TRANSPORTATION RESEARCH RECORD

No. 1487

Planning and Administration
Safety and Human Performance

Nonmotorized Transportation Research, Issues, and Use

A peer-reviewed publication of the Transportation Research Board

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY PRESS
WASHINGTON, D.C. 1995

Transportation Research Record 1487
ISSN 0361-1981
ISBN 0-309-06150-4
Price: $26.00

Subscriber Categories
IA planning and administration
IVB safety and human performance

Printed in the United States of America

Sponsorship of Transportation Research Record 1487

GROUP 5—INTERGROUP RESOURCES AND ISSUES
Chairwoman: Patricia F. Waller, University of Michigan

Global Task Force on Nonmotorized Transportation
Chairman: V. Setty Pendakur, University of British Columbia
Secretary: Walter B. Hook, Institute for Transportation Development Policy
Ahmed H. Abalkhail, Adetumji Ademiyi Bolade, Kay Colpitts, David R. Danforth, Harry T. Dimitriou, G. A. Edmonds, Erik T. Ferguson, Ralph Gakenheimer, Xavier Godard, Paul Guitink, Anthony Hathway, Charles A. Hedges, Ralph B. Hirsch, John Howe, Christer Hyden, Ben H. Immers, Darshan Johal, Peter M. Jones, Emanuel Klaesi, Kenneth E. Kruckemeyer, Henning Lauridsen, Joshua D. Lehman, Thomas R. Leinbach, Andrew C. Lemer, Slobodan Mitric, John Morrall, El Sadig M. Musa, Ricardo Oliveira Neves, Michael A. Replogle, Avinash C. Sarna, Richard G. Scurfield, Richard M. Soberman, Yordphol Tanaboriboon, William S. Thornhill, Bill C. Wilkinson III

Transportation Research Board Staff
Robert E. Spicher, Director, Technical Activities
Richard F. Pain, Transportation Safety Coordinator
Nancy A. Ackerman, Director, Reports and Editorial Services

The organizational units, officers, and members are as of December 31, 1994.

Transportation Research Record 1487

Contents

Foreword

Nonmotorized transportation continues to be a major topic for the international transportation community. Just the enormous volume of nonmotorized transportation suggests that these modes must not be ignored in transportation planning, safety, and operation. As the papers in this volume attest, researchers are trying to understand how nonmotorized transportation functions as part of transportation systems and in the larger economic and social fabric of cities and countries. Nonmotorized transportation has economic and environmental benefits that are discussed in this volume. As the nature and benefits of nonmotorized transportation are better known, transportation planners and policy makers should be in a position to include the mode in their formal deliberations, plans, and policies. The papers in this volume indicate that this must happen globally if the world's transportation needs are to be met in a balanced, sustainable form.

Using Transportation Tools Developed in the Third World To Promote Transportation and Development in America's Inner Cities

BRUCE EPPERSON

The establishment of effective urban transportation systems in many lesser developed countries (LDCs) has been impaired because of the indiscriminate importation of Western methods and technologies. In particular, the application of sophisticated four-step computer models and a reliance on formal cost-benefit analysis have predetermined the selection of highly capital intensive transport systems, such as subways, rapid rail lines, and elevated expressways. As an alternative, the LDCs themselves have evolved a developmental approach to transportation planning and implementation that relies on lower-cost sketch planning methods and emphasizes planning on a corridor or district basis. Equally important, this approach explicitly incorporates consideration of the distributional effects of policy alternatives and recognizes the importance of "informal" transport sectors, including nonmotorized transport modes and many forms of irregular (and often illegal) transit services. The issue is examined to determine whether these tools can be imported into industrialized nations to address the needs of their ailing urban cores. A survey of transportation programs around the country suggests that two promising areas are to encourage entrepreneurial paratransit and to promote nonmotorized modes as a stand-alone mode in core areas and as an adjunct to transit in more suburbanized areas. The problems faced in implementing both are primarily cultural and institutional, not technical.

In the past decade, several planning scholars and practitioners have argued that the establishment of effective urban transportation systems in many lesser developed countries (LCDs) has been impaired because of the indiscriminate importation of Western methods and technologies. In particular, the application of sophisticated four-step computer models and a reliance on formal cost-benefit analysis have been criticized as predetermining the selection of highly capital intensive transport systems. The resulting construction of subways, heavy rail lines, and elevated expressways have often been socially and economically destructive and offered little long-term relief from congestion or mobility problems (*1*).

These critics have argued that the unique needs of LDCs require an end to the wholesale importation of Western technologies and the establishment of a locally supervised developmental approach to transportation planning and implementation (*2*). The developmental approach relies on lower-cost sketch planning methods and emphasizes planning on a corridor or district basis instead of for an entire urban area all at once. Equally important, this approach explicitly incorporates consideration of the distributional effects of policy alternatives and recognizes the importance of informal transport sectors, including nonmotorized transport (NMT) modes and jitneys, shared taxis, and other forms of irregular (and often illegal) transit. Where applied, this approach has created significant cost savings, a more equitable distribution of project costs and benefits, and an improved mesh between transportation and social development goals.

