Nonmotorized Transportation Equivalents in Urban Transport Planning

V. SETTY PENDAKUR, MADHAV G. BADAMI, AND YUH-REN LIN

The benefits of nonmotorized modes are discussed by quantifying the "bicycle equivalents" for motorized modes in terms of parameters such as resource and energy consumption, air emissions, land use, and accident risk. The current status of nonmotorized transportation (NMT) in the United States is described, and factors contributing to its low usage—even over short distances—are explored. The potential for NMT over these distances is demonstrated, and implications are drawn for NMT policy and for transportation investment decisions to achieve a balanced and integrated NMT-inclusive urban transportation system.

Transportation in general, and cars in particular, plays a vital role in modern industrial societies. Cars enable freedom and mobility for those who can afford them. However, they also produce a string of significant environmental, economic, and welfare impacts. One can gain an appreciation of the benefits of nonmotorized modes by comparing them with motorized modes in terms of parameters such as resource and energy consumption, air emissions, land use, and accident risk. Figures 1–6 show these comparisons.

Data presented in Figure 1–6, except for total regulated emissions (Figure 3), are in terms of bicycle equivalents rather than absolute quantities in order to highlight the dramatic differences between motorized and nonmotorized modes. For example, in the case of energy use in operation (Figure 2), bicycle equivalents for motorized modes were calculated by dividing energy use per person kilometer for each mode by the energy use per person kilometer on a bicycle. U.S. data has been used where possible. Figure 3 compares, for each mode, the total of the emissions that are regulated for passenger cars and light-duty trucks as well as heavy-duty vehicles in the United States (carbon monoxide, nonmethane hydrocarbons, nitrogen oxides, and particulate matter) on the basis of grams per passenger kilometer. Information used in preparing Figure 1–6 was drawn from various sources (*1–5*). Bicycle equivalents shown must be considered only as indicative. All sources and assumptions are indicated clearly in the figures.

Occupancy factors used for the motorized modes were for journey-to-work (JTW) trips in the United States. Single-occupancy cars and light trucks and vans (LTVs) are also shown. Bicycle occupancy was assumed as 1. Energy use figures for the various motorized modes in Figure 2 are for the peak period, during which most JTW trips take place. In terms of energy consumption and emissions, the peak period is critical, because stop-and-go traffic flow caused by congestion tends to increase these (*6*). Further, the peak period has significant implications for land use and municipal expenditures, since transportation systems generally are designed to cater for peak traffic flow.

With regard to the peak period in the United States, it is important to point out that it now extends over 10 hr, from 9 a.m. to 7 p.m. And JTW trips do not, contrary to common belief, account for the lion's share of peak-period travel. 1990 *Nationwide Personal Transportation Survey* (NPTS) data (*5*) show that only between 1 and 9 a.m. do JTW and other work-related trips account for the bulk of person trips (47 to 60 percent) and vehicle trips (62 to 67 percent). Between 9 a.m. and 7 p.m., family and personal business (FPB) accounted for 41 to 56 percent of person trips and 42 to 61 percent of vehicle trips. It is FPB trips (particularly errand running) that are responsible for this 10-hr peak period.

Though FPB is more important than JTW and other work-related activity in terms of person trips, vehicle trips, person kilometers and vehicle kilometers (despite a shorter average trip distance) during the peak period of 9 a.m. to 7 p.m., and in terms of all these parameters except vehicle kilometers overall (*5*), JTW and other work-related activity has the lowest average vehicle occupancies (1.14 and 1.42, respectively, compared with 1.78 for FPB). JTW is the trip purpose with the highest percentage of single-occupant vehicle trips: as many as 91 percent of all personal motorized vehicle trips for the JTW are single-occupancy as opposed to only 61 percent for FPB. (However, in terms of actual numbers, there are more single-occupant personal motorized vehicle trips for FPB than for JTW.) Thus, while recognizing the importance of FPB trips, it should be noted that JTW in the United States is still significant in terms of energy and environmental impacts per person kilometer.

Figures 1–6 are self-explanatory and clearly demonstrate the benefits of nonmotorized modes. The energy benefits, on a passenger kilometer basis, of switching from even a vanpool—by far the best motorized mode—to a bicycle are significant. In terms of road and parking space, the figures demonstrate Tolley's observation that the bicycle (or pedestrian) has little effect on the "opportunity surface" of others (*7*). Further, the much lower road use and pavement strength requirements for nonmotorized modes have substantial implications for materials and energy consumption, environmental pollution, and expenditures associated with road construction, repair, and maintenance.

