Title

Enhancing Resource Sustainability by Transforming Urban and Suburban Transportation

Author

Delucchi, Mark

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Enhancing Resource Sustainability by Transforming Urban and Suburban Transportation

Mark A. Delucchi

Abstract

Urban regions worldwide are dominated by the need to provide for large numbers of high-speed, high-mass vehicles. Current strategies result in congestion, social fragmentation, and environmental degradation. An alternative urban design is presented that incorporates two separate road systems: one for light, low-speed vehicles and another for heavy, high-speed vehicles. This design enhances travel efficiency and sense of community, while minimizing energy use, water pollution, and nonrenewable resource consumption.

Introduction

For many years the United Nations Population Division has documented the extensive migration of rural populations to urban regions, as people everywhere strive for better jobs and lives. The result, especially in Asia over recent years, has been an accelerated growth of existing cities and, in many cases, the effective creation of new cities that are sprawling, congested, and dependent on the automobile. This raises an obvious question: If an additional two billion people live in and around cities by mid-century, can the urban and suburban landscape be designed or redesigned to have a more sustainable transportation system?

History offers no encouragement so far as improved urban designs are concerned. City planners, transportation planners, and policy analysts have struggled for decades to reconcile the frequently expressed desire for "livable cities" with the actual lifestyle choices made by individuals. By and large, they have failed, and car use around the world has grown unabated. As people's

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wealth increases, they buy cars and live in bigger homes further away from city centers. In an era of rapidly expanding personal mobility, cities have been constructed and reconstructed to accommodate fast, heavy motor vehicles. Nothing short of outright prohibition or economic catastrophe—not even high fuel prices, improved access to public transit, or better zoning—will stop this trend.

The result is a host of seemingly intractable problems: unacceptable congestion and fatalities on streets and highways, environmental degradation, ugly infrastructure, social fragmentation and insularity, and cultural impoverishment. Unable to stop the fundamental transportation and land use forces at work, people have tried to mitigate at least some of the undesirable consequences of the present system. There have been some notable successes: emissions of urban air pollutants from new, well-maintained cars are dramatically lower than emissions from cars thirty years ago, and in recent years the number of annual motor-vehicle-related deaths has stabilized, in large part due to tougher laws, greater use of seat belts, and improved vehicle design. However, there are still serious environmental concerns (such as global climate change), economic and environmental problems associated with oil use, appalling death and injury on the highways, rising traffic congestion, undeniably ugly transportation infrastructure, and increasing social fragmentation, which many blame on automobile-driven suburban sprawl (Burchell et al. 2002).

Is There Anything We Can Do?

There have been many efforts to plan towns and transportation systems to accommodate walking, bicycling, small vehicles, and other modes that can mitigate the impacts of automobile use. The approach taken here, however, is novel in that it completely separates high-speed, high-mass vehicles from low-speed, low-mass vehicles on a city-wide scale. Thus, instead of having a single road system that serves everything from 25-kg children walking at 3 km/h to 70,000-kg trucks traveling at 100 km/h, this new design creates towns with two separate road systems, segregated according to the mass and speed. Cut-off points of 40 km/h top speed[1] and 500 kg maximum curb weight distinguish low-speed, lightweight modes (LLMs) from fast, heavy vehicles (FHVs). LLMs include any mode of transport under these limits (e.g., pedestrians, bicycles, pedicabs, mopeds, motor scooters, motorcycles, golf cars, minicars). FHVs include conventional cars, trucks, and vans driven daily as well as tractor-trailers which deliver most consumer goods. The physical infrastructure of the LLM network ranges from an undifferentiated narrow lane that handles

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[1] Note that the maximum speed limit is a design or technology limit, not an enforcement option: the LLMs are to be constructed so that they are incapable of exceeding the maximum allowable limit. This requirement already has been implemented in the U.S. in the recent regulations governing the safety and speed of "low-speed vehicles" (Federal Register 1998).

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all LLMs (where traffic volumes are very low) to a multi-lane roadbed for motorized traffic, with a paved bicycle path and an unimproved pedestrian path on the side (where traffic volumes are high). FHV roads will be similar to present conventional roads.

This approach is distinctive at several levels: It accepts that many people may wish to live in single-family homes, in relatively low density, and get around mainly in automobiles (LLMs or other vehicles). Thus, the town is designed to accommodate these preferences. At the same time, it offers qualitative improvements in, for example, safety, aesthetics, travel pleasure, infrastructure cost, social organization, and pedestrian space. To accomplish this, travel is separated according to kinetic energy of modes. Finally, the proposal delineates a land use and transportation infrastructure layout that enhances efficiency and community, while minimizing energy use, water pollution, and nonrenewable resource consumption.

A New Transportation/Land Use System

It is possible to build *new* communities and transportation systems that accommodate people's strong preferences for automobility and single-family homes, while ensuring that these are safer, cleaner, more pleasant, and more socially integrated than traditional transportation and planning measures. In this chapter, I propose a transportation system and an urban design that meets these criteria. Two points are central to this proposal:

1. Virtually all that is undesirable in the current land use transportation system stems from the fact that FHVs are present everywhere.
2. Every place within a community (i.e., every household, business, and public place) must have direct access to two completely independent travel networks: one that serves FHVs; one that accommodates LLMs.

FHVs are dangerous. They consume a lot of energy and materials, contribute to pollution in significant ways, and require an extensive, expensive, and unsightly infrastructure. FHV roads cut a wide swath through communities, crowding out people, places, and other forms of transportation. However, most people depend on FHVs to provide an irreplaceable service. Thus, current infrastructure designs must ensure that FHVs have access to all areas. The basic conflict posed by people's dependence on FHVs and the problems that stem from their presence everywhere can be resolved, however, if non-motorized traffic is separated from motorized traffic on the LLM network where traffic volumes are high.

What exactly would this dual-mode transportation network and community look like, and what advantages would it have over present transportation and land-use plans? In turn I discuss the plan and its general advantages, review

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similar ideas, discuss the impacts on transportation problems, and discuss the economics.