This paper seeks to examine the issue from the other side to determine whether these tools can be imported into industrialized nations to address the needs of their ailing urban cores. After all, these areas often share many of the interrelated and self-generating problems as Third World cities, and several of the same conceptual and technical shortcomings that inhibited the use of Western transportation systems in nonindustrialized nations are also resulting in an ineffectiveness when applied in their own inner cities. It is concluded that these methods not only can be used, but should be used.

RISE AND FALL OF THE MEGAMODEL: WESTERN TRANSPORTATION PLANNING AND THE THIRD WORLD, 1945–1990

The use of large-scale computer models to plan and program transportation projects began in the United States in the early 1950s with the development of regional models for Chicago and Detroit (*3*). Creating these models from scratch proved to be an ambitious task: the Chicago Area Transportation Study required more than 500,000 man-hr of work before it was ready to yield results. The basic system architecture that resulted from these studies came to be known as the urban transportation planning process (UTPP, or UTP process). The UTPP model became applied more widely after the custom-made models of the early 1950s were replaced with relatively affordable off-the-shelf packages. At the same time, the federal government created the Highway Trust Fund to underwrite the costs of constructing and maintaining the Interstate highway system. Although the fund paid for up to 90 percent of the costs of building the Interstates, the actual planning and construction of these projects were still the responsibility of state highway departments. To ensure that candidate projects were the best use of available funds, the federal government came to rely more and more on the use of UTPP outputs, particularly in combination with formalized cost-benefit analysis procedures. Following the lead of their client base, consultants and model developers refined their tools to home in on the question of evaluating alternative freeway proposals, rendering the models less capable of exploring basic transportation policy questions.

However, by the mid-1970s the UTPP was encountering significant opposition. Its reliance on quantifiable effects tended to discount such hard-to-measure impacts as the deterioration of air and water quality, neighborhood disruption, and an unequal distribution

Metro-Dade Department of Planning, 111 N. W. First Street, Miami, Fla. 33128.

of costs and benefits to different social and economic groups. The conversion of costs and benefits to a common monetary unit masked what amounted to significant value judgments under the guise of objectivity. Almost always, the analysts and engineers in charge of these projects were unaware of the implicit "value loading" that they introduced while converting raw data into a form usable in their models.

In the United States, this concern resulted in the creation of a parallel shadow planning process of mandated environmental impact statements and required community participation formats. In addition, a reassessment of the UTPP has taken place within the transportation profession, including a reluctance to use the UTPP model as a monolithic tool for planning and justifying regional transportation strategies. Increasingly, individual modules have been used to evaluate specific transportation questions in a less deterministic planning process.

As the use of UTPP megamodels became less popular in the West, their practitioners began to market these products to Third World governments. A UTPP study was undertaken in Bombay, India, in 1955 and in San Jose, Puerto Rico, in 1959. By 1975 the UTPP model had been applied to at least 17 major LDC cities by American, British, Japanese, and German firms. In the next 10 years, a dozen more projects had been completed in the Third World.

SHORTCOMINGS IN USE OF WESTERN TRANSPORTATION METHODS IN LDCs

If anything, the crisis of confidence in the UTPP-based transportation planning and development process has been even more sudden and pronounced in LDCs. There are several reasons for this, given in the following sections.

Inappropriate Representation of Consumer Behavior

Traditional planning models are predicated on the assumption that individuals seek to maximize their welfare by minimizing the time and costs of travel. This behavioral assumption may not work well when applied to societies with cultural attitudes toward the value of time that are very different than those typical of the industrialized world. In this case, the development of highly capital intensive transport systems may be a poor choice because large sectors of the economy are unwilling to pay for travel time savings that are little valued (*4*).

Such problems are compounded by the widespread poverty prevalent in many Third World cities. The emphasis on personal choice that forms the basis of the trip distribution and mode split modules of the UTPP model breaks down when a significant proportion of the population has extremely limited economic options—or, as is all too often the case, no options at all. In this instance, the advantages of a new transport system may well be appreciated but will remain unaffordable to many (*5*).

In either of these cases, Western models tend to overestimate both the use and benefits accruing from the development of fast, but expensive, transportation innovations.

Inability To Deal with Modal Diversity

As a result of their greater constraints on resources, LDC societies have tended to retain a wider range of transport technologies, particularly those that serve distances between 0.5 and 20 km (0.3 and 12 mi). In general, these modes can be grouped into two types:

1. NMT, including walking, bicycling, handcarts, pedalcarts, and animal-driven carts and wagons, is frequently used for distances of up to 10 km (6 mi) or to convey heavy or bulky loads over pedestrian distances.
2. Various intermediate-technology transit vehicles are grouped together in this paper under the label "irregular transit." Examples include rickshaws and pedalcabs, motorcycle-based autorickshaws, jeepneys, jitneys, shared taxis, and minibuses. Not only do they form a unique class of technologies, but irregular transit systems also represent an attempt to overcome the inherent technological shortcomings of a mode through ad hoc innovation and flexible small-scale entrepreneurial management practices. Many of these practices represent flexible methods of cost sharing between owners, operators, and users.