An important factor not included in the figures is noise, and the benefits of nonmotorized modes are obvious. Another vitally important issue that rarely gets mentioned is that of transportation wastes. Cars produce great quantities of waste—many of them hazardous, such as engine oil and transmission fluids—but cycling produces no wastes whatsoever, except for vehicle and parts disposal, and even these are of small magnitude (Figure 1).

CURRENT STATUS OF NMT IN THE UNITED STATES

According to the 1990 NPTS, about 43 and 44.4 percent of all person trips in the United States are performed in single- and multiple-

School of Community and Regional Planning, University of British Columbia, 6333 Memorial Road, Vancouver, British Columbia, V6T 1Z2, Canada.

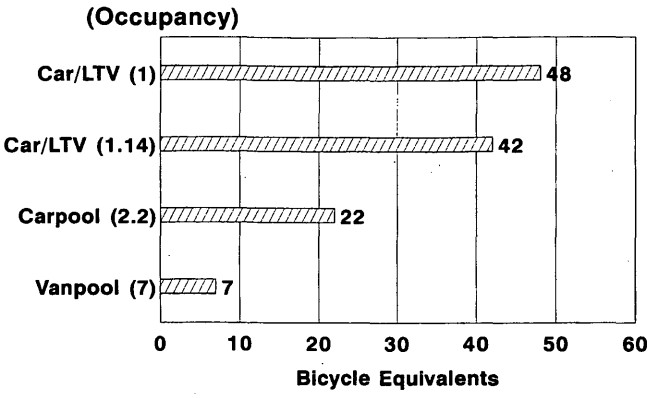

FIGURE 1 Material requirements, United States, 1989; bicycle = 30 kg/person (*1,2,5*).

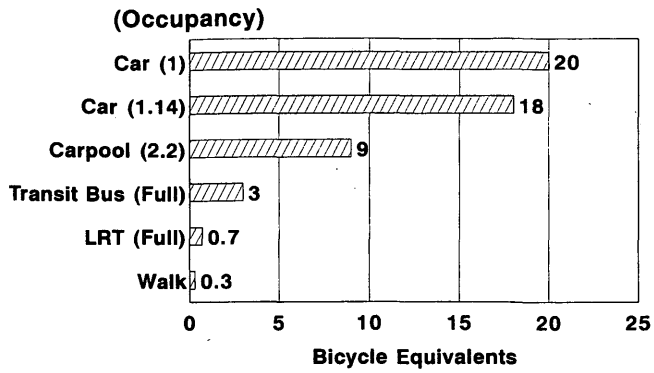

FIGURE 4 Road space requirements; bicycle = 3 m²/person at 10 km/hr, speed = 40 km/hr for car or carpool, 30 km/hr for bus and light rail transit, and 5 km/hr for walking (*1,3,5*).

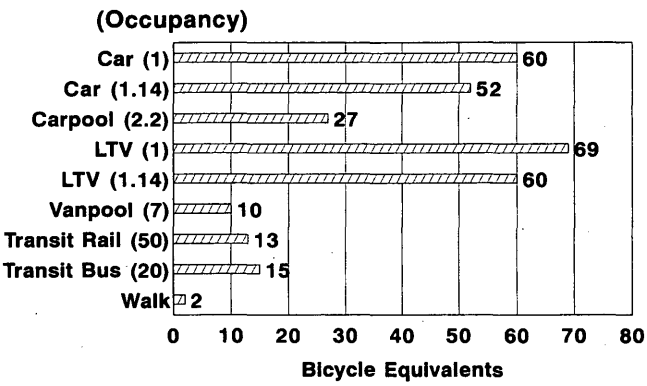

FIGURE 2 Energy use in operation, United States, 1989; bicycle = 92 kJ/person-km, fuel economy = 15.7 L/100 km for car or carpool and 18.1 L/100 km for LTV or vanpool while commuting (*1,5*).