The Plan

As stated, this proposal envisions a city designed with two universally accessible but completely independent transportation networks: one for LLMs, the other for FHVs. The two travel networks are accessible to every individual in the community and each provides access to every area of the community. The two networks are physically separated such that they *never intersect*. There is no possible physical interaction between FHVs and LLMs, as this would immediately and unacceptably increase the risks to the occupants of LLMs and reduce convenience to all users. Also, because FHVs perform valuable functions for the community, it must be recognized that few people or businesses would want to be in a community where FHV use is restricted. Thus, *two* universally accessible, but separate networks are needed.

In contrast to multi-modal solutions, in which users must shift themselves and any baggage, cargo, and personal belongings back and forth between multiple travel modes in a single trip, this dual infrastructure design creates two complete systems with alternative temporal, spatial, and social sensibilities. Just as in pedestrian malls or downtown areas, where cars are sometimes banned, the LLM system creates a space in support of a less harried lifestyle. Since the LLM network is accessible to everyone and accommodates all forms of travel, from pedestrians to fully featured motor vehicles,[2] it offers a complete and convenient new lifestyle network—one that is functionally equivalent to the current automobile and road system, but without any of the undesirable features. The LLM network is actually more convenient by any measure than a conventional single street system.

The Design

How can two street systems be designed to be co-extensive yet non-intersecting? In abstract geometric terms, the solution is two parallel radial/ring networks (Figure 24.1): a system of LLM streets (depicted in blue) that extend outward from the town center, interlaced with a system of FHV roads (shown in red) that radiate inward from a circumferential outer beltway. This enables two universally accessible yet completely separate travel networks and, furthermore, generates what many consider to be an ideal small town—one

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[2] A fully featured LLM is a mini-car that is just like a conventional FHV except that it is smaller and slower: it has a completely enclosed cabin, full and comfortable seats, adequate leg room and storage space, air conditioning and heating, entertainment systems, a smooth quiet ride, good handling, power steering, power braking, power windows and door locks, a responsive and reliable motor, an attractive design, and robust construction. In the cost analysis, the cost of an LLM mini-car is estimated with all of these features.

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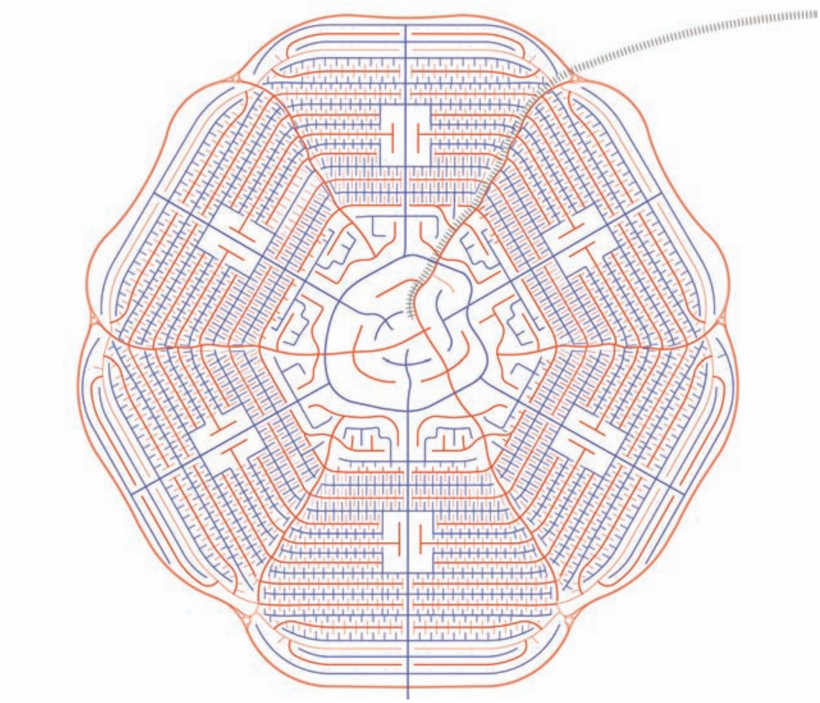

Figure 24.1 The plan in abstract: FHV roads are red and LLM streets are blue.

containing a commercial town center, high-density residential living immediately outside the center, and low-density living space on the outskirts.

The entire town lies within an outer, high-speed beltway for FHVs. A central LLM road rings the commercial and civic center of the town. The town center, like the neighborhood areas around the center, is accessible to FHVs as well as LLMs. Between the outer FHV beltway and the central LLM ring road, neighborhoods are built that are accessible everywhere to FHVs and LLMs. The LLM streets all radiate outward from the LLM ring road around the town center, and the FHV roads radiate inward from the FHV beltway around the entire town. The LLM street system includes separate bicycle and pedestrian paths in some places. The two networks service every individual location but never intersect.

The town center, the area inside the central LLM ring road, contains most of the shops, schools, offices, churches, civic buildings, intercity transit stations, and other commercial and retail spaces. The radial LLM streets feed into the central ring road and provide direct, LLM-only access from all neighborhoods to all areas in the town center.

The residential neighborhoods begin on the outside of the central LLM-ring road, with high-density multifamily dwellings closest to the town center and large-lot single-family homes furthest. This traditional pattern of decreasing density is repeated along each LLM “branch” radiating out from the LLM ring road. Again, the two networks serve all households, but never intersect—every property has access to an LLM road in one direction and an FHV road in another (Figure 24.2). Each major radial “branch,” comprising one major LLM/FHV pair, functions socially as a neighborhood, with a neighborhood park, neighborhood school, public gardens, and a few neighborhood shops.

Every place within the town (i.e., home, business, and public area) either “faces” the LLM community network and “backs” onto the FHV network, or else borders one of the road systems (LLM or FHV) and shares a driveway that leads to the other system (Figure 24.3). The FHV roads that radiate inward from the outer high-speed beltway interlace with, but never touch, the LLM streets that radiate from the town center. The idea is to have the FHV roads remain on the “backs” of housing units, rather like service alleys, and the LLM streets to be on the fronts, like community paths or streets. Private driveways connect both of the networks with private garages or parking areas.