UTPP models have trouble dealing with modal diversity because their cost and complexity increase geometrically with each additional transport mode considered. As a result, UTPP-based transport planning tends to be confined to the consideration of the few modes included in the model. Further compounding the problem is the tendency of the infrastructure supporting various transport modes to be progressively less tolerant of modal diversity as the level of technology increases. The flow of a collector or minor arterial street may not be affected significantly by the addition of a few bicycles or handcarts, but the level of service of an expressway will quickly degrade if only a few slow-moving vehicles are introduced.

Entrenched Social Stratification and Distribution of Costs and Benefits

Many Third World nations experience such extremes of wealth and poverty that they can be characterized as having dual economies. One economy serves the needs of the affluent and features modern technologies, formal (i.e., taxed and regulated) markets and much of the outward appearance of Western countries. The other serves disadvantaged groups and is marked by traditional technologies, informal markets, and moderate to severe levels of economic and political deprivation (*6*).

In these circumstances, Western planning techniques, which assume that the benefits of social investment are spread more or less equally among all members of a community, must be treated as highly suspect. Using classical economic theory, this assumption has been incorporated in the concept of Pareto optimality, which states that if one or more individuals gain from an investment while no one loses, a net gain in social welfare has occurred. An even more relaxed version of this concept is embodied in the Kaldor-Hicks criterion, which posits that a social gain has occurred if the gainers could compensate all losers and still realize a benefit, even if the compensation does not, in fact, occur. The Kaldor-Hicks criterion forms the theoretical basis for the cost-benefit analysis methodology. As Khisty observed, "the implications of the Kaldor-Hicks criterion for potential Pareto improvements is highly questionable and is of special importance when socioeconomic standards of a community are so distinct that transportation improvements frequently benefit particular groups of society systematically at the expense of others" (*7*).

ESTABLISHMENT OF DEVELOPMENTAL APPROACH TO TRANSPORTATION

The concept of a developmental approach to transportation planning and implementation was first outlined by Dimitriou and Safier in 1982 and initially applied in a study for the government of Indonesia on the island of Java. Other similar case studies have been reported for Madras, India; Tehran, Iran; and Katmandu, Nepal (*8*). All stressed

> measures aimed at improving the productive potentials of cities, the distribution of urban opportunities, and the improvement of social life and the physical environment by aiming to:
> 1. Maintain/increase the creation or growth of real resources per capita.
> 2. Decrease poverty and deprivation.
> 3. Promote increased accessibility to, and responsiveness of, public sector administration in urban affairs.
> 4. Promote adaptable physical and spatial arrangements to accommodate needs as well as cultural/social identity. (*2*)

In practice, this has meant a highly decentralized strategy focusing on the corridor or neighborhood level. Within a corridor, the competing demands of motorists, cyclists, pedestrians, adjacent shopkeepers and residents, and even itinerant street vendors are considered. For example, sidewalk obstructions such as power transformers, controller boxes, and utility poles can be buried or moved to private property and the space gained can be allocated to nonmotorized traffic and to economic opportunities for the urban poor by designating areas of the sidewalk for street vending. In Tehran, management of the street area entailed management of the djubes, or streetside drainage and sewage ditches. Some djubes were realigned to reallocate right-of-way width between road and walk, which are separated by the ditches. Other djubes were narrowed and lined with cement. All were bridged at specified locations to channelize pedestrian flows, thus minimizing vehicle-pedestrian conflicts and improving pedestrian accessibility. These actions also resulted in an improved sanitary and olfactory environment of the district.

A comparison of the alternatives examined in one program demonstrate the ability of this strategy to generate employment and foster economic development. In Patna, India, it was found that the equivalent of a $12,000 (U.S.) investment in line-haul buses generated 2 new jobs, whereas a similar investment in autorickshaws generated 6 jobs and one in pedal rickshaws, 75 jobs (*9*). These benefits are in addition to the enhancement of mobility for the poor: because of the relatively high fares, buses in India (and much of the Third World) are considered practical transportation only for emergencies, and autorickshaws and pedal rickshaws are much more effective in providing usable transportation services for the poorest third of urban dwellers.

DEVELOPMENTAL APPROACH FOR AMERICAN INNER CITIES

Like many LDCs, the central cities of America's urban areas have developed dual economies marked by extremes of wealth and deprivation. Gleaming downtown towers of glass and chrome throw shadows over ghettos marked by incidences of disease and mortality that often exceed those of all but the poorest of Third World cities. In some of these areas, families must trace back four generations before they can recall a head of household who has experienced long-term employment. Although there is disagreement about the causes of this bifurcation, three significant trends stand out:

1. A massive reduction in the nation's manufacturing sector and its promise of good wages for low-skilled but hard-working employees. The shift to a service-oriented economy has resulted in a split between low-skill, low-wage jobs and high-wage, information-management jobs requiring years of specialized training or education.
2. A fundamental shift in urban form to one based around increased mobility, for both people and information. The most obvious example of this is the automobile, but no less important are the television, the telephone, and the computer network. Generally these transport systems use infrastructure that has been developed with public subsidies that have allowed their use to be priced below its true market cost. But access to these networks requires the user to acquire an access device such as a car, telephone hook-up, or personal computer, which itself is not subsidized. If an individual can pay this fixed cost, then the variable costs of actually using the network are quite low. In the case of the automobile, they are virtually zero.
3. A shift in employment opportunities away from the central city toward the suburbs. This is the result of shifting manufacturing processes, which now are best housed in wide, low structures, and the shift to service sector firms, which require proximity to both customer and employee. Of all types of service sector employers, only the high-skill, high-wage industries of government, finance, and law appear to have chosen consistently to remain in central business areas.