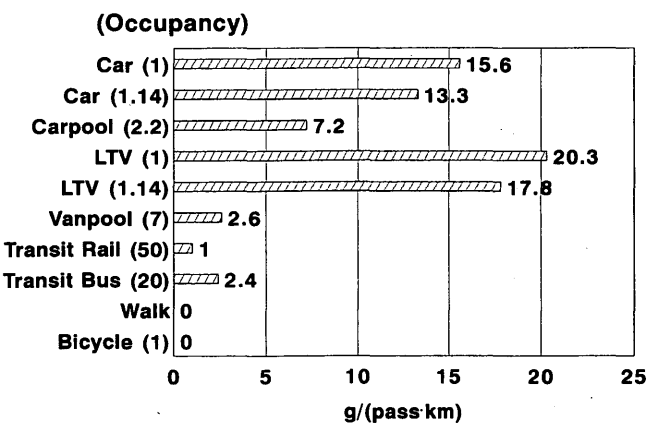

FIGURE 3 Total regulated emissions, United States, 1989 (fuel economy assumptions as in Figure 2) (*1,5*).

occupant motorized private vehicles, respectively (Figure 7). Only 2, 0.7, and 7.2 percent of person trips are by public transit, bicycle, and walking, respectively. It should be noted that there is a dramatic difference in modal shares between specific trip purposes. For example, 75 and 17 percent of JTW person trips in the United States are in single- and multiple-occupant motorized private vehicles, respectively, and only 4, 0.3, and 4 percent are by public transit, bicycle, and walking respectively. The corresponding figures for FPB person trips are 42.4, 50, 0.9, 0.3, 5.6, and 0.8 percent (*5*).

Figure 8 shows the share of single- and multiple-occupant motorized private vehicles, public transit, and nonmotorized modes for different trip distances in the United States. The NPTS data group trips 8 km and less under one distance category. The 1980 Canadian data (the latest available to the authors, and restricted to JTW), on the other hand, show modal shares separately for distances below 1.6 km, 1.6 to 3.2 km, and 4.8 to 8 km (*8*). Since the bulk of nonmotorized trips are 8 km or shorter, the Canadian data better present the importance of nonmotorized modes over these distances. However, the Canadian data do not separate out NMT from other modes (taxis, motorcycles) for various distance categories, whereas the NPTS data do; they also separate out cycling and walking trips.

At any rate, Figure 8 demonstrates that private motorized vehicles (many of them single-occupant) dominate, even over short distances—this despite the benefits of nonmotorized modes already outlined. Factors such as poor ability to carry passengers and goods and vulnerability to bad weather are certainly drawbacks of nonmotorized vehicles, but there are other reasons as well for their low modal shares.

Externalization of Costs of Motor Vehicle Use

Expenditures in terms of fuel production and distribution, road construction, and maintenance, and vehicle ownership and operation are calculable, and are either covered, wholly by car owners or partially subsidized from general tax revenues. But over and above these market costs are significant nonmarket costs due to motor vehicles that are externalized to society at large. These costs are difficult to calculate and in many cases deferred to the future (Figure 9). They include health care costs due to air pollution and noise and costs related to reduced crop yields, lost economic productivity due to congestion, high costs of transportation systems, and traffic

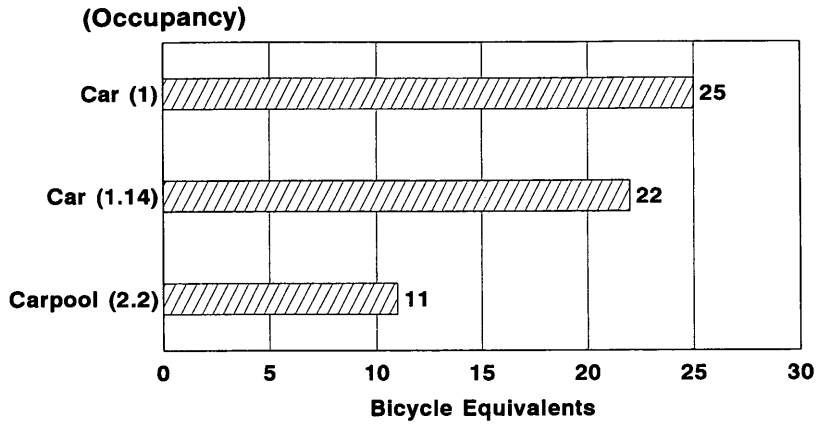

FIGURE 5 Land requirements for parking, United States, 1989; bicycle = 1.1 m^2/person (*1,5*).

