	2,031	185
Spain	25	14,048	1,142
Sweden	2	1,500	110
Switzerland	1	600	45
Taiwan	2	5,000	61
United Kingdom	2	12,091	820
United States	4	3,122	313
Total	136	236,754	13,056



DEMAND-RESPONSIVE, MULTI-MODAL SYSTEMS

Emerging fourth-generation systems include all the main components seen in third-generation systems but differ in that they are linked with public transit. The goal is seamless integration of bikesharing with public transportation and other alternative modes, such as taxis and carsharing. This means that bikesharing stations and parking are conveniently located near transit stations, transportation schedules (such as bus and train arrivals and departures) are coordinated, and a single payment smartcard creates access to all available options.

Cleaner technologies are also a key development in fourth-generation systems. BIXI in Canada has solar-powered, mobile stations that will likely be standard in future systems. The stations can be moved to different sites after usage patterns are observed. Other improvements in this generation include cleaner technologies and incentives that encourage sustainable bicycle redistribution. Giving riders a price reduction or extra time credit for leaving bicycles at empty docking stations can reduce the need to use trucks to redistribute bicycles.

BIKESHARING BENEFITS

Bikesharing has many potential benefits for individual users and society, but research on the social and environmental benefits of bikesharing is limited. Early program data suggest that bikesharing has the potential to reduce emissions due to modal shifts. For instance, SmartBike, Vélib', and BIXI have estimated the average distances for trips that their programs divert from other modes of travel (Table 2). If bikesharing replaces trips made by cars, there is a notable potential to reduce GHG emissions.

Some programs have reported on modal shifts attributable to bikesharing's introduction. After the 2007 launch of Bicing in Barcelona, the city's bicycle mode share more than doubled from 0.75 percent in 2005 to 1.76 percent in 2007. Following Vélib's 2007 launch, the bicycle mode share in Paris increased from about 1 percent in 2001 to 2.5 percent in 2007. Velo'v in Lyon, France reported that bicycle use reduced the automobile mode share by 7 percentage points. A survey of SmartBike members in Washington, DC found that 16 percent of their bikesharing trips would have otherwise been made by car.

TABLE 2
Average Bikesharing Distances
Covered by Bicycle Per Day

PROGRAM	CITY	AVERAGE DAILY DISTANCE COVERED BY BICYCLE
BIXI	Montreal, Canada	35,075 km (2009 data)
Capital Bikeshare	Washington, DC	8,369 km (2011 data)
SmartBike	Europe (Norway – Trondheim, Drammen, and Oslo; Sweden – Gothenburg and Stockholm; France – Rennes, Caen, Dijon, and Perpignan; Italy – Milan; Spain – Barcelona); and the US (Washington, DC)	200,000 km (2008 data)
Vélib'	Paris, France	903,104 km (2010 data)



BIXI



Vélib'



Capital Bikeshare

While limited, available data also suggest that bikesharing has changed behavioral trends. For example, during the first year of Velo'v, Lyon documented a 44 percent increase in bicycle trips. Ninety-six percent of Lyon's bikesharing members were new users who had not previously bicycled in the Lyon city center. In addition, bicycle riding in Paris increased by 70 percent after the launch of Vélib'.

BIKESHARING IMPLEMENTATION: LESSONS LEARNED

The evolution of bikesharing technologies and business models has led to a range of options for program implementation. For instance, Mexico City—one of the most congested cities in the world—implemented bikesharing as a way to help alleviate traffic congestion. Despite historically low cycling levels, this program has reached capacity at 30,000 members, with a waiting list to join. Hangzhou—a city with historically high levels of cycling—launched bikesharing as a feeder service for public transit throughout the city by placing the docking stations near transit stops. Hangzhou's program has expanded several times to meet demand. Montreal deployed bikesharing as a strategy to complement bus and rail transportation because it provides a low-carbon solution to the “first mile/last mile” problem. By bridging the gap between existing transportation modes, it encourages individuals to use multiple modes. Residents fully embraced the program as part of everyday transportation, with BIXI users completing 1.1 million trips during the first season and 3.3 million trips during the second. These examples suggest that despite varying cycling levels, and differing transportation needs, bikesharing has been able to adapt and succeed under a range of circumstances. ➤

The goal is seamless integration of bikesharing with public transportation and other alternative modes.