The result of these three trends is that the poor are concentrated in urban cores while jobs migrate to the suburbs. Unable to pay the up-front costs of access to transportation and information networks, they remain trapped and dependent. The challenge, therefore, is twofold: to provide increased mobility to inner-city residents and to reestablish an indigenous economy in the inner city that both services and employs its residents.

Improving Transit: The Entrepreneurial Edge

Mass transit is the transportation lifeline in inner-city areas. According to the 1983 National Personal Transportation Study (NPTS), 17.7 percent of all trips made by center-city residents are made by transit, as compared with only 3.8 percent of all trips made by suburban dwellers. For black inner-city residents, more than one in four trips is made by transit (*10*). Nationwide, two out of three transit riders are black or Hispanic. Even so, transit agencies have spent the past two decades constructing express bus and rapid rail systems serving the needs of suburbanites traveling into downtown, often using increased local bus fares or decreased service to help pay the bill. Pucher (*11*) labels this practice price discrimination:

> When they were privately owned, most transit systems designed their services and fare structures to maximize profits or minimize losses. In the current era of overwhelmingly public ownership, the goal appears to have shifted to the maximization of total transit patronage. Economic theory indicates that, with respect to either of these goals, the optimal strategy for the transit system would be to offer the best service and most discounted fares to those customers with the most elastic demand and, conversely, to provide the inelastic submarket with the lower quality of service at premium fares.

One often-proposed solution to this reverse-commute problem is the use of vans or minibuses operating on timed reverse-commute routes or on a demand-responsive (dial-a-ride) system. Although such paratransit services are readily adaptable to both urban and suburban environments, most forms of this service tend to cost more than line haul on a seat-mile basis. In the past, this price difference has been paid by employers needing low-wage service workers. But frequently such programs have had a cyclical life span, as employers withdraw their participation during slack economic times when there is little or no shortage of willing workers. In a study of reverse-commute paratransit services over a 20-year period, Rosenbloom (*12*) found that the only successful nonprofit operations were those connecting high-wage workers to commuter rail stations.

On the other hand, Rosenbloom did find one thriving sector of the paratransit market: irregular private transit services, including shared taxis and jitneys. The term jitney refers to a broad variety of cost-sharing techniques, ranging from employees who exchange rides for gas money as they travel to and from work, to mobile tradesmen who use a van or station wagon as a shared taxi during slack days, to large firms that rent out modified vans to individual operator-entrepreneurs for the day or week. Up to 2,500 jitneys are estimated to work the streets of New York, and about 300 operate in Miami (*13*).

Jitneys usually are heavily regulated, and traditional transit operators, who claim that the jitneys engage in "cream skimming" on their best routes, have pressed for vigorous enforcement of these rules. Several researchers who have examined these claims have found they contain little merit (*14,15*). Because few if any municipal bus routes show a true profit, there is no cream to skim. Instead, jitneys should be considered deficit skimmers: by reducing the need for federally subsidized municipal service on high-volume routes, jitneys free transit resources that can then be applied to less-used routes that would not be profitable for private operators. Although certain regulations, such as those dealing with equipment safety and insurance, are reasonable, many rules, particularly those that mandate the use of a fixed route or schedule and prevent route diversions to allow for door-to-door service, appear to be designed to impose on private operators the same level of user-unfriendliness that has made municipal transit the transportation mode of last resort. In addition, it appears that some municipal operators have had a policy of licensing jitneys on certain routes, only to revoke the license and take over service once a ridership base has been established (*16*).

Government transit operators would better serve their inner-city constituents by using available resources to foster this flexible and adaptable transportation service. Insurance for single-vehicle commercial operators is often prohibitively expensive: municipal transit agencies could require their insurance carriers to extend insurance to these entrepreneurs at a reasonable price as a precondition for doing business with the agency. Transit operators could provide driver instruction and field offices for issuing commercial driver's licenses or chauffeur's permits. Transit garages could be used to provide low-cost vehicle safety inspections and minor safety-related maintenance at an affordable price. This would both promote jitney safety and bring in ancillary revenue.

For many large cities, the provision of transit services is one of the largest sources of skilled and semiskilled trades employment opportunities, a powerful weapon in the war on urban poverty. Turning transit into an effective antipoverty tool first and foremost means ending the transit industry's near-obsession with labor force reductions, particularly by replacing employees with capital-intensive, high-cost technologies. In the past 25 years, labor cost reduction has become the holy grail of American public transit, providing the justification for a score of staggeringly expensive rail systems that have failed to meet financial or engineering goals. As researchers have since discovered, the alleged benefits of replacing employees with technology were based on evaluative methodologies so poorly developed that their results are indistinguishable from outright fraud (*17*). Rather than seeking to displace employees, transit operators should work to secure new opportunities to use their talents. The use of maintenance facilities to support entrepreneurial paratransit ventures is but one example of this.

