Roadway Infrastructure for Neighborhood Electric Vehicles

ARAM G. STEIN, KENNETH S. KURANI, AND DANIEL SPERLING

The neighborhood electric vehicle (NEV) is a small, electric car designed for low-speed, local trips in neighborhoods and urban areas. The market potential for NEVs depends in part on the availability of a network of safe and accessible roads. The processes involved in developing new infrastructure are explored, and some design concepts are presented. To accommodate NEVs safely on existing roads designed for large vehicles and fast-moving traffic, infrastructure standards and designs will need to be modified; this will occur through a process of experimentation as the market for NEVs grows and planners and engineers discover which designs work and which do not. The results of local experiments will provide the evidence for modifying state and federal rules and guidelines codified in geometric and traffic control policy manuals. Ultimately the provision and management of road infrastructure must become more flexible to accommodate alternatives to the full-size, gasoline-powered automobile.

Pedestrians, bicycles, automobiles, trucks, and buses are part of a larger infrastructure system. At certain times and places these modes compete for scarce resources—notably road space and parking. Other times they complement one another: pedestrians and bicyclists may work together to lobby for new paths that neither could obtain alone, or auto and transit trips may be linked to provide suburban residents with access to downtown employment. And at still other times, a travel mode may operate in a constrained environment or serve a specialized purpose such that it faces little competition from any other mode. Travel modes may share common facilities or may travel on dedicated rights-of-way (ROWs). Motor vehicles have streets and freeways; bicyclists have streets, bike lanes, and paths; and pedestrians have crosswalks, sidewalks, and pedestrian malls.

Of all these modes, motor vehicles—automobiles and trucks—have shaped U.S. cities, in part through the demands for specific infrastructure designed to serve them. Energy-efficient and low-polluting alternatives such as walking, bicycling, and using small vehicles have been marginalized. Many suburban residents have nowhere to walk or cycle. Their shops, restaurants, theaters, schools, and workplaces are inaccessible except by car. Urban residents play a daily game, circling blocks in search of a parking space large enough for their automobile—one more low-speed, stop-and-go, inefficient, and highly polluting trip.

This paper explores infrastructure designs for small, less polluting vehicles suitable for nonfreeway travel. These vehicles are referred to as neighborhood electric vehicles (NEVs); others refer to these small cars, sometimes with slightly different applications in mind, as subcars (*1*), city cars, and station cars. [Note that these small cars could operate on other fuels or engines, but California's zero-emission vehicle mandate puts a premium on electric propulsion (see the papers by Lipman et al. and Sperling, this Record)]. NEVs are designed for short trips on surface streets, to carry small loads, and generally for one or two people, although they might be designed for additional passengers. They are not intended to be freeway capable, allowing for a dramatic reduction in energy and power needs. NEVs would serve those trips that consumers find too long for walking and bicycling but that do not require the use of full-size automobiles.

Institute of Transportation Studies, University of California, Davis, Davis, Calif. 95616.

Existing competitive and complementary relationships among travel modes will be upset and reformulated when a new travel mode is introduced. The purposes of this paper are to identify the types of infrastructure needed to accommodate NEV transportation, to understand the underlying institutional processes involved in designing and implementing improvements, and to present some generalizable NEV-friendly infrastructure concepts.

DIVERSIFYING TRANSPORTATION INFRASTRUCTURE

High levels of safety and accessibility have been attained by refining vehicle technology and driver capabilities for multipurpose roadways. NEVs are not always well served by this system, but that does not mean that NEVs are inherently less useful and less safe than full-size automobiles. With their own infrastructure and supportive design practices, NEVs can be far safer and more convenient than full-size cars. With their own lanes, paths, and parking, NEV users could attain high levels of safety, convenience, and accessibility. NEV-friendly infrastructures would take account of and exploit the NEV's reduced length and width, lower speed, lighter weight, and reduced noise.

The type and scale of NEV infrastructures would vary across communities, depending in part on which vehicle types prevail. The slower, open chassis "low-end" NEVs [with top speeds of about 35 km/hr (~20 mph)] may be too vulnerable on high-speed, high-volume streets and may require more extensive traffic separation than the quicker, fully enclosed "high-end" NEVs [with top speeds of up to 65 km/hr (~40 mph)]. High-end NEVs may require only limited changes to the existing networks.

Improvement in safety, however, is only one reason for enhancing and diversifying infrastructures. Regardless of safety features or speed capabilities, NEV users may prefer separate lanes and paths because of the enhanced driving experience or easier access to destinations. Demand for NEV-friendly infrastructure may depend on the traffic environment and driver preferences, as well as safety and performance attributes of NEVs.