To promote success and future bikesharing growth, cities must develop a comprehensive bike-sharing strategy including safety campaigns, linked public transit options, and cycling policies. A comprehensive strategy also encourages city officials to favor supportive infrastructure, such as bicycle lanes, and policies that increase bikesharing accessibility and overall safety. Lessons learned from past and present programs provide key insights into successful bike-sharing implementation.

Bikesharing programs must overcome several challenges to ensure future growth. Despite technological advances, both third- and fourth-generation bikesharing programs must consider bicycle theft and vandalism. A 2009 survey of Vélib' reported that, since its launch in 2007, 7,800 bicycles disappeared and another 11,600 were vandalized. High rates of theft raise concerns since Vélib' employs bicycles that cost about €400 (US \$530). To limit the impact of theft and vandalism, Hangzhou's program uses inexpensive bicycles.

Another area to consider is bicycle redistribution, which refers to the process of relocating bicycles according to demand patterns. Vélib', for instance, manages its bicycle fleet by using natural gas vehicles to transport bikes from one station to another. BIXI and Hangzhou use trucks to redistribute bicycles. BIXI has incorporated on-board computers in its trucks so the drivers can easily assess which stations

are overcrowded or are experiencing bicycle shortages. Programs such as BIXI, Vélib', Capital Bikeshare, and DublinBikes also encourage redistribution by providing users with an additional fifteen minutes at no extra cost to relocate their shared bicycle from a full station to a nearby station with available return slots.

Helmet laws also present a concern for bikesharing programs. At present, the largest bikesharing programs (e.g., Vélib', BIXI, and the Hangzhou Public Bicycle system) do not require helmets for users over 18. In contrast, helmet use for Melbourne Bike Share in Australia is mandatory for all ages, and Melbourne's volume of users and trips remains low compared to other bikesharing programs. Many critics view Melbourne's mandatory helmet law as a major contributor to its poor performance.

Cities also need to improve bicycle infrastructure. A survey by Jennifer Dill and Theresa Carr found that every additional linear mile of bike lanes per square mile leads to a 1 percentage point increase in bicycle commuters. While this survey does not prove a cause-and-effect relationship, it does highlight the fact that commuters will use bicycle lanes when provided.

HANGZHOU PUBLIC BICYCLE

The Hangzhou Public Bicycle program in China provides many insights. In a March 2010 survey of Hangzhou Public Bicycle members and non-members, we found that bikesharing is attracting users who simultaneously employ other transportation modes such as buses, walking, autos, and taxis. In addition, users are incorporating bikesharing into their everyday commute. The survey also found that member households with personal vehicles were using bikesharing services. In fact, members exhibited a higher rate of auto ownership (22 percent) than non-members (11 percent). This suggests that car ownership does not reduce the likelihood of bikesharing use.

Overall, the Hangzhou survey found that members were satisfied with the service. Recommendations for program improvement included more bicycle parking spaces, increased bike availability (more stations and bikes), and extended service hours. Members also indicated that the program should provide real-time information regarding bike and parking availability. Non-members noted that improving bicycle locking mechanisms, increasing the number of stations, and improving the member enrollment process could attract them. These lessons can be used to expand bikesharing in Hangzhou and other cities.

CONCLUSION

A growing demand for sustainable transportation has led cities worldwide to adopt bikesharing. As of Spring 2011, there were an estimated 136 bikesharing programs in approximately 165 cities around the world, each learning lessons from the past and each other to gain a greater understanding of implementation and operational procedures.

Ongoing research is still needed, particularly in the areas of social and environmental benefits, sustainable business models (most bikesharing programs lose money), supportive infrastructure, and safety. Nevertheless, our case study on Hangzhou's bikeshare program suggests that auto ownership may not discourage bikesharing, which is a promising prospect for car-dependent cities worldwide. ♦

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Car ownership
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PARKING INFRASTRUCTURE AND THE ENVIRONMENT

MIKHAIL CHESTER, ARPAD HORVATH, AND SAMER MADANAT

WE KNOW SURPRISINGLY LITTLE ABOUT how parking infrastructure affects energy demand, the environment, and the social cost of vehicle travel. Passenger and freight movements are often the focus of energy and environmental assessments, but vehicles spend most of their lives parked. Because abundant free parking encourages solo driving and thus discourages walking, biking, and the use of public transit, it greatly contributes to urban congestion. The environmental impacts of parking and the driving it promotes are often borne by local populations and not the trip-takers themselves.