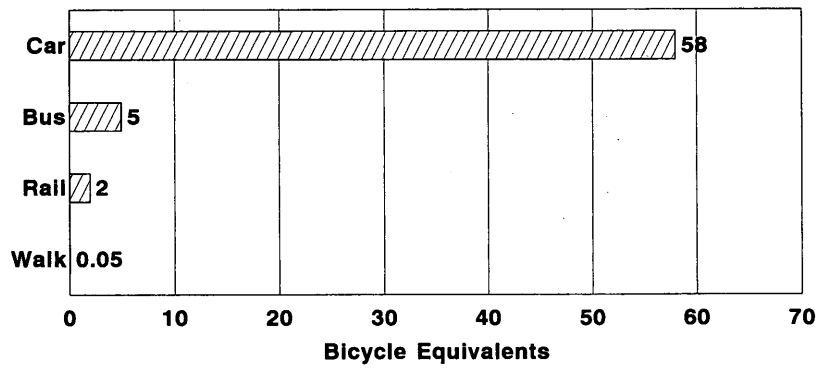

FIGURE 6 Accident risk, Germany, 1989; bicycle = 0.2 hr life lost/person-km (*4*)

injuries and deaths not covered by insurance (*1,3,9,10*). Figure 10 shows the extent to which transportation costs are externalized in various categories in the United States.

Vicious Circle

Automobile subsidies and externalization of the costs of motorized travel lead to a perception that driving is less costly than it actually is, which leads to excess provision of transportation infrastructure and excess consumption of that infrastructure by motor vehicle drivers (*9*). Further, conventional urban transport planning tends to favor highways and high speed by assigning considerable importance to even very small time savings for motorists; the resulting time losses for pedestrians and cyclists are ignored. The net result is reduced access for alternatives to cars in general, and nonmotorized modes in particular. Consequently, social inequity is exacerbated (*3,7,11*). It

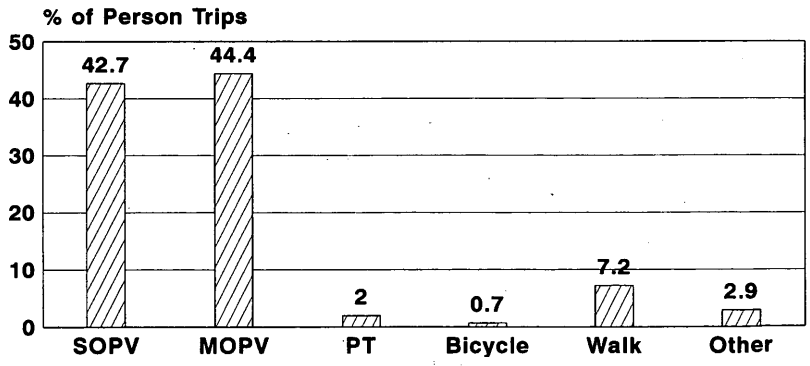

FIGURE 7 Mode choice, United States, 1990 (PT = public transit, SOPV and MOPV = single- and multiple-occupant vehicle) (*5*).

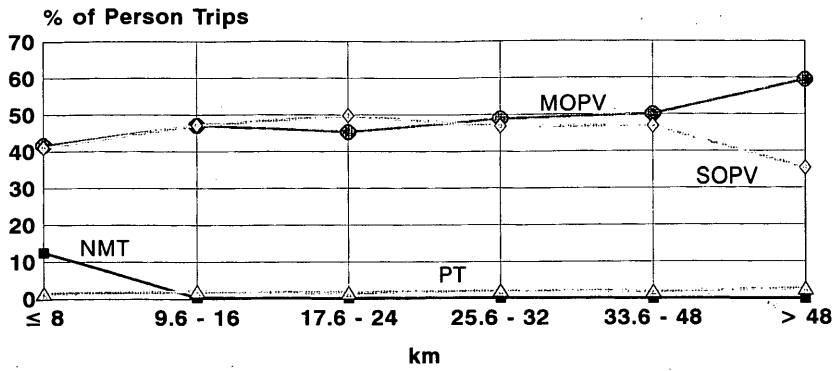

FIGURE 8 Distance and mode choice, United States, 1990; *X*-axis not to scale (*5*).

is instructive to note that average commute time, which includes both travel and waiting time, improved more for private vehicles than for other modes between 1983 and 1990 in the United States (*5*).