FHV roads serve two primary functions: (a) they provide households direct access, via the outer beltway, to *outside* of the town, and (b) they provide persons and goods from outside the town direct access to the inner civic,

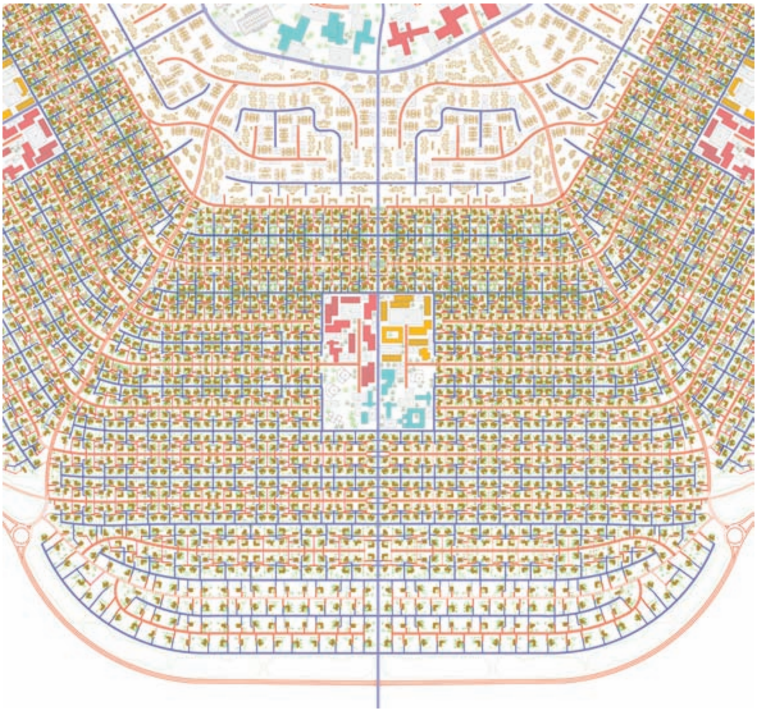

Figure 24.2 Detailed view of a main LLM/FHV branch with structures and landscape.

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Figure 24.3 Schematic view of a block in a residential area.

commercial, and service core of the town center, via two or three FHV roads that penetrate all the way to the town center. These penetrating FHV roads go underneath the central LLM ring road and come up into roads and parking areas on the "back" side of businesses, offices, schools, etc. In contrast, the primary function of the LLM streets is to provide access *inside* the town—in particular, to and from the town center—via the central LLM ring road.

Thus, the FHV and LLM networks complement each other functionally: the LLM network is designed primarily for trips within town, while the FHV network is designed for all other trips. It is possible, however, to use the FHV network for any within-town trip, but the system is designed so that within-town trips are generally safer and more convenient via the LLM network. The design also provides for the possibility of extending a few LLM streets under or over the high-speed FHV beltway to connect to the LLM network of a neighboring town. However, a greenbelt between the outer FHV beltway and the ends of the LLM residential streets may be more desirable, to buffer the residential areas from the noise and unsightliness of the beltway, and to delineate boundaries.

General Advantages

The proposed plan gives rise to appealing town characteristics.

- Stores, offices, schools, civic buildings, parks, intercity transit stations, etc. are located in the town or neighborhood centers; they are not distributed disjointedly over a suburban landscape (Figure 24.4).
- High-density multifamily housing units are located around the core, offering convenient pedestrian, bicycle, and LLM access to the town center for those who prefer higher-density, more urban lifestyles.
- Retailers who are not frequented regularly (e.g., auto dealers, appliance dealers) can position their businesses along the outer beltway, and thus

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Figure 24.4 Town center.

be easily accessible to both consumers and deliveries without disrupting the look, function, and feel of the town itself.

- Major residential LLM branch roads function as neighborhoods, with small neighborhood parks, elementary schools, and some shops in a neighborhood center.
- Suburban single-family homes are not restricted by policy; instead, the transportation system integrates these dwellings with the rest of the community to create a coherent town.
- Unlike conventional street systems, which divide and separate communities and generally do not promote a pleasant street life, the LLM network facilitates access, promotes interaction, and integrates the town, helping to create the sort of "unified street space" advocated by some urban designers and town planners (e.g., Southworth and Ben-Joseph 2004b).

Under this plan, the transportation system and the urban form are able to coexist. Due to the interpenetrating radial-arm system (with an inner ring road for LLMs and an outer beltway for FHVs), it is logical for major nonresidential (and non-neighborhood) destinations to be located near the center.

By contrast, consider current urban designs that are based on a sprawling grid. Within a grid, there is no real functional community center. Thus, by nature, these designs promote fragmented, nonintegrated development patterns and results in tracts of housing interspersed with strip malls.

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The proposed plan discussed here, however, offers the social benefits of organized development and low-impact transportation, while providing the widest possible range of travel and lifestyle choices—including unrestricted suburban living and automobile travel.

Size and Growth of Towns

The size of the proposed new town and transportation system is ultimately limited by the maximum acceptable travel time on the LLM network from the outer ends of the LLM radial streets to the city center. This constrains the town to a maximum diameter of about 6.5 km (4 miles). A town of this size would accommodate 50,000–100,000 people.

A maximum diameter of 6.5 km maximum ensures that travel times on the LLM network are reasonable. If, for safety reasons, LLMs are built so that they cannot exceed 40 km/h, then an average trip of 1.5–2.5 km into the center would take about 5 minutes, while a trip across town would average about 10 minutes. For comparison, these travel times are similar to those for present suburban road networks. It is expected that many people would be willing to use bicycles, at least occasionally for trips of 3 km or less, on a convenient, safe cycling network. Thus, the radial LLM streets (and adjoining bicycle and pedestrian paths) should generally not exceed 2.5 km in length. If the town center has a radius of 0.8 km, the town itself would be no larger than 6.5 km in diameter.