The transportation life-cycle assessment (LCA) framework allows us to understand the full costs of travel, including energy use and environmental effects. Past LCAs, however, have focused on evaluating the resources directly used for travel and have not considered the extensive parking infrastructure, including the costs of its construction, operation, maintenance, and raw material extraction and processing. This narrow focus is understandable given the diversity of parking spaces and the lack of available data on parking infrastructure. For example, consider the great differences in energy use and emissions associated with curb parking spaces, multi-story garages, and private home garages. Furthermore, it is difficult to assign the energy use and environmental effects of parking to individual actors. Should we assign the cost of parking to an automobile driver, or to the builder of the strip mall where the driver shops, or to the shop where the driver parks?

To determine the full social cost of parking, we develop a range of estimates of the US parking space inventory and determine the energy use and environmental effects of constructing and maintaining this parking. We find that for many vehicle trips the environmental cost of the parking infrastructure sometimes equals or exceeds the environmental cost of the vehicles themselves. Evaluating life-cycle effects, including health care and environmental damage costs, we determine that emissions from parking infrastructure cost the US between \$4 and \$20 billion annually, or between \$6 and \$23 per space per year.

A US PARKING SPACE INVENTORY

To estimate the number of parking spaces in the US, we have developed multiple scenarios that include survey data and new estimates for different types of parking spaces. We evaluate on-street, surface, and structured spaces.

There are roughly 240 million passenger vehicles and 10 million on-road freight vehicles in the US. All passenger vehicles require a home base and commuting vehicles also require a work space. In addition, using data from a nationwide inventory, we reach >



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TABLE 1

Parking Spaces in the US (in millions)

	ON-STREET	OFF-STREET		TOTAL	PARKING AREA AS % OF US LAND AREA
		Surface	Structure		
Scenario A	92	520	110	722	0.64
Scenario B	180	520	110	810	0.66
Scenario C	150	610	84	844	0.68
Scenario D	1,100	790	120	2,010	0.90

a figure of 105 million metered spaces. We add to this running total several different estimates of the number of additional spaces of different types, and summarize the estimates and their resulting land use characteristics in four possible scenarios in Table 1.

Scenario A includes the number of parking spaces at commercial sites, derived from national estimates of commercial floor area and the minimum parking requirements for each land use. This is added to the home spaces, work spaces, and the metered space inventory, taking into account the overlap between commercial square foot estimates and work spaces. Scenario A, with 722 million spaces, can be considered a conservative inventory before taking into account the high uncertainty about the number of on-street non-metered spaces.

In Scenario B, we evaluate roadway design guidelines and distances of urban and rural roadways to determine nationwide on-street parking. This estimate takes the mileage of non-bridge and non-tunnel urban arterial, collector, and local roadway shoulders and assumes that one-half of their potential area is designated as on-street parking with either one or both shoulders used. Adding this to Scenario A's estimate produces 810 million spaces. While Scenario B includes on-street parking, the estimate conservatively assumes that a small fraction of curbside urban roadway area is actually designated as parking.

Scenario C is based on observed ratios of four spaces per vehicle for cities and 2.2 spaces per vehicle for rural areas. Scenario C weights these ratios by urban and rural vehicle travel to produce a nationwide average of 3.4 spaces per vehicle, or 844 million spaces.

Finally, Scenario D is based on an unverified estimate of 8 spaces per vehicle that is often mentioned in planning literature; it produces an estimate of 2 billion spaces, which is the high end of our range. We include this ratio as an upper-bound assessment that could capture spaces missed in previous scenarios.

EMBEDDED ENERGY AND EMISSIONS IN PARKING INFRASTRUCTURE

Valuing and allocating the total cost of parking infrastructure is not simple because not all externalities can be priced, costs are borne by many people, and parking spaces are spread throughout the built environment. However, LCA is a framework to estimate the magnitude of these effects. LCA's basic tenet is that an activity like parking cannot



function without support from other services. Energy use, environmental degradation, and greenhouse gas emissions (GHG) result from parking construction and maintenance activities. Parking's physical infrastructure requires processed materials, energy, labor, and other inputs, which in turn depend upon their own supply chains. For example, asphalt requires aggregate, which is mined and then must be transported. Each of these activities consumes energy and produces emissions.