Another result of subsidies and externalization is sprawl, though these are by no means the only reasons for this phenomenon (*12*). As cities become dispersed, person kilometers increase geometrically and, as nonmotorized modes are less preferred for longer trips, motorized modes, particularly cars, become more predominant (*13*). Excessive reliance on cars and dispersed land use patterns tend to become self-reinforcing. As non-car modes become less viable, the car is held up as the only worthwhile alternative, and the system is designed increasingly to suit cars. Conversely, the fact that the other modes are becoming more difficult to use is used as a justification not to provide for them, which in turn makes them even less practical than they were and makes those who rely on them more vulnerable. A vicious circle has begun, and the car becomes self-perpetuating. Hillman (*14*) notes that in the United Kingdom, expenditures for cycling are constantly downscaled on the grounds that cycling plays an increasingly small role, as reflected in the dramatic drop in its use in official surveys over the past 20 to 30 years.

POTENTIAL FOR NMT

Khisty (*13*) makes the point that mode choice is determined so that travel time is minimized for the distance to be traveled; as distances increase, modes capable of higher speeds are chosen. The distance beyond which walking and cycling would not be considered for urban travel, or the "refusal distance," is of the order of 0.4 and 1.5 km, respectively, in developed countries. Although the distance-speed-mode choice relationship is generally true, nonmotorized trips—and the actual distances beyond which the nonmotorized modes would be refused in favor of motorized modes, assuming factors such as weather and a need to serve passengers or carry things are not a constraint—would most likely increase in proportion to several factors:

- The extent to which the transportation system accommodates NM modes, in terms of, for example, elimination of barriers and obstacles, protection from motorized traffic, and low waiting times at intersections, and the extent to which priority is deemphasized for motorized modes, particularly cars.
- The extent to which the social costs of motorized modes are internalized; as cost internalization increases, these modes

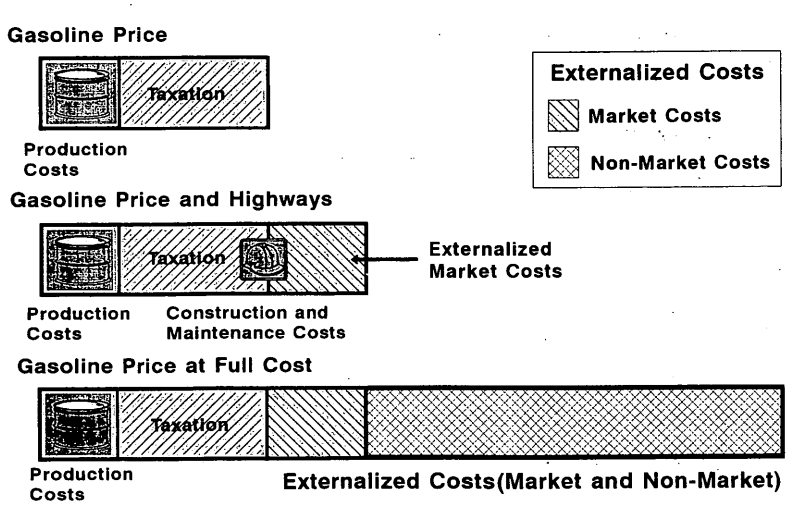

FIGURE 9 Externalization of costs (*3*).

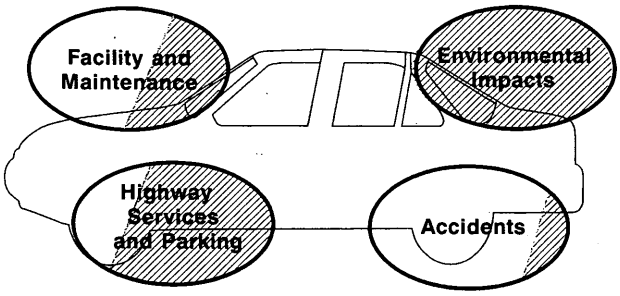

FIGURE 10 Uncovered transportation costs (shaded areas) (*9*).

are less likely to be chosen on the basis of time savings alone.

- The level of (unrelieved) congestion; as congestion increases, motorized mode speeds will most likely be hurt more than nonmotorized mode speeds.

In the European case, for example, the bicycle is superior to all motorized modes up to 5 km (Figure 11). Further, Illich (*11*) and Seifried [quoted by Whitelegg (*3*)] show that the average "social speed" for a bicycle is similar to that for cars (Table 1). The social speed takes into consideration the time that individuals spend earning the money needed to cover the costs of each mode. When this time is accounted for, actual time savings afforded by cars become considerably reduced; additionally, when external costs are factored in, the average social speed for bicycles compares favorably with that for cars.