Separate NEV lanes and paths might be provided where there are high speed limits, high truck volumes, multiple lanes, a history of reckless driving and car accidents, or congested traffic. Where separate NEV lanes and paths are in place, traffic control devices will be necessary to inform the public of proper facility use. Lane use signs would be needed to inform NEVs of upcoming lane separation and merging lanes, warning and ROW signs would have to be placed at the intersections of NEV paths and roadways, and route guidance signs similar to street signs and route guidance signs used for orienting motor vehicles on the larger network will be necessary to orient NEV traffic on NEV paths. Preferential parking might be provided in congested downtown areas or at transit stations.

NEV-centric infrastructure could be broadly introduced into new land use developments. New developments can be designed around NEV-centric design concepts. Land use designs can emphasize short trips; ROWs can be created for an internal network of NEV paths. NEVs are suited to pedestrian- and transit-oriented developments and mixed-use neighborhoods where many activities are within easy access of residences. NEVs represent a useful and possibly superior vehicle for residents of such communities. An expanded discussion of neotraditional land uses that may be amenable to NEV transportation can be found elsewhere (*2–4*).

EVOLUTION OF TRANSPORTATION INFRASTRUCTURE

It will take time for NEV-friendly and NEV-centric infrastructures to evolve. Today's infrastructures did not appear spontaneously in their present forms. Many years were spent expanding and refining the networks and developing standard practices. Traffic lanes were quite narrow until vehicle speed capabilities increased and trucks began sharing the roads. When safety became an issue, streets were widened, speed limits lowered, or restrictions imposed on vehicle commingling. Eventually geometric standards for street widths, curves, and intersection designs were codified in state and federal rules and guidelines. Traffic control devices were created and modified to enhance safety not only for autos and trucks but also for bicycles and pedestrians.

Infrastructure design and management (and codified rules) evolve over time as a result of continuing experimentation. To evaluate which is the safest and most comfortable lane width, engineers experiment with a variety of lane sizes and vehicle speeds. They test driver responses to new traffic control concepts. They experiment with sign sizes, symbols, and locations. NEV-centric designs will evolve through this same process of experimentation, although modern computer simulation techniques are now available to expedite the process.

Infrastructure design does not evolve randomly; it evolves in response to shifting demand and organized interest groups. Throughout the history of civilization engineers have responded to changing transportation technologies, land use strategies, and demands for greater transportation safety and efficiency (*5*). The demand for automobiles and trucks over carts and carriages resulted in a dramatic shift in engineering design. Before the automobile made its debut, bicycle lobbies were a major voice in the design of transportation facilities (*6*). Today although small relative to automobile lobbies, bicycle lobbies still take an active role in engineering design. The construction and modification of road infrastructure to serve NEVs will depend on advocacy by NEV interest groups. These lobbies, like all the others, will include vehicle owners, vehicle manufacturers, and various public interest groups.

In the near term one would expect that NEVs will be purchased in small numbers by people who live in places amenable to their use. As the number of NEV owners grows, towns will begin incremental improvements to local infrastructures. Increased NEV-centric infrastructure will attract more people and vehicle manufacturers to the NEV concept, and as the market grows the NEV lobby will grow as well. Local lobbies will turn into regional and state lobbies, and eventually state and federal policies toward future community planning and roadway improvement projects will be influenced.

Consider the retirement community of Palm Desert, California. For years golf carts were used for recreation in Palm Desert, but they were not permitted on public streets except to travel to and from golf courses. Based in part on a survey of residents' desired golf cart use, Palm Desert and the South Coast Air Quality Management District lobbied the California state legislature to allow the city to conduct a golf cart pilot program. The state set conditions and required the local engineers to implement safety enhancements to the existing city streets. In response Palm Desert developed and implemented improvement strategies and created new design standards (*7*). The city now has golf cart lanes on higher-speed streets, separate ROWs, and new traffic control devices designed specifically for golf carts. In 1994 the city was evaluating the effectiveness of these infrastructures. This pilot program has stimulated interest in NEVs in several California cities including Davis, Sacramento, Berkeley, San Francisco, Santa Cruz, and Los Angeles.

CODIFYING GUIDELINES

The deployment and modification of roads and traffic controls are overseen by state and federal agencies. To enhance safety FHWA and the National Committee of Uniform Traffic Control Devices specify application, design, and placement standards for traffic control devices. FHWA states that traffic control devices "on all streets and highways in each State shall be in substantial conformance with standards issued or endorsed by the Federal Highway Administrator" (*8*). AASHTO establishes standard practices for geometric design of streets and highways and for bicycle facilities.