We evaluate the life-cycle effects of each parking space type and quantify the materials, energy use, GHG emissions, and conventional air pollutant emissions associated with it. After performing this analysis, we then normalize the results to a passenger-kilometer-traveled basis taking into account the varying lifetimes of parking spaces and structures. Our methodology measures only air emissions. Other major impacts from parking infrastructure include heat island effects and alterations to water flows (such as more frequent and higher peak flows, lower water tables, and increased chemical contamination). Thus our LCA costs are lower bound estimates.

Not all energy use and emissions generated by parking can be allocated to the automobile. The availability of parking encourages people to drive, but at the same time high automobile use encourages businesses, developers, and government agencies to provide parking. Accurately allocating all the environmental effects of parking between drivers and other actors is not possible because causality is unclear. However, it is important to >

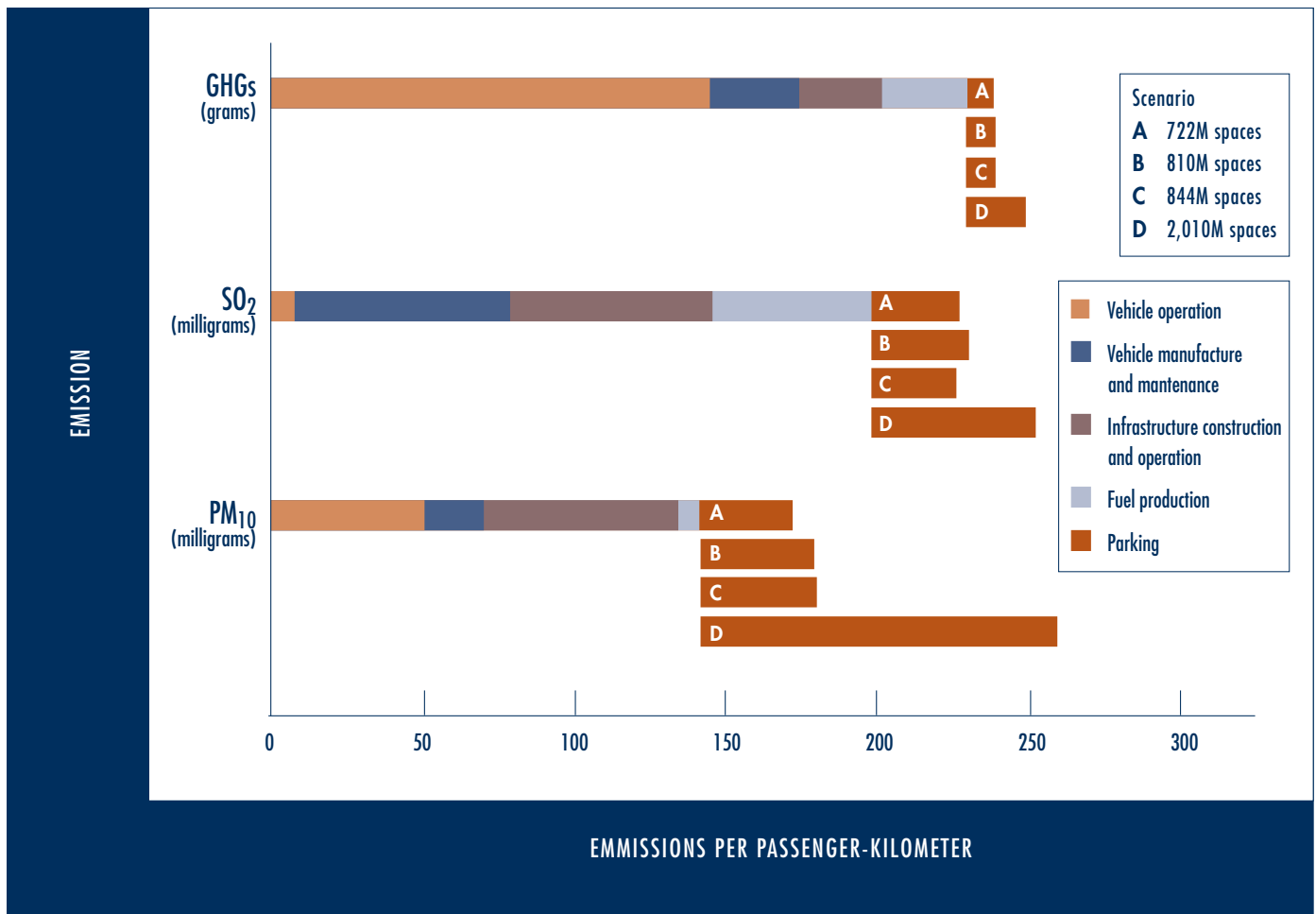


FIGURE 1
Life-Cycle Sedan Emissions per Passenger-Kilometer

illustrate the potential total costs of personal vehicle use. Figure 1 shows total emissions caused directly and indirectly by automobiles if all the LCA emissions from parking are attributed to automobiles.

In some cases larger reductions in environmental impacts may be achieved by focusing on parking infrastructure (and other life-cycle components) instead of the vehicle’s tailpipe, where significant strides towards reducing pollution have already been made. For certain pollutants, parking infrastructure contributes a significant share—and sometimes even the largest share—of life-cycle effects. For example, parking’s contribution to the production of SO₂, which causes respiratory damage and acid deposition, largely results from electricity generation in the supply chain. SO₂ emissions from parking exceed the SO₂ emissions from driving. The majority of parking-related PM₁₀ emissions, which cause cardiovascular harm, stem from hot-mix asphalt plants as well as the mixing and placing of asphalt. PM₁₀ emissions from parking are about the same as those from driving.



VALUING THE IMPACTS OF PARKING INFRASTRUCTURE EMISSIONS

Estimating the monetized health and environmental costs of parking infrastructure represents an important step in developing total transportation cost assessments to inform policy decisions. We evaluate these costs using an approach developed by the National Research Council's *Hidden Costs of Energy* study. This allows an assessment of the total impact of parking construction and maintenance by assigning damage costs to each pollutant. We can then evaluate the effects of parking in typical high-impact urban and low-impact rural counties. Using these estimates, LCA enables us to attach dollar amounts to the external costs of parking infrastructure.