Just as planning for cars, externalizing the cost of cars, and allowing dispersed land use lead to low shares for nonmotorized modes, planning for NMT, internalizing car costs, and promoting high-density land use are bound to result in increased use of these modes. The Dutch experience demonstrates the extent to which success can be achieved in this direction. In 1990 walking and cycling accounted for about 11 percent of annual passenger kilometers but as much as 46 percent of total trips. About 50 percent of employees commuting up to 5 km, and 25 percent of those commuting 5 to 10 km used the bicycle (*15*).

The top priority for any NMT substitution policy should be to attract those who drive alone in motorized private vehicles; it is this substitution that will have the maximum benefit (Figures 1–6). Second, it should focus on distances over which NMT is competitive with motorized modes. Thus, short-distance single-occupant private motorized vehicle trips should be the primary target for NMT substitution.

Figure 12 shows the cumulative distribution of all person trips and person trips in single-occupant private motorized vehicles as a function of distance in the United States (*5*). As many as 63 percent of all person trips, and 60 percent of all person trips in single-occupant vehicles, are performed over distances of 8 km or less. As far as JTW and FPB person trips are concerned, as many as 46 percent of the former and 69 percent of the latter are performed over distances of 8 km or less. Further, JTW trips of 8 km or under in single-occupant private motorized vehicles account for 32 percent of all JTW person trips. Finally, 25 percent of all person trips and 40 percent of all vehicle trips for all trip purposes are performed in single-occupancy private motorized vehicles over distances 8 km or under. This indicates the potential for increased use of nonmotorized modes, particularly cycling, if adequate provisions are made for these modes and all costs of motorized travel are internalized.

Figure 13 shows the graph for person trips in single-occupant motorized private vehicles in Figure 12 redrawn. The *y*-axis coordinates corresponding to 1.6, 3.2, and 5 km were interpolated from Figure 12. This interpolation shows that roughly 38 percent of all person trips, as well as of all person trips in single-occupant private motorized vehicles, are performed over distances 5 km or below in the United States. No doubt, many persons performing such trips may not be able, or willing, to switch to nonmotorized modes. But if even 10 percent of the estimated 39.49 billion single-occupant private motorized vehicle trips up to 5 km in the United States were performed by bicycle, assuming an average trip distance of 2.5 km, approximately 12.34 billion or roughly 4.6 billion (U.S.) worth of gasoline would be saved annually. This is just one example of the benefits that could accrue from even this limited substitution. Benefits would also be realized in terms of the other effects in Figures 1–6.

CONCLUSIONS

When the many benefits of nonmotorized modes are considered along with the minimal additional infrastructure that they require, it makes sense—from the energy, environmental, economic, public health, and social equity viewpoints—to promote them as much as

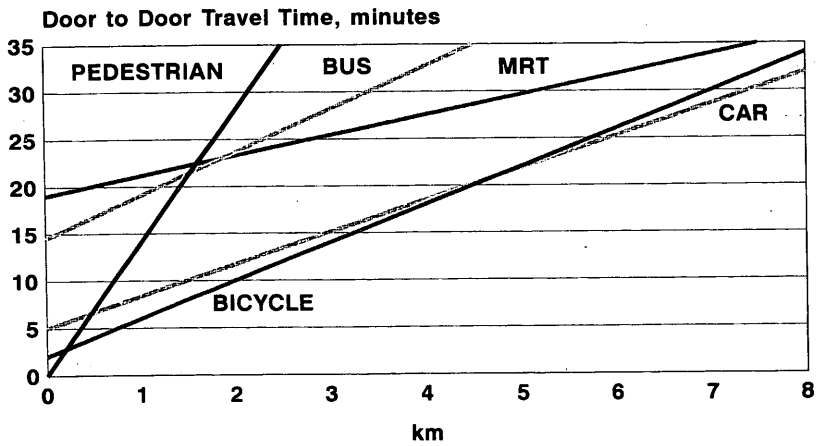

FIGURE 11 Urban travel times, Europe, 1988 (*3*).