Local governments follow these state and federal standards and procedures for three reasons. First, the standards have evolved from years of refinement. If they are followed properly the safety and efficiency of transportation facilities will likely be improved. Second, for any projects that use state or federal financing, local authorities are required to comply with those guidelines; rarely would they be able to forgo those funds. Finally, if localities follow the standards, they may be less vulnerable to lawsuits charging negligence. Courts have recognized the individual's right to collect damages when injuries result from an improperly designed facility. The state and federal standards provide a framework for this notion of "proper" design.

Because the NEV is a new class of vehicle, NEV infrastructure will ultimately require new design guidelines set forth by AASHTO and FHWA. Before NEV-centric designs can be codified and published in policy manuals, they must be widely examined by many organizations and individuals. AASHTO states "During the developmental process, comments [are] sought and considered from all the States, the Federal Highway Administration, and representatives of the American Public Works Association, the National Association of County Engineers, the National League of Cities, and other interested parties'' (*9*).

The FHWA approval process for traffic control devices is also extensive. The city of Palm Desert, for example, spent 2 years petitioning FHWA to approve a golf cart symbol. It did finally succeed, but only after being forced to make numerous design revisions in accordance with conformity guidelines in the *Manual on Uniform Traffic Control Devices* (MUTCD) (*8*).

DESIGN AND IMPLEMENTATION

Starting Point for New Designs

Although AASHTO and FHWA have not specified any dimensions of NEV lanes and curves or the placement and contents of NEV signs, they do provide design processes. Local planners and engineers can use these existing processes contained in AASHTO's manual on geometric design and FHWA's MUTCD to help develop NEV-centric design concepts.

The most critical factor in geometric design is the ''design vehicle.'' The physical characteristics of this vehicle determine lane widths, curve radii, sight distance, grading, and parking. The design vehicle is specified to have larger physical dimensions and a larger minimum turning radius than most vehicles in the design class (*9*). Vehicle speed, acceleration, and braking capabilities are also parameters used in facility design. It will be necessary to specify these for NEVs to determine maximum grades, minimum length of passing zones and merging lanes, signal timing, as well as where NEVs will be allowed and what types of traffic separation will be required.

Table 1 compares the critical dimensions of AASHTO's design passenger car with the dimensions of the authors' proposed NEV design vehicle. On the basis of the author's review of existing NEV models and prototype attributes the authors propose a vehicle design width of 1.5 m (5 ft), sufficient for a fully enclosed NEV with spacious side-by-side seating. The authors also propose that the design length, wheelbase, and minimum outside turning radius be 2.7 m (9 ft), 1.8 m (6 ft), and 4 m (13 ft), respectively. As Table 1 shows the acceleration of AASHTO's passenger car far exceeds the capabilities of the NEV. It takes the AASHTO design passenger car 69 m (225 ft) to accelerate from 0 to 30 mph, whereas the NEV of the proposed design needs twice that distance. For this reason NEVs may require greater sight distances, longer merging lanes, and longer minimum green times for traffic signals at wide intersections with actuated signals calibrated for higher-speed traffic.

In the area of traffic control the MUTCD provides a list of five basic requirements for any traffic control device. Devices must (a) fulfill a need, (b) command attention, (c) convey a clear and simple meaning, (d) command respect of road users, and (e) give adequate time for proper response (*8*). Design, placement, operation, maintenance, and uniformity characteristics must all be considered to meet these basic requirements. The most challenging requirement that must be satisfied is conveying clear and simple meanings. Because NEVs are an unfamiliar technology, it may be difficult to find familiar words and images to represent the NEV in a manner that is accurate and easy to interpret. NEV attributes easiest to represent in visual images may be the small wheel base, short overhang over the front and rear wheels, and single or double vehicle occupancy. Educational plaques might include words such as *small, mini, micro, slow, reduced-speed,* and *low-speed.* So not to be confused with larger, freeway-capable automobiles, terms such as *vehicle, car,* or *cart* are preferred to *auto* and *automobile.*

Infrastructure Design Concepts

Figure 1 shows a simple network with a NEV path and lane and several traffic control devices. The path turns into a dedicated NEV lane when it joins a road for full-size motor vehicles. Suggested signage and geometric designs are presented in Figure 1 and are described below.