The parking infrastructure estimated in Scenarios A through C costs the US between \$4 and \$20 billion per year. Per space, this amounts to between \$6 and \$23 per year. The low end of this range represents a parking space constructed in a low-density rural area, whereas the high end typifies a space in a high-density urban environment. Everyone bears this cost in the form of adverse health impacts, building damage, and reduced agricultural production, to name a few.

Underpriced parking not only increases automobile dependence but is also environmentally damaging to construct and maintain. We hope that our life-cycle assessment will help planners and public officials understand the full cost of parking. ♦

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Ending the Abuse of Disabled Parking Placards

DONALD SHOUP

ALMOST EVERYONE can tell an anecdote about disabled placard abuse. One of mine stems from a visit to the Capitol building in Sacramento. After noticing that cars with disabled placards occupied almost all the metered curb spaces surrounding the Capitol, I talked to one of the state troopers guarding a driveway entrance. He watched all the arrivals and departures at the nearby metered spaces every day. When I asked the trooper to estimate how many of the placards he thought were being used illegally, he responded, “All of them.”

Newspapers often report placard abuse, such as the scandal that occurred when 22 UCLA football players were found to be using disabled placards to park on campus; the athletes got their placards by forging doctors’ signatures for such conditions as asthma and palsy. UCLA seems to be unusual only in the large number of athletes who were caught misusing disabled placards, because similar scandals have erupted on other campuses. In 2003, the quarterback at Florida State University earned national attention for repeatedly parking illegally in spaces reserved for the disabled. Placard abuse is common enough to have its own website, handicappedfraud.org.

Making curb parking accessible to people with disabilities is a laudable goal, but treating disabled placards as free parking passes has encouraged widespread abuse by able-bodied drivers who simply want to park wherever they want, whenever they want, without paying anything. Because of the widespread abuse, disabled placards do not guarantee a physical disability. Instead, they often signal a desire to park free and a willingness to cheat the system. Placard abusers learn to live without their scruples, but not without their cars.