TABLE 1 Social Speed, Germany, 1990: Bicycle Versus Car

	Bicycle	Car
Average Speed	15 km/h	60 km/h
Annual Cost	120 DM	16000 DM
Monthly Income	1600 DM	6400 DM
Hours Worked	15	400
Social Speed	14 km/h	21 km/h
External Cost	nil	30 pf/km
Adjusted Social Speed	14 km/h	18 km/h

DM -- Deutsche Mark; pf -- pfennig

possible. Motorized private vehicles undoubtedly have an important role in the transportation system, particularly over long distances, but they have significant social costs as well.

Transportation investment decisions consider only a limited set of costs (Figure 14) and thus lead to excessive provision for, and reliance on, motorized personal vehicles, even for short distances. Factoring in costs that are currently externalized (Figure 15) is the first step toward achieving a balanced, integrated multimodal urban transportation system. Further, urban transportation policy should move away from accommodating cars and consciously seek to enhance the use of nonmotorized modes.

Although the need to travel long distances can be decreased through urban restructuring and proximity planning, NMT policy realistically should focus on maximizing the use of nonmotorized modes in the distance range in which they are competitive with motorized personal vehicles; it should be remembered, however, that this range is itself partly a function of the extent to which nonmotorized modes are accommodated and motorized modes de-emphasized. Over intermediate distances, the aim should be to integrate NMT with transit and to moderate the use of motorized personal vehicles (Figure 13). Single-occupant private motorized vehicle users should be the primary target of an NMT substitution policy. Strategies for different distance ranges that will help bring about an appropriate modal mix are summarized here:

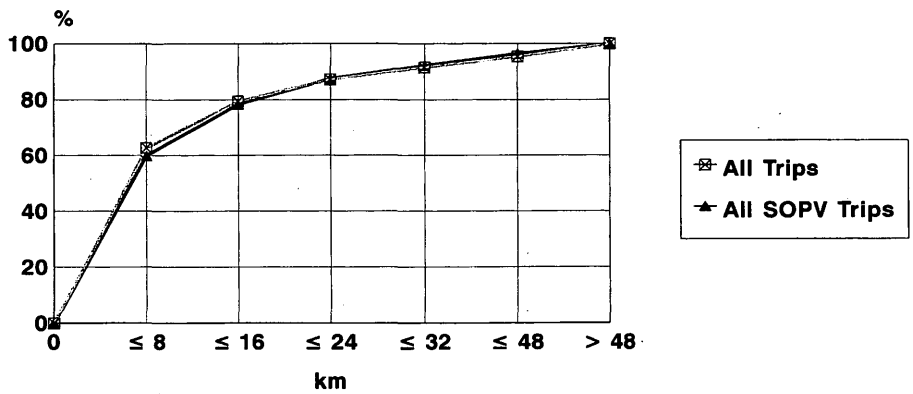

FIGURE 12 Cumulative distribution of person trips by distance, United States, 1990 (*X*-axis not to scale) (*5*).

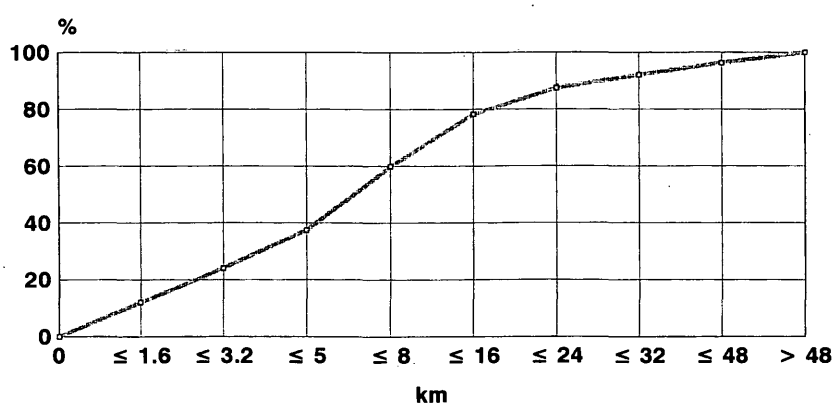

FIGURE 13 Cumulative distribution of SOPV person trips by distance, United States, 1990 (*X*-axis not to scale) (*5*).