Figure 24.2 illustrates a complete radial section of the LLM and FHV networks from the outer FHV beltway to the service core in the center of town along one LLM/FHV neighborhood branch. With a maximum 6.5-km diameter, the whole community (which certainly does not have to be precisely circular, but which is presented as such for convenience) has a maximum area of about 33 km^2. At relatively high suburban commercial and residential densities, this accommodates as many as 100,000 people—probably the upper limit for a single town/transport network. At cozier dimensions and lower densities, the plan would accommodate around 50,000 people, which may be preferable. At this size, the town would have its own postal code and main post office, its own high school, civic and institutional center, recreational and entertainment programs, library, and community park as well as a viable commercial/retail core. Other facilities of regional importance (e.g., a college campus, theme park, government buildings) could also be accommadated.

Therefore, this plan allows growth of a transportation network and community from just one short radial arm and a rudimentary town center (i.e., a few thousand people) up to a small city of 100,000 people. A rudimentary town can also grow into a larger town by adding or extending neighborhood branches or by increasing the density along existing branches and in the town center.

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Review of Plans Similar in Some Respects

Sustainable Transportation, Smart Growth, and New Urbanism

Obviously, I am not the first to wonder what can be done within the framework of the present market-oriented, mobile, time-driven, suburban society to create more livable, socially integrated communities. Indeed, the literature on "sustainable transportation," "smart growth," and "new urbanism" is too vast to summarize here (for examples, see Steg and Gifford 2005; Turton 2006; MIT and CRA 2001; Dearing 2000; *Progress* 2000; Geller 2003; EPA 2008b; Calthorpe 2002). It appears, however, that most proposals for sustainable transportation enhance walking, bicycling, and other transit modes *at the expense* of convenient automobile use and single-family suburban living. Realistically speaking, such proposals are thus not likely to lead to large-scale transformations in urban living and driving, although they might be effective and beneficial when targeted to dense urban centers. Rather than attempting to force people out of their cars or suburban homes, this proposed system *expands* travel and lifestyle choices at essentially no private cost, but with very substantial social gain.

Prior Studies of Small Vehicles and Associated Infrastructure

Years ago, Garrison and Clarke (1977) observed that the primary impediment to extending modal options in the direction of low-speed and light-weight is the "one size fits all" mentality that permeates the transportation infrastructure, and thus the structure of lives. Following up on this, Pitstick and Garrison (1991) analyzed how the transportation system could be restructured to accommodate "lean" vehicles (i.e., small, fuel-efficient, one- or two-passenger vehicles). Most pertinently, Bosselmann et al. (1993) examined how neighborhoods and roads should be changed to accommodate small, clean, inexpensive motor vehicles. They addressed many of the issues that I raise here and came to many similar conclusions, although they have not proposed a similar transportation and town plan. Finally, Sheller and Urry (2000) analyze the interaction between automobility and urban planning, and conclude with suggestions on how to redesign automobiles and urban public spaces to "address the negative constraints, risks, and impacts of automobility." They propose extensive use of "micro cars...integrated into a mixed transportation system that allowed more room not only for bikes, pedestrians, and public transportation, but also for modes of travel that we have only begun to imagine. This would require redeployment of existing urban zoning laws to exclude or severely delimit 'traditional' cars....and to place lower speed limits on them." Thus, Shelly and Urry (2000) recognized the advantages of making cars smaller and slower as well as of redesigning urban areas to accommodate such vehicles better.

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Planned Communities

Although there has been a long history of "new town planning" and plenty of planned communities that have resulted, there appears to be no actual plan or transportation system with the key feature of two autonomous but universally accessible personal transportation systems, segregated according to the kinetic energy of the modes. A few existing communities have the equivalent of a complete dedicated LLM network, but none of them have a universal FHV network. This makes them unsuitable for the vast majority of households. Some communities, such as Palm Desert, California, have LLM streets and lanes integrated with FHV roads; however, the LLM network is not completely separated from the FHV network, and hence it is too unsafe and, in contrast to the FHV network, too inconvenient to be heavily used.

Peachtree City, Georgia, a master-planned community southwest of Atlanta, has a 113-km network of paved recreational paths for pedestrians, bicyclists, and golf carts. While this system, which allows motorized golf carts to share paths with pedestrians and cyclists, is a step closer to the proposal outlined here, it is the sort of plan that dedicates separate paths only to nonmotorized transport. It is not designed to accommodate full-featured LLMs: the paths are designed for golf carts, which are limited by city ordinance to a top speed of 32 km/h. In addition, the paths are not designed to handle heavy traffic flows; the paths are not wide enough for two golf carts to pass (Stein et al. 1995) and are not completely coextensive with the FHV network.

Several neighborhoods and towns exist that have a complete conventional street system *and* an extensive dedicated bicycle and pedestrian paths that are accessible to most or all homes and which (within the neighborhood or town) do not intersect with the conventional street system: Village homes in Davis, California; the town of Radburn in New Jersey; the town of Houten near Utrecht in The Netherlands; and Milton Keynes in southeast England.

Village Homes is a 28.3 ha subdivision with 225 homes and 20 apartment units in the west part of Davis, California. Most houses "face" a community greenbelt with a bicycle and pedestrian path serving all the houses. Automobile access is via narrow, curving roads along the side of the house opposite the bicycle and greenbelt side. The roads end in cul-de-sacs. The social space created by the car-free pedestrian and cycling greenbelt in Village Homes is pleasant, and was inspirational as I developed similar ideas on a city-wide scale for the present plan.

The traffic and cycle plans in Radburn, New Jersey, and especially in Houten, The Netherlands, are considerably more developed than is the plan for Village Homes. Radburn, built in 1930, has 469 single family homes, 48 town houses, 30 two-family homes, and a 93-unit apartment complex, arranged to "face" public pedestrian and park open spaces, with car access at the "back" of the houses via roads that end in cul-de-sacs (Freeman 2000; Wikipedia 2009). The pedestrian path does not cross any major roads.