NONMOTORIZED MODES: CITY TRANSPORT OR SUBURBAN RECREATION

Paratransit is one way to overcome the inherent disadvantages of transit at densities lower than urban. Another is to combine modes by using other forms of transport as a feeder mode to gather riders at relatively high intensity transit centers. Although transit operators have made good use of park-and-ride lots for many years, these facilities are designed to service a middle-class, car-owning clientele living in far-flung suburban areas. What is needed in the moderate densities of older suburbs or fringe areas is a similar method of increasing the accessibility of line-haul transit routes, but for a constituency that does not own cars. One promising low-cost alternative is combining bicycles with buses or trains. A Phoenix "Bike-on-Bus" demonstration project in spring 1991 proved so successful that Phoenix Transit elected to install the front-mounted two-bicycle carrying racks on all 350 of its buses. A detailed survey of the users of the service during the 3-month demonstration revealed the following:

- 90 percent were commuting to or from work or school.
- The median age was 31. (The median age for all bus users was 35.)
- 91 percent were male. Most reported themselves as belonging to skilled trades, blue-collar occupations.
- Half of the users did not have a car available for the trip being made at the time the survey was taken. Almost two-thirds reported that they would have either taken the bus or ridden their bike as a solo mode had the service not been available.
- The mean average self-reported total trip time was 58 min, with an average to-bus ride of 9.2 min and an average from-bus time of 7.5 min. Thus, the in-bus travel time was more than 42 min, indicating that service users were taking relatively long trips (*18*).

Phoenix Transit counted 1,404 users in the last month of the demonstration project. On the basis of per-bus utilization figures, this would suggest a usage rate of nearly 10,000 users per month after the racks are installed systemwide. The transit system plans to augment the Bikes-on-Bus service with a program to install permanently anchored bike racks and enclosed bicycle lockers at bus transfer locations and transit terminals.

The success of the Phoenix program demonstrates that multimodal projects can greatly expand the reach and efficiency of transit systems. The user profile that emerged shows that even though transit use continues to be highly dependent on economic and demographic factors such as automobile availability, income, and the supply and price of parking at employment centers, relatively inexpensive and easily implemented measures can help transit overcome the problems posed by newer urban forms to reach out and assist their traditional client groups.

Within the more dense core area, the bicycle and other NMT vehicles need to be fostered as a stand-alone mode. Despite more than 20 years of bicycle planning in this country, very little has been done to make bicycle use in the inner city either safer or easier. This has largely been the result of state and local policies favoring the interests of experienced sport cyclists over those of their more numerous utilitarian counterparts. Much of this can be traced to a lack of involvement of traditional cycling-oriented nongovernmental organizations (NGOs) with issues relevant to the inner city. Most American cycling NGOs have been targeted at either sport cyclists or environmental activists. Both of these interest groups historically have exhibited an antiurban, middle-class bias.

One significant exception is the New York–based Institute for Transportation and Development Policy (ITDP). For more than a decade, ITDP has developed innovative manufacturing, financing, and support programs centered on bicycles and other appropriate-technology transport modes to promote both mobility and economic development. Through its efforts, this NGO has trained hundreds of economically, physically, and socially disadvantaged individuals to repair and manufacture bicycles, wheelchairs, and carts and has put thousands of these vehicles into the hands of workers and entrepreneurs. However, to date, ITDP has focused its efforts in LCDs in Africa, Asia, and Latin America. As a model for fostering mobility and economic development in America's inner cities, ITDP offers a far more promising model than has this country's own NMT-oriented organizations.

The expansion of NMT can also be a powerful employment generator. Both China and Cuba recently have taken steps to deregulate the entry of bicycle mechanics into the economy, as a means of both fostering bicycle travel and encouraging young men and women to enter the mechanical trades in a semientrepreneurial manner. Requiring a relatively small investment in tools and training, many bicycle mechanics in the LDCs later transition into the repair of motorcycles and transit vehicles. In America, bicycle repair operations are usually a part of larger establishments that sell bicycles and other sporting goods. This means that mechanics are usually located in the suburbs (to service a high-end recreational client group) in businesses that require a high capital outlay for a sales inventory. Few inner-city cyclists have ever been inside a bicycle store, and almost none have had their bicycles worked on by an experienced mechanic.

Operating out of a small storefront with a minimum initial investment in tools and spare parts, an inner-city bicycle repair operation could provide both employment and convenient, inexpensive service to core area cyclists, greatly increasing the efficiency and safety of their bicycles. Transit operators could promote these businesses by using them as a way of providing secure, weather-protected bicycle day storage near transit terminals and stations.

Fostering NMT also often requires retrofitting older neighborhoods with sidewalks, bicycle facilities, and devices to control motor vehicle speeds and flows. Public works projects of this type offer greater opportunities to train and employ neighborhood residents than does the development of large high-technology transport systems, which usually require the importation of an expensive specialized work force. When completed, neighborhood projects promote a renewed vitality within communities instead of drawing economic opportunity and community development efforts into a few selected corridors or around a few targeted station sites.

Traditionally, such programs have suffered from a lack of funding due to a federal transportation financing structure that has ignored the economic development aspect of the transportation infrastructure development process. Much of this changed in 1991 with the passage of the Intermodal Surface Transportation Efficiency Act (ISTEA). Several states and urban areas have taken advantage of ISTEA's flexible funding structure to promote air quality and transportation alternatives, but few local agencies have recognized the opportunities allowed in the legislation to effect meaningful socioeconomic changes or integrate explicit social or economic justice considerations into their transportation development policies or procedures.