Geometrics

The NEV lane and one-way NEV path should be at least 2.1 m (7 ft) wide, providing at least a 0.3-m (1-ft) buffer zone to either

TABLE 1 Comparison of AASHTO and NEV Design Vehicles

	Design Vehicle Characteristics, by Vehicle Type	
Physical Attribute	AASHTO Passenger Car	Neighborhood Electric Vehicle
Height (m)[a]	1.30	1.37
Width (m)	2.14	1.53
Length (m)	5.80	2.75
Wheelbase (m)	3.36	1.83
Minimum Turning Radius[b]		
Outside (m)[c]	7.32	3.97
Inside (m)[d]	4.21	2.14
Acceleration (m/s^2)[e]	1.31	0.67
Distance required to accelerate from 0 to 30 mph (m)	69	134

[a]Conversion: 1 meter = 3.28 feet
[b]Vehicle speed less than 10 mph.
[c]Track of the outer front overhang.
[d]Track of the inner rear wheel.
[e]From 0 to 30 mph on level surface.

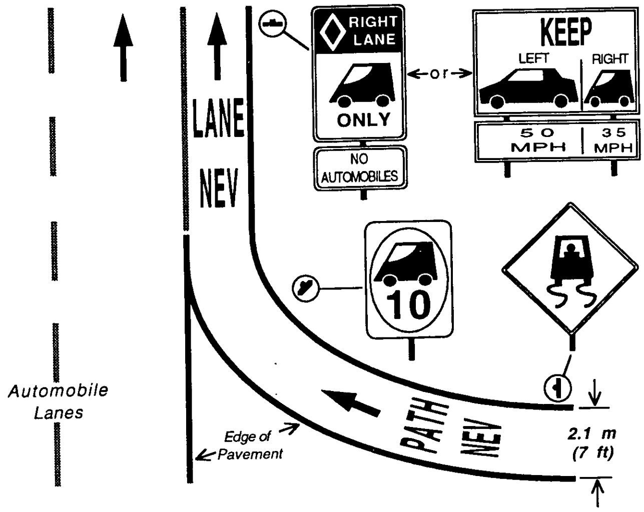

FIGURE 1 Suggested signage and geometric standards for NEVs.

side of the NEV. AASHTO specifies lane widths that provide at least this much space to either side of vehicles, even on facilities where speeds and traffic volumes are low. So not to be confused with an automobile lane, lane width should not exceed 2.4 m (8 ft). Clear lane markings, signs, and a preference toward lanes of minimum width will help reduce driver confusion. For purposes of drainage, clearance from roadside obstructions, and emergency stopping, NEV paths should have a 0.6-m (2-ft) graded area adjacent to the pavement. AASHTO specifies this minimum dimension for both motor vehicle and bicycle facilities (*9,10*). Where space permits, shoulders should be made wide enough for NEVs to completely pull off the traveled way. This becomes increasingly important as vehicle speeds and volumes increase.

The authors propose a wider lane and path standard than those developed for golf carts because the authors' design vehicle is wider than the golf cart and may operate above golf cart speeds on these facilities. In Peachtree City, Georgia, which has 97 km (60 mi) of golf cart paths (*11*), pavement widths for two-way paths are 2.4 m (8 ft), which is not wide enough to accommodate two NEV design vehicles passing each other. Before establishing extensive NEV networks, width criteria for lanes, paths, and curves should be matched carefully with the vehicle and its expected operating speed.

Traffic Controls

NEVs will require traffic controls to provide notices of warning, regulation, and direction. Figure 1 shows two types of traffic partition signs in the upper right. The preferential lane sign provides NEVs with the option of using a NEV lane, but would not require it. Slower NEVs could use the separate lane, whereas faster NEVs could commingle with traffic. For peak-hour NEV lanes, such a sign could be accompanied by parking regulation information. The other travel path sign strictly regulates lane use. This sign would require NEVs to use the separate lane. These signs may be appropriate in areas deemed unfit for commingling at all times by all NEVs. Respective lane speed information can also be posted on these signs or speeds can be stenciled onto the street surface.

Route guidance and warning signs are also invaluable on NEV networks. On NEV paths routes should be marked with NEV-specific signs to orient drivers. Warning signs should inform drivers of potential hazards, such as the tight curve shown in the example in Figure 1.

Implementation Strategies

Of the three types of surface streets—local, collector, and arterial—access to arterial streets is most problematic. Retrofitting of arterials will require creative solutions. Speed limits could be reduced, NEV lanes could use parking channels and road shoulders, and travel lanes may be narrowed to make space available for NEV lanes. NEVs may also use existing bicycle lanes, or ROWs can be expanded. Planners will see advantages and disadvantages in each strategy.