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Houten, a town of some 50,000 near Utrecht, has a dedicated bicycle network consisting of collector arms that originate in residential neighborhoods and connect to a "backbone" that runs to the city center. The car-only network consists of an outer ring road from which car roads penetrate partly into the residential areas of the city, interlacing to some extent with the dedicated bicycle roads. There is limited access by car to the city center (Beaujon 2002; Tiemens 2009). Therefore, Houten shares several key features with the plan outlined in this chapter. The main differences are that the system described here separates LLMs (mainly full-featured automobiles) from FHVs, whereas Houten separates primarily bicycles from cars. Additionally, in the system outlined here, the two networks go everywhere, but *never* intersect at grade or share travel space, whereas in Houten the bicycle and car network often intersect at grade or share the same road space, mainly in residential areas.

Impact of the LLM Network on Transportation Problems

Road Capacity and Congestion

Congestion depends on the relationship between travel demand and infrastructure capacity. Congestion is most serious at peak commute hours on major roads that serve a wide travel area and tends to worsen as the areas served by the major roads expand. Traffic planners for new communities thus try to anticipate the eventual extent of development and where and how people will travel. Because the plan here prescribes limits on the extent of major LLM roads and directs flows towards the center of town, it may facilitate planning street capacity for maximum and average daily traffic flows.

The LLM network directly connects the residential areas with neighborhood nodes and the center of town. There are no cross-links within or between major branches. For the purpose of planning street capacity, it probably is reasonable to assume that households will travel down the branch to the neighborhood node or town center and then back. The traffic volume along a main LLM branch will be determined by the extent of the minor branches feeding into the main branch (see Figure 24.2), and by the housing density along minor branches. The extent of the minor branches is limited ultimately by the requirement that the travel time from the end of the outer LLM branches to the center of town not be significantly greater than it would be in a conventional street system (otherwise, people might prefer a conventional street system). It is hypothesized that a town radius of 3–5 km is the upper limit on desirable town size.

Thus, in planning an LLM street system, balance between costs (money and loss of land) and benefits (faster and safer travel) can be found relatively easily

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in choosing street width and speed limits. In general, streets will be very narrow at the ends of residential areas (say, about ~3.7 m), wider along the radial arms, and widest (about 7.6 m) on the LLM ring road, which will have two relatively wide lanes for motorized LLMs, a completely separate paved path for non-motorized LLMs, and an unimproved pedestrian path. Roundabouts at the major intersections will allow the high traffic volumes near the town center to flow smoothly and safely.

Environmental Impacts

Energy Use, Oil, and Greenhouse Gas Emissions

From shortly after the Arab oil embargo of 1974 until the fall in oil prices in the mid-1980s, U.S. energy policy was concerned with conserving energy and reducing oil use. Since about 1988, energy policy in the U.S. and Europe has increasingly focused on reducing emissions of so-called greenhouse gases, which are thought to be changing the global climate (IPCC 2007a, c). Analysts now routinely evaluate transportation plans for their energy use, oil use, and greenhouse gas emissions.

LLMs use much less energy and have much lower emissions than do conventional FHVs. Thus, the huge reduction in average kinetic energy throughout a town based on an LLM network translates directly (although not proportionately) into a large reduction in the total life cycle energy required for the manufacture, operation, and maintenance of vehicles and infrastructure. Because emissions of CO_2 and other greenhouse gases are closely related to energy use, a large reduction in life cycle energy use results in large reductions in greenhouse gas emissions.

To analyze life cycle energy use and emissions of greenhouse gases, an expanded version of the life cycle emission model (LEM) developed by Delucchi (2003) was used. This model estimates emissions of urban air pollutants and greenhouse gases from the life cycle of fuels from feedstock production to end use and from the life cycle of materials from raw resource extraction to manufacture and assembly. It does this for a wide range of transportation modes, vehicle technologies and energy sources, including buses, trains, and electric vehicles.

For this analysis, conventional travel modes were compared with LLMs in the United States for the year 2010. Table 24.1 shows the life cycle CO_2-equivalent emissions estimated by the LEM. The CO_2-equivalent is a way of expressing the impact of emissions on global climate; it is equal to actual emissions of CO_2, plus emissions of other gases expressed in terms of the amount of CO_2 that would have the equivalent effect on climate. The other gases are CH_4, CO, hydrocarbons, NO_x, SO_x, particulate matter, and refrigerants.

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Table 24.1 Life cycle CO_2-equivalent emissions from transportation modes in the U.S., in 2010. One passenger per vehicle is assumed for both fast, heavy (conventional) vehicle (FHVs) and light, low-speed mode (LLMs).

		g/pass-km (gasoline FHV) % change vs. gasoline FHV	
Mode	Mode technology	Fuel cycle[(a)]	Fuel + material[(a)]
FHV	Gasoline vehicle, 8.4 l/100-km city driving	275 g/km	331 g/km
FHV	Diesel (low-S) vehicle version of gasoline	+ 13%	+ 10%
FHV	Hydrogen (NG) fuel cell version of gasoline	–61%	–52%
Transit	Diesel-fuel (low-S) bus: 10, 20 passengers(b)	+ 2%, –49%	–2%, –51%
Transit	Heavy-rail train: 20%, 40% capacity(b)	–60%, –80%	–60%, –80%
Transit	Light-rail train: 20%, 40% capacity(b)	–62%, –81%	–65%, –83%
LLM	Gasoline car, 4.1 l/100-km city driving	–55%	–56%
LLM	Electric car, 11.3 km/kWh, U.S. power(c)	–80%	–76%
LLM	4-stroke gasoline scooter	–82%	–82%
LLM	Electric scooter, U.S. power(c)	–87%	–84%
LLM	Bicycling	–99%	–96%
LLM	Walking	–100%	–100%

(a) The fuel cycle includes the life cycle of fuels, from feedstock production to end use, and emissions related to vehicle maintenance, repair, and servicing. The fuel+material life cycle includes the life cycle of fuels plus the life cycle of all materials, vehicle assembly, and infrastructure construction.