NEED FOR FOCUSED RESEARCH

Very little research has been performed on the use of NMT in the inner city and the mobility needs of the urban poor. As a result, many well-meaning programs have failed because they were based on false assumptions or targeted a nonexistent clientele. For example, in the United States, bicycle planning after the mid-1970s was based on the assumption that almost all bicycle use was voluntary and that very few cyclists rode because they lacked other transport options. It was not until recently that research has revealed that the poor and other transportation-disadvantaged persons make most of the existing utilitarian cycle trips (*19*).

Although virtually the entire subject area is ripe for investigation, the most pressing needs appear to be in the following areas:

- *Nonmotorized trip generation and distribution patterns for cyclists across the income spectrum.* The 1990 NPTS included detailed data about bicycle and pedestrian travel for the first time. However, because the survey was conducted using telephone interviews, its survey sample was skewed away from the poorest households. In addition, more than a third of all walking trips and over half of all bicycling trips were listed as being taken for social and recreational purposes. There is a need to differentiate between (*a*) purposeful trips to a specific location to access social and recreational opportunities and (*b*) travel taken without a destination made because the trip itself is considered the recreational opportunity.

The final product of such research would be a quantitative methodology for predicting present and future bicycle and pedestrian flows and the spatial location of these flows. Such a procedure forms the basis of the transport analysis for motorized modes and should be adopted for use by NMT planners.

- *Methods for objectively evaluating the cycling and walking environment.* A level-of-service (LOS) methodology for pedestrian facilities was developed in the 1960s by Fruin, and later a preliminary set of roadway operational standards for bicycles was included in the *Highway Capacity Manual* (*20*). However, the pedestrian LOS methodology is useful only at high levels of crowding (which occurs fairly infrequently), whereas the components used to develop the bicycle LOS standard have focused more on measuring the delay that bicycle use imposes on motor vehicle traffic than on determining the quality of service that a roadway delivers to cyclists.

Methods for assessing how well a corridor or facility is providing service to bicycle or pedestrian users are important for two reason. First, LOS is a significant determinant of route choice for NMT users. Unlike motorists, who are deflected from the shortest or fastest path between two points only by substantial congestion or severely unpleasant operational conditions, relatively small changes in the travel environment can have large impacts on the selection of a travel route by NMT users (A. Sorton, unpublished work, 1994). Second, the quality of the nonmotorized travel environment greatly influences the go/no-go decisions of potential travelers. For those with few modal options, the lack of safe and convenient nonmotorized routes results in decreased access to employment, shopping, medical services, and other basics of life.

• *The role of transportation development in generating economic development.* The relationship between transportation infrastructure and the creation of employment opportunities has been evaluated in depth only for new motor vehicle roadways built in undeveloped "cornfield" locations. Little or no work has been done on the role of improved mobility on central-city job creation, and little has been done on the role of improved transit accessibility in either suburban or center-city economic development. Some studies have evaluated land development in the area of suburban rapid rail stations, but rail and bus development have not been compared, and employment resulting from such development has not been studied.

Although some historical studies have critically evaluated the accuracy of performance and efficiency projections of large-scale rapid rail projects, little or no work has been done on the employment impacts of such development. Some have suggested that such projects result in an expansion of employment opportunities for white-collar staff workers while removing blue-collar line jobs.

CONCLUSION

The concept that Western planners can learn from the experience of their Third World colleagues may prove to be a bitter pill to swallow. After all, such a confession requires admitting that Western nations have allowed their inner-city areas to deteriorate to the point where traditional solutions do not work, and that technology itself is not capable of solving all problems for all people in all circumstances.

However, it is a pill planners must learn to swallow. Single-minded devotion to ever-more sophisticated forms of technology as the answer to urban ills is destroying America's cities and turning hundreds of thousands of its residents into either dependent chattel or criminals. The author does not intend for this paper to be a blanket indictment of technology or technologically sophisticated transport tools. He does, however, indict the concepts that technology is always the answer and that if a new technology does not help (or even it if harms) a problem, area, or population group, it is the fault of the group, who deserve what they get.

Westerners must acknowledge the diversity of their citizens and communities, as well as the diversity of their needs. They must also acknowledge that in some ways they are not so very different from the Third World and that innovation must be judged on its own merits and not on the basis of where it came from or who it was intended for. The continued price of technological chauvinism is too high. It can no longer be afforded, in terms of wasted money, wasted neighborhoods, or wasted lives. The pill may be bitter, but what is it compared with the disease?

ACKNOWLEDGMENTS

The author wishes to thank the following individuals who reviewed earlier drafts of this paper and provided many useful suggestions: John Howe, C. Jotin Khisty, V. Setty Pendakur, and Charles Wright. N. J. Quinlan provided valuable bibliographic and research assistance.