Modifying Street Parking

Curbside parallel parking spaces along arterial streets are a perfect size for NEV lanes. Conversion of parking spaces to NEV lanes might face strong opposition, however, from businesses and residents who will lose their parking, local governments that will lose parking revenue, and pedestrians opposed to losing the parked-car buffer zone between sidewalks and moving vehicles. On the other hand in some cases parking removal may reduce traffic congestion by eliminating street-side activity or by forcing people to find alternatives to their automobiles.

Planners must be creative in appeasing those affected by parking removal. Compromises may include increasing parking capacity elsewhere or using the parking channel for only parts of the day.

Sharing Bicycle Facilities

The use of bicycle lanes and paths as shared-use NEV facilities may be feasible in special circumstances, but it may not be acceptable for many bicyclists if it is adopted as a general policy. Just as automobiles and trucks threaten NEVs, NEVs threaten bicyclists. Commingling may not be appropriate when bicycle or NEV volumes are high or where bicycle lanes or paths are narrow. The California Department of Transportation restricts the use of bicycle paths by all motor vehicles with the exception of mopeds (*12*). A combination of legislation and development of appropriate traffic controls and geometrics may be needed before NEVs and bicycles share the same ROW.

The advantage of sharing the same facilities is that many bike lanes and paths are already in place in many cities and may be easily upgraded to serve NEV traffic. On streets that already have bike lanes, introduction of a third lane may cause confusion for facility users.

Selecting from Remaining Options

Perhaps the most cost-effective way to retrofit an existing road for NEVs is to lower speed limits. Lower speeds may make a facility safer for everyone. Some facilities will still be driven at speeds above the posted limit, so planners should be concerned with the actual speeds on a facility and not measure safety solely by what is posted. The lowering of speed limits may cause congestion and decrease facility throughput. Pretimed traffic signals may also need to be recalibrated for the reduced traffic speeds.

In some areas the use of street shoulders may be the only feasible option for introducing NEV lanes. Shoulders are the last uniform element of the roadway that has not been fully dominated by the automobile. The conversion of road shculders may be controversial, especially near state and federal highway facilities, because their use as through lanes is not part of AASHTO's definition of shoulders. Redefinition may require legislation. It may also be necessary to upgrade shoulders to achieve uniform lane width standards.

Automobile lane widths may also be reduced or ROWs may be expanded to make room for NEV facilities. Lane narrowing will be possible only where broad lanes are common. In the case of four-lane arterials, center lanes may need to be restriped, whereas two-lane arterials can be reduced by imposing a NEV lane along the edge. Side effects may result from lane narrowing. Speeds may drop when lanes are narrowed and capacity may be reduced (*9*). Lane narrowing may be attractive on some streets as a traffic-calming strategy for reducing speed differentials between vehicle types. However drivers may not feel as comfortable or safe on narrow lanes, especially when traffic or truck volumes are high. Expansion of the ROW may require substantial commitment in resources, depending on land costs and existing road border conditions. In urban, residential, and commercial areas additional ROWs may not be available because of existing sidewalks, front yards, storefronts, driveway curb cuts, and drainage channels.

Instead of retrofitting existing facilities a less costly strategy for providing NEV access may be to build new paths between abutting properties and cul-de-sacs, along storm channels, through fields and alleyways, beside train tracks, and inland to existing roadways. In the development of bicycle paths during the 1970s bicycle organizations were dismayed that bicycle trails did not contribute useful linkages for utility bicycling (*13*). The effectiveness of separate paths should be measured in part by their proximity to population centers and their ability to provide access to activities.

CONCLUSION

Roadway infrastructure can be built and modified to enhance the safety and utility of NEVs. The challenge is most difficult when existing roads serve fast-moving traffic, but improvements are possible, as demonstrated time and again with other modes. New design concepts and practices will evolve through experimentation. Local planners will need to work with regulators to develop sensible guidelines and standards for both geometrics and traffic control devices. In some cases dedicated paths will prove to be attractive and effective. More commonly, especially initially, efforts will need to be focused on conversion and adaptation of existing facilities: removing street parking, narrowing lanes, lowering speed limits, and upgrading shoulders. The need for enhanced infrastructures will ultimately depend on the size of NEV markets, the performance capabilities and safety characteristics of NEVs, the expectations of NEV users, and the traffic environments where these vehicles will operate.

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