Anecdotes and newspaper reports are not hard evidence, but if placard abuse were rare, one would expect to find some studies that report little abuse. I have never seen one. Instead, I have seen several careful studies that show widespread abuse. A survey in downtown Los Angeles shows how extensive the abuse can be. A research team from UCLA observed a block with 14 parking meters for a full day, and most of the curb spaces were occupied most of the time by cars with disabled placards. For five hours of the day, cars with placards occupied all 14 spaces. The meter rate was \$4 an hour, but the meters earned an average of only 32¢ an hour. Cars parked free with placards consumed \$477 worth of meter time during the day, or 81 percent of the potential meter revenue on this block. Several drivers with disabled placards were observed carrying heavy loads between their cars and the adjacent businesses.



Placard abusers steal revenue from cities, and drivers with real physical disabilities have a harder time finding curb spaces, which are usually the most convenient spots for people with disabilities to park. When all the curb spaces near their destinations are occupied, drivers who have difficulty walking may have to park much farther away or even abandon their trips.

If a state exempts all cars with placards from paying at meters, how can cities prevent placard abuse *and* preserve disabled access? Virginia has a sensible policy. It exempts drivers with disabled placards from paying at meters, but it also allows cities to set aside this exemption if they give reasonable notice that payment is required. In 1998, Arlington removed the exemption for placards and posted “All May Park, All Must Pay” on every meter pole. Because it is easier to pull into and out of the end space on a block, Arlington puts meters reserved for drivers with disabilities at many of these end spaces. The purpose is to provide parking in convenient locations for people with disabilities, not to offer a subsidy that invites gross abuse. Cities can reserve the most accessible meter spaces for disabled placard holders, but accessible is not the same as free.

A neighboring city, Alexandria, is considering a similar opt-out policy as part of a broader strategy to manage on-street parking and reduce placard abuse. To gauge the seriousness of abuse, the Alexandria Police Department interviewed drivers who were returning to cars displaying disabled placards and found that 90 percent of the placards checked were being used illegally.

Because parking with placards seems to be an almost ethics-free zone, cities should aim to avoid creating financial incentives to abuse any placard policy. Raleigh, North Carolina, for example, allows drivers with disabled placards to park for an unlimited time



at meters, but requires them to pay for all the time they use. Placard users push a button on the meter allowing them to pay for time beyond the normal limit for other drivers, and enforcement officers can then check to see whether the cars using this privilege display a placard.

If people with disabilities must pay at meters, their difficulty in getting to and from the meters may be a barrier, especially at pay-and-display meters. If it is raining or snowing, the barrier will be even greater. To solve this problem, some cities offer placard holders the option to pay with in-vehicle meters or by cell phone. Offering these options can forestall objections that the payment method is itself an obstacle to people with disabilities.

Ending free parking for placard users will bring in new revenue that can pay for services benefiting all people with disabilities, not just drivers with placards. If a city proposes to end free parking for cars with placards, it can estimate the meter revenue currently lost because of placard use and commit all the new meter revenue to pay for specialized transportation services for everyone with disabilities.

The data from Alexandria illustrate how an all-must-pay policy can benefit the disabled community. The police survey found that placard abuse accounts for 90 percent of the revenue lost from the placard exemption. Alexandria also estimated that an all-must-pay policy will yield \$133,000 a year in new meter revenue currently lost to the placard exemption. If placard abusers account for 90 percent of this lost revenue, they misappropriate \$120,000 of the subsidy intended for people with disabilities, while people with disabilities receive only \$13,000. Spending the full subsidy to provide paratransit services or taxi vouchers for everyone with disabilities seems much fairer than wasting 90 percent of it to provide free parking for able-bodied placard abusers. The transportation subsidy for the disabled community will increase by 10 times, at no additional cost to the city government. Because almost all the additional spending will come at the expense of disabled placard abusers, it is easy to see why Alexandria is considering a shift to Arlington's all-must-pay policy, while Arlington is not considering a return to the all-placards-park-free policy.

Beyond raising revenue to finance new transportation services for everyone with disabilities, the all-must-pay policy can also eliminate the culture of corruption that has grown up around using disabled parking placards as free parking passes. Cities and states encourage this corruption by making it so easy, so profitable, and so rarely punished. Because enforcement is difficult, the chance of getting a ticket for placard abuse is so low that even high fines do not prevent violations.