REFERENCES

1. Wright, C. *Fast Wheels, Slow Traffic: Urban Transport Choices.* Temple University Press, Philadelphia, Pa., 1993.
2. Dimitriou, H. T. Policy-Making and Planning for Non-Motorized Urban Transportation Systems: A Developmental Approach. In *Transportation Research Record 1396,* TRB, National Research Council, Washington, D.C., 1993, pp. 50–57.
3. Weiner, E. History of Urban Transportation Planning. In *Public Transportation,* 2nd ed. (G. Gray and L. Hoel, eds.), Prentice-Hall, Englewood Cliff, N.J., 1992.
4. Pendakur, S. V., and M. Guarnaschelli. Motorized and Nonmotorized Transport in Katmandu, Nepal: Where do the Pedestrians Fit? In *Transportation Research Record 1294,* TRB, National Research Council, Washington, D.C., 1991, pp. 26–33.
5. 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.
6. Dimitriou, H. T. Transport and Third World City Development. In *Transportation Planning in Third World Cities* (H. Dimitriou and G. Banjo, eds.), Routledge, London, 1990.
7. Khisty, C. J. Research on Appropriate Planning Methodology in Developing Countries. In *Transportation Research Record 1028,* TRB, National Research Council, Washington, D.C., 1985, pp. 18–25.
8. Proudlove, A., and A. Turner. Street Management in Transportation. In *Planning in Third World Cities* (H. Dimitriou and G. Banjo, eds.), Routledge, London, 1991.
9. Replogle, M. A. Sustainable Transportation Strategies for Third-World Development. In *Transportation Research Record 1294,* TRB, National Research Council, Washington, D.C., 1991, pp. 1–8.
10. Gordon, P., A. Kumar, and H. W. Richardson. The Spatial Mismatch Hypothesis: Some New Evidence. *Urban Studies,* Vol. 26, No. 3, 1989, pp. 315–327.
11. Pucher, J. Discrimination in Mass Transit. *Journal of the American Planning Association,* Vol. 48, No. 3, Summer 1982, pp. 315–326.
12. Rosenbloom, S. *Reverse Commute Transportation: Emerging Provider Roles.* Drachman Institute, Tucson, Ariz., 1992.
13. Machabala, D. Opportunistic Vans Are Running Circles Around City Buses. *Wall Street Journal,* July 24, 1991.
14. Cervero, R. Profiling Profitable Bus Routes. *Transportation Quarterly,* Vol. 44, No. 2, 1990, pp. 183–201.
15. Pickerell, D. *Is There Any Cream To Skim? An Analysis of Urban Transit Costs and Revenues by Type of Service.* Center for Transportation Studies, Massachusetts Institute of Technology, Cambridge, 1986.
16. Urban Mobility Corporation. *The Miami Jitneys.* Office of Private Sector Initiatives, FTA, U.S. Department of Transportation, Aug. 1992.
17. Pickerell, D. A Desire Named Streetcar: Fantasy and Fact in Rail Transit Planning. *Journal of the American Planning Association,* Vol. 58, No. 2, 1992, pp. 158–176.
18. *Bike on Bus Demonstration Program: Evaluation Report.* Phoenix Transit Administration, Arizona, Sept. 1991.
19. Antanakos, C. Nonmotor Travel in the 1990 Nationwide Personal Transportation Study. Presented at 74th Annual Meeting of the Transportation Research Board, Washington, D.C., 1995.
20. *Special Report 209: Highway Capacity Manual,* 3rd ed. TRB, National Research Council, Washington, D.C., 1994.

Any errors in this paper are solely the responsibility of the author.

Treatment of Walking as a Mode of Transportation

MARCUS WIGAN

Walking is viewed from many different perspectives, but it lacks informed advocacy groups and a unified policy treatment. Walking is treated here as a full transportation mode that both genders use. Significant gender differences are disguised by combining cycling and walking into a single nonmotorized transportation mode. New data derived from Australian travel surveys are presented, and the relative importance of walking to other transport modes is illustrated in terms of the fractions of trips and of travel time.

Walking is the most widespread mode of movement, but it is not always treated as a full mode of transportation. "Pedestrian" is the term used for the mode of transport. Pedestrians are rarely treated on the same level as vehicle-based modes. ["Nonmotorized transportation" (NMT) is now used to lump walking and cycling together, although they have very different usage and network profiles.] Major factors that influence the treatment of travel modes are strong advocacy groups, information about the mode, its performance and impacts, and the people and groups affected.

Many groups represent the handicapped and mobility constrained; few represent pedestrians as a whole. Information about walking and pedestrians therefore is largely limited to areas in which government bodies have been required to take an interest or commercial investments rely on passing pedestrians. Only injury data are collected and made available on a regular basis. As a result, most pedestrian policies focus on reducing reported injuries rather than integrating walking into the treatment of mobility.

Walking is an essential component of almost all trips and determines physical access to facilities of all kinds. Public transportation such as trains and buses requires walking both for access and for movement within the vehicles themselves. Private transportation also includes a walking component—from house to vehicle and parking place to destination.

What does a pedestrian trip comprise? To whom is walking most important? How does pedestrian activity compare with other modes of transport? How does one evaluate travel and access by foot in specific locations and for the walking stages of complex journeys? Walking provides the initial access (and egress) to trips by other modes and is the unrecorded off-road section of trips that are recorded.