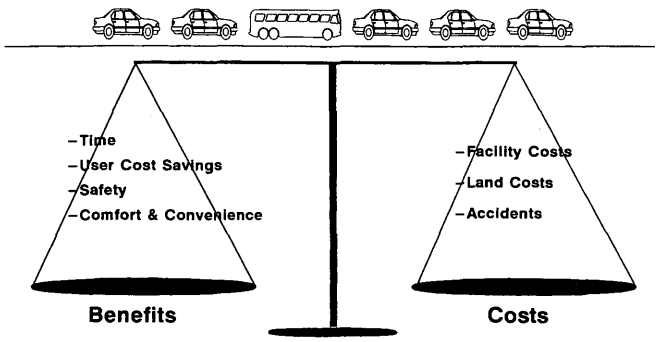

FIGURE 14 Current investment decision matrix.

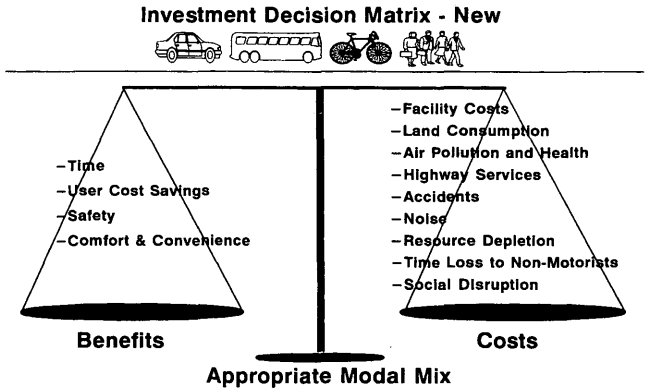

FIGURE 15 New investment decision matrix.

- NMT-dominant distances: Full cost accounting/recovery; discourage motorized transportation (MT), plan for NMT.
- NMT and MT mix: full cost accounting/recovery; moderate MT, plan for NMT and MT.
- MT and long distance: full cost accounting/almost full cost recovery; plan for urban restructuring.

Studies should be conducted to determine the conditions under which single-occupant private vehicle users would most likely switch to NMT, and also other "enabling" factors, and policy should be targeted accordingly.

REFERENCES

1. Gordon, D. *Steering a New Course: Transportation, Energy, and the Environment.* Island Press, Washington, D.C., 1991.
2. *The State of Canada's Environment.* Minister of Supply and Services Canada, Ottawa, 1991.
3. Whitelegg, J. *Transport for a Sustainable Future: The Case for Europe.* Belhaven Press, London, 1993.
4. Bendixson, T., and J. Whitelegg. Assessments of Institutional Responses. In *Transport, the Environment and Sustainable Development* (D. Banister and K. J. Button, eds.), E & FN Spon, London, 1993.
5. Oak Ridge National Laboratory. *1990 NPTS Databook: Nationwide Personal Transportation Survey.* FHWA, U.S. Department of Transportation, 1993.
6. Faiz, A., et al. *Automotive Air Pollution: Issues and Options for Developing Countries.* World Bank, Washington, D.C., 1992.
7. Tolley, R. A Hard Road: The Problems of Walking and Cycling in British Cities. In *The Greening of Urban Transport: Planning for Walking and Cycling in Western Cities* (R. Tolley, ed.), Belhaven Press, London, 1990.
8. Statistics Canada. *Travel to Work 1976–1980.* Minister of Supply and Services Canada, Ottawa, 1982.
9. Mackenzie, J. J., R. C. Dower, and D. D. T. Chen. *The Going Rate: What It Really Costs to Drive.* World Resources Institute, New York, 1992.
10. *Market and Government Failures in Environmental Management: The Case of Transport.* Organization for Economic Cooperation and Development, Paris, France, 1992.
11. Illich, I. *Energy and Equity.* Harper & Row, New York, 1974.
12. Hanson, M. E. Automobile Subsidies and Land Use: Estimates and Policy Responses. *Journal of the American Planning Association,* Vol. 58, No. 1, Winter 1992, pp. 60–71.
13. Khisty, C. J. Transportation in Developing Countries: Obvious Problems, Possible Solutions. In *Transportation Research Record 1396,* TRB, National Research Council, Washington, D.C., 1993, pp. 44–49.
14. Hillman, M. Planning for the Green Modes: A Critique of Public Policy and Practice. In *The Greening of Urban Transport: Planning for Walking and Cycling in Western Cities* (R. Tolley, ed.), Belhaven Press, London, 1990.
15. Pettinga, A. Can the Big Cities be Bicycle Friendly Cities? In *Congestion Management, NMT and Sustainable Cities* (V. S. Pendakur, ed.), World Bank, Washington D.C. (forthcoming).