(b) The average occupancy of buses in the U.S. is around 10, and average capacity factor for trains is around 20% (see statistics reported by the Federal Transit Administration). Emissions per passenger km are shown at both the current average occupancy and double the current average.

(c) The average power mix in the U.S. in the year 2010 is estimated to be 50% coal, 1% fuel oil, 25% natural gas, 14% nuclear, 8% hydro, and 2% biomass.

The results reported in Table 24.1 show that LLMs will provide large reductions in life cycle emissions of greenhouse gases, even when compared with relatively efficient subcompact gasoline FHVs (e.g., 8.4 l/100 km in city driving). Full-feature electric LLMs, which are anticipated to comprise most of the traffic on the LLM network, offer emissions reductions of around 80% compared with FHVs. They offer lower emissions than public transit, except as compared with rail transit that has *double* the current average load factor in the U.S. And of course the smaller LLMs, such as scooters and bicycles, offer greater reductions in emissions than even high-occupancy public transit.

Because of the close relationship between energy use and greenhouse gas emissions, percentage reductions in energy use are similar to the percentage reductions in emissions shown in Table 24.1. Percentage reductions in oil use are similar for the petroleum-using options and greater for the electric options. LLMs reduce total energy use for transportation, and thus reduce petroleum consumption.

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Water Pollution

Oil, fuel, coolant, and other chemicals leak or are discarded from motor vehicles and petrol stations and eventually pollute rivers, lakes, wetlands, and oceans. Impervious surfaces, such as roads, collect the pollutants and transmit them to water bodies during runoff from rain and snow melt. This polluted runoff, in turn, can significantly degrade rivers, lakes, streams, and wetlands, and even threaten human health. Gaffield et al. (2003) note that storm runoff is a major threat to water quality.

LLMs and the LLM infrastructure will greatly reduce problems associated with runoff and water pollution. Consider the LLMs first: If LLMs are either nonmotorized or electric-powered, then compared with FHVs and LLMs powered by internal combustion engines, leaks and discharges of lubricating oil and engine coolant will be greatly reduced, and leaks of fuel (and constituent chemicals, such as the oxygenate methyl tert-butyl ether) from vehicles and underground tanks will be eliminated. Furthermore, to the extent that the use of motor fuel affects the probability of large spills of crude oil in sensitive habitats, the use of nonmotorized or electric LLMs will reduce the frequency and costs of oil spills. Finally, the much lower vehicle mass and speed of LLMs compared with FHVs will also reduce the creation of dust from tires and brakes and hence reduce the concentrations of these pollutants in runoff.

In terms of the LLM infrastructure, because streets intended for LLMs do not need to support wide, heavy, high-speed vehicles, alternate surfaces (e.g., permeable street surfaces) can be used instead of conventional solid pavements with curbs, gutters, and storm drains to control street runoff. Permeable pavements allow water to seep through the surface of the road, so that something akin to natural filtration can occur. This filtration removes water pollutants and replenishes local groundwater, thereby enhancing soil quality and promoting plant growth. In addition, permeable pavements may absorb and store less heat and be less reflective and less prone to cause glare.

Aesthetics

The present motor-vehicle infrastructure is ugly (Button 1993). Roads, gas stations, car sale lots, car repair shops, parts stores, parking lots, and garages form dreary, chaotic strip developments decried by architects and city planners (e.g., Wright and Curtis 2005; Kunstler 1993). Surveys report that the general public feels that the world would be more attractive without roads (Huddart 1978), and that residential streets would be more attractive without large cars (Bayley et al. 2004).

Because of the low speed and small size of LLMs, the LLM network will not have wide roads, traffic lights, medians, railings, or shoulders. In addition, if motorized LLMs use electric motors, the LLM network will not need gasoline stations. All of these features will make the LLM network much less visually

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intrusive and socially divisive than the present street system. Indeed, properly designed, an LLM network could be an aesthetically pleasing, integral part of a townscape. Even the FHV network in the plan outlined here would be less unsightly than a conventional suburban FHV road system, because houses and businesses are (or should be) oriented away from the FHV road, which function rather like service alleys.

Community Fragmentation

The roads and freeways intended to connect people to places can divide communities, impede nonvehicular circulation, and create barriers to social interaction (Wright and Curtis 2005; Sheller and Urry 2000; Marshall 2000). The conventional FHV infrastructure itself can physically split (or even bury) neighborhoods and vehicle traffic can disrupt the social functioning of neighborhoods and communities.

The LLM network will function to define, unify, and connect neighborhoods rather than to separate and isolate them. No high-speed, high-volume roads transect the neighborhoods. Virtually all roads—FHV as well as LLM—in the system terminate in cul-de-sacs which, when part of a coherent town plan and pedestrian-friendly infrastructure, can help create an “ideal suburban residential environment” (Southworth and Ben-Joseph 2004a).

Economics of the Plan

What would the dual LLM–FHV infrastructure cost society in comparison with a functionally similar all-in-one network? What would LLMs cost households, compared with what would be purchased and used were LLMs not available?

Infrastructure Costs

How does the overall cost of the LLM–FHV network compare with the cost of a comparable conventional suburban road network? In this section, it will be shown that the overall infrastructure costs will probably be about the same, despite there being two networks in this plan. Several reasons contribute to this. First, LLM streets will be relatively inexpensive per meter of width per kilometer, because they do not have to be designed to carry heavy loads; they will not need traffic lights, sound walls, barriers or railings, medians, or any other roadside material except for street lights and signs; they will be narrow and thin enough so that water runoff can probably be handled by making the surface permeable rather than by constructing gutters and storm drains. Second, LLM roads will be much narrower than conventional suburban roads: an estimated average of 5.8 m, compared with an average of about 9.8 m in new suburbs (Delucchi 2005). Third, the FHV road network in the dual LLM–FHV

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plan would also cost less per kilometer than a conventional FHV grid system, because it will carry less traffic, it will not need space for on-street parking, sidewalks, or bicycle lanes, and it will have fewer intersections and hence less of the cost associated with building and controlling intersections.