Charging all drivers for parking at meters and spending the new revenue to provide transportation for the entire disabled community can improve life for almost everyone—except the drivers who now abuse disabled parking placards. ♦

FURTHER READING

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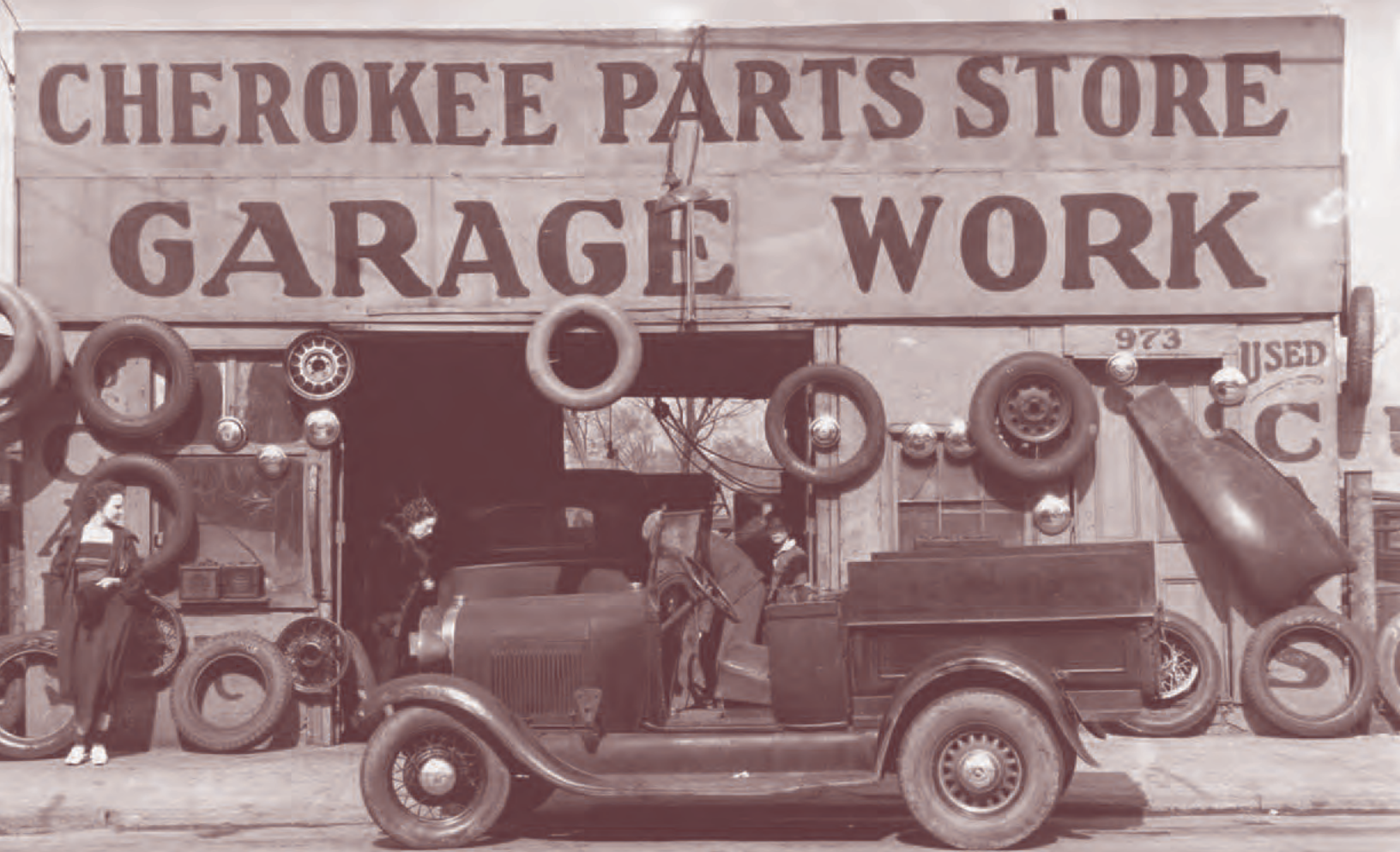
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