Finally, even though it might appear that the two complete road systems in the dual LLM–FHV plan would have roughly double the linear extent of a conventional FHV grid system, this is not the case since there are relatively few intersections in the LLM–FHV plan. As depicted in Figure 24.5a, the road has no cross streets and six housing lots line each side of the road. Figure 24.5b shows an intersection in which nine housing fronts line the roads (2 house fronts along each of the 4 arms of the cross, plus the one in the middle). Compared with a conventional grid system, the radial plan has relatively few intersections, and hence at a given housing, density will tend to have less road extent in the LLM or the FHV network.

In the single-family residential areas, there may be two or even three houses between each LLM and FHV (see Figure 24.3). No house borders the LLM *and* the FHV road, which means that no house has a road on both sides of it; each house does, however, share a driveway with one or two other houses. The alternative is for each house to have direct access to the LLM network on one side of it and to the FHV network on the other, via its own private drive, but it is suspected that most people will prefer to not have a road on both sides. The shared-driveway alternative illustrated in Figure 24.3 does entail longer driveways than in the road-on-both-sides alternative, but assuming that driveways are narrower than roadways, the net effect should be a reduction in paved area relative to the alternative in which there is only one house between each LLM and FHV road.

Considering all these factors, it is estimated that the total cost of the dual LLM–FHV street system will be equal to or even slightly less than the total cost of a comparable conventional suburban road network.

Cost of the Modes

The LLM network allows any mode that weighs less than 500 kg and has a top speed of 40 km/h or less. This accommodates everything from pedestrians to luxury vehicles indistinguishable from FHVs save for the limited top speed

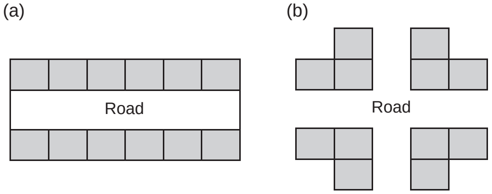

Figure 24.5 Twelve houses positioned (a) along a road with no cross streets versus (b) on a road with a cross street.

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and weight: pedestrians, bicycles, pedicabs, electric-assist bicycles, mopeds, motor scooters, covered motor scooters, three-wheel taxis, golf carts, simple neighborhood electric vehicles, and luxury mini-cars. Walking is essentially free, and non-motorized transport almost free. Mopeds, motor scooters, and simple electric vehicles designed like golf carts are also inexpensive to own and operate: they cost no more than a few thousand Euro (compared with at least 15,000 € for most new FHVs) and have low operating costs. Because these modes are so inexpensive, any household that can use them probably will.

The question of cost, and hence the question of what people might actually purchase and use, becomes interesting when full-featured LLM motor vehicles are considered. Although the LLM network will make cycling and walking much more attractive than they are in any conventional suburb, it is expected that many people will want to make most of their trips in LLMs that have all of the features of conventional FHVs.

So how much will full-feature LLMs cost? To answer this question, the "Advanced Vehicle Cost and Energy use Model" (AVCEM), developed by Delucchi and colleagues at U.C. Davis, was used (Delucchi 2000a; Delucchi and Lipman 2001). This model designs a motor vehicle to meet range and performance requirements specified by the modeler, and then calculates the initial retail cost and total life cycle cost of the designed vehicle.

AVCEM was specified to simulate low-mass, low-speed, full-feature motor vehicles driven over a low-speed urban drive cycle. The assumed and simulated characteristics of a gasoline LLM, a battery-powered electric LLM with a 32-km range (BPEV-20), a battery LLM with a 48-km range (BPEV-30), and a conventional gasoline FHV (a Ford Escort) are shown in Table 24.2. The vehicles have air conditioning, heating, entertainment systems, power steering, and power brakes.

The results of the retail cost and life cycle cost analysis are shown in Table 24.3. AVCEM estimates that in high-volume production, a full-feature gasoline LLM will sell for under 6,000 €, and its BPEV counterpart for only 300–500 € more, depending mainly on the size of the battery (which in turn is determined by the desired driving range). The estimated retail prices given here are consistent with limited data on the retail price of ultra-mini gasoline cars and neighborhood electric vehicles.[3]

AVCEM estimates that a full-feature LLM will sell for substantially less than a subcompact FHV (Table 24.3) and less than half of the price of a midsize FHV (Delucchi 2000a). The battery-electric LLM has a slightly higher initial cost than does the fossil fuel LLM, but has the same total lifetime cost as the fossil fuel LLM when gasoline costs about 0.4 €/l including taxes. The small extra initial cost is due almost entirely to the initial cost of the battery,

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[3] For example, according to a brochure provided by the manufacturer, the ZENN EV (a low-speed, full-featured, neighborhood electric vehicle) is expected to sell for between 7,000–10,000 €, at quite limited production volumes.

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Table 24.2 Characteristics of full-feature cars in the lifetime cost analysis. Gas FHV = a conventional Ford Escort; Gas LLM = a low-speed, low-mass gasoline vehicle; BPEV-32 = battery-powered electric vehicle with a 32-km range; BPEV-48 = battery-powered electric vehicle with a 48-km range. The BPEVs have lead-acid batteries that store about 35 Wh/kg, weigh about 68 kg, and cost 225–270 €/kWh.

Item	Gas FHV	Gas LLM	BPEV-32	BPEV-48
Weight of the complete vehicle (kg)	1004	435	418	449
Maximum power to wheels (kW)(a)	67	21	10	11
Coefficient of drag(b)	0.30	0.28	0.22	0.22
Acceleration 0 to 40 km/h, 7% grade (sec)	4.64	6.08	6.08	6.09
Fuel efficiency (l/100 km, km/kWh-outlet)(c)	8.43	4.15	11.3	11.0
Vehicle life (km)(b)	241,350	112,630	135,156	135,156

(a) The maximum power available to the wheels assumes no air conditioning or heating or optional accessories. The BPEVs have much less maximum power than, but the same performance as, the gas LLM because an electric motor, unlike a heat engine, can deliver maximum torque at very low rpm.

(b) It is assumed that battery-electric LLMs have a lower coefficient of drag and a longer life than does a comparable gasoline LLM.

(c) The fuel efficiency calculation does assume year-round average use of air conditioning and heating.

because the balance of the electric LLM costs roughly the same as the fossil fuel LLM.

Any LLM, whether gasoline or electric, will have lower running costs than an FHV. LLMs will have lower insurance costs because of the reduced all-around crash risks, lower registration costs because of their lesser value or lower weight, lower fuel-tax or road-tax costs because of their much lower weight (which reduces energy use and road damage), lower energy costs, and slightly lower maintenance, repair, and inspection costs. Overall, the battery electric LLM will have about the same life cycle cost as a fossil fuel LLM when gasoline sells for about 0.4 €/l, including taxes (Table 24.3).

Table 24.3 shows the *private* costs, and on this basis, fossil fuel and electric LLM are roughly comparable. It is, however interesting to compare options on a social-cost basis, which includes so-called "external costs" as well as private costs. Using the analysis of externalities presented in Delucchi (2000b), Delucchi and Lipman (2001) estimate the social value of the reductions in oil use, noise, water pollution, air pollution, and climate change provided by conventional electric FHVs compared with conventional fossil fuel FHVs. They find that these reductions are worth 0.002–0.016 € per km, with a best estimate of 0.005 €/km. In the case of electric LLMs versus fossil fuel LLMs, the best estimate of the value of these reductions would be a little lower—about €0.005/km—because a fossil fuel LLM has significantly lower oil use and climate change costs (but probably not lower air pollution costs) than does a fossil fuel FHV, because of the relatively high fuel economy of a fossil fuel LLM. Thus,

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Table 24.3 Retail and life cycle costs of full-feature LLMs.

Item	Gas FHV	Gas LLM	BPEV-20	BPEV-30
Full retail cost of vehicle, including taxes (€)	11,200	6,500	7,000	7,100
Battery contribution to retail cost (€)	—	—	520	670
Average maintenance cost (€/yr)	360	140	100	100
Energy cost (€/l or €/kWh)(a)	0.30	0.30	0.05	0.05
Total life cycle cost (cents/km)(b)	16	14	14	14
Breakeven gasoline price (€/l)(c)	—	—	0.45	0.40

(a) Excludes fuel taxes, which add in the U.S. ~ 0.08 €. For EVs, low nighttime recharging rates are assumed.
(b) Equal to the initial cost, plus the present value of all future cost streams: insurance, maintenance and repair, fuel, registration, parking, tolls—everything.
(c) The price of petrol, including taxes, at which the total lifetime cost per km of the BPEVs equals the total life cycle cost per km of the fossil fuel LLM.

the quantifiable social benefits of electric LLMs appear to be positive but relatively small compared to the total private lifetime cost. Nevertheless, on this basis it is recommended that LLMs be required to be zero-emission modes.

Implications for Resources and Sustainability

One aspect of dual-mode urban transportation systems that is particularly relevant to this volume is the implications of such designs for resources and sustainability. To explore the implications, recall that the design calls for a city of 50,000–100,000 people within an area of 33 km^2, or a population density of roughly 1500–3000/km^2. This generates a population density midway between high-density cities (e.g., Hong Kong and Singapore) and low-density cities (e.g., Melbourne and low density parts of Los Angeles). The anticipated rates of resource use reflect their population density to some degree.

- *Land*: A key element of the dual-mode design is land use per capita, which is markedly lower than occurs in some suburbs (e.g., Melbourne's population density is 265/km^2; Australian Bureau of Statistics 2005). This would manifest itself in lower overall land allocation for housing, thereby retaining more land for alternative uses. In addition, because land near cities is often highly fertile (Seto et al., this volume), land saved from housing could be used for agriculture.
- *Energy*: Table 24.1 demonstrates that energy savings for LLM vehicles relative to FHV vehicles can be more than 50% on a passenger-km basis.

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- *Water*: Leakage of lubricants and coolants to water bodies is decreased when LLM vehicles are substituted to FHV vehicles, with beneficial implications for water quality.
- *Nonrenewable resources*: FHVs use 20% or more of the annual production of materials such as steel (Marcus and Kirsis 2003) and zinc (Graedel et al. 2005). LLMs probably would need less than half of this (see the weights in Table 24.2). In addition, if the average residence size per person would be smaller in dual-mode cities than in suburbia, the need for variety of construction materials (e.g., cement, copper) would decrease.

Thus, although the biggest resource gains from dual-mode cities would likely be in energy savings, such cities seem likely to make contributions to a more sustainable society in every category addressed above.

Summary

Most transportation-related problems are ultimately attributable to the high kinetic energy of fast, heavy motor vehicles. The challenge is to find a way to lower the kinetic energy of personal travel dramatically, without compromising any of the benefits of motor vehicle use or suburban living. I believe that the only way to achieve this is to create two autonomous and universally accessible travel networks: one for fast-heavy vehicles, the other for low-speed, light transportation modes.

The town plan and transportation system proposed here offers a safe, convenient, clean, and pleasant environment. It should be attractive to households *without* requiring economic or regulatory incentives or injunctions. The requisite technologies, and analyses of their economic and social impacts, are available now.

An additional benefit, somewhat ancillary to the motivations of most urban planners, is a positive impact of such systems on sustainability. Dual-mode systems have the promise of reducing demand for certain nonrenewable resources, of decreasing the energy use in transportation, and of ameliorating transportation-related impacts on water quality. Because sustainable actions are ultimately personal choices, two-mode systems encourage choices that simultaneously improve both perceived quality of life and sustainability. This approach may thus serve as an example of the sort of more general planning that can ultimately enhance links between society and sustainability.

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