This first access/last egress stage (and modal transfer stages) are critical to people with constraints on personal movement. Estimating mode choice models requires careful discrimination between on-vehicle and out-of-vehicle waiting and walking time, but once the model has been estimated, the walking information is often ignored.

Unlike vehicle-based modes, walking trips are very difficult to define: is a journey through or entirely within a large building a "trip"? In the case of a movement inside a small house this might be easy to decide, but when the trip is made along a street converted into a covered mall, it is less easy to determine.

Vehicle trips involve the use of a bicycle, car, or other vehicle. It is this association that defines the start, end, location, and duration of a trip. Walking trips usually are defined by their location alone as the person always has the "mode" in use for movement in all locations. This fits in with the policy emphasis on safety treatments of specific locations. Pedestrian travel choices and mobility decisions often are ignored or estimated from inadequate information.

DEFINITIONS

Walking is applied to travel by foot for exercise or enjoyment or for reaching a specific location for some purpose. Power walkers on the footpath, trail hikers, and pedestrians moving inside and outside transport interchanges are all walking. People both walk and cycle as ends in themselves for exercise and sightseeing, and the ability to use off-road rights of way as alternatives to the normal transportation network is shared.

A *trip* is a movement between locations; 400 m is a sensible distance to quality as a transport journey—but only if the access and egress stages of vehicular journeys are assumed to have no impact on the vehicular travel. (In fact, the 1991 Greater Sydney Household Interview Survey used a definition that required walking trips to be recorded by the surveyed person *only* if they exceeded 100 m, or 110 yd, *in public areas.*) People make real efforts to park less than 400 m (440 yd) from their destination, yet the disutility of that final 100 to 399 m (100 to 440 yd) is frequently ignored as a "trip" for transport measurement purposes.

Distance is not always a good measure for transport comparisons. A typical walking speed is 4 to 5 km/hr (2.5 to 3 mph), so 400 m (440 yd) translates to a 5-min trip, which would be 1 to 3 km (0.6 to 2 mi) by car in an *un*congested area.

Pedestrian is used to describe someone who is walking, usually in public places, and particularly on or adjacent to public rights of way for vehicles.

A person observed "during the walking stages of a trip" appears to be somehow different from a "pedestrian." Dealing with walking as a transportation mode is made more difficult by confusion between the concepts:

- Mode = person (in walking), and
- Round trip = use of multiple modes by the same person.

Cambridge Systematics, 68 Castle Street, Eaglemont, Victoria 3084, Australia.

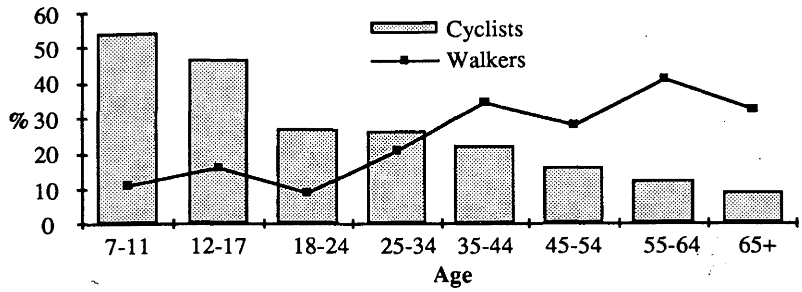

FIGURE 1 Walking and cycling participation as function of age for U.S. fitness enthusiasts.

CONTEXT

Walking and pedestrians are considered important by a wide range of groups in different contexts, so walking provisions are considered piecemeal and not as part of a transport and trip end access system. These provisions include

- Very high costs and vulnerability in road accidents;
- Pedestrian phases and road crossings for traffic lights;
- Access by the aged, disabled, and children;
- People flows on footpaths and in malls and transport interchanges;
- Predictions of passing trade by foot for retail siting and valuation;
- Health, recreation, and exercise;
- Valuation of waiting and walking times;
- Segregated NMT movement networks;
- Parking location, pricing, and choice; and
- Provision of activity in public areas as a security measure.

Planners and environmental designers are concerned with the social and commercial success of space dedicated for pedestrians, and the factors that make it attractive often are measured by shop rentals and the levels of pedestrian activity over time.

Traffic policies emphasize segregating pedestrians from traffic as a measure to reduce injuries and value the benefits in these terms. Traffic design requires pedestrian crossings to be provided and used. Designers need to know how far people will divert to use a crossing or a bridge, what speed they normally walk, how long they will wait for a pedestrian light phase without jaywalking, and how quickly they will cross. Transportation planning often recognizes walking and waiting time as an element in mode choice but rarely looks closely at the walking trips themselves, except when they influence the "major" mode choice decision.

To what extent can walking substitute for motorized transportation? What are the effects on different groups of altering the relative attractiveness of motorized and nonmotorized modes? These questions require a "transport" view of walking.

The assumption that travel is undertaken simply to reach a destination is far less convincing for NMT than for motorized modes. Tourist and sightseeing travel occurs on motorized modes, but exercise, health, and recreation play an important part when bicycles and walking are involved. Environmental contributions, exercise, and health are all factors in NMT travel.

Australian transportation surveys (*1*) show that both walking and bicycle participation rates tend to decrease with age for adults. However, if recreational and health participation are examined, U.S. evidence (*2*) shows that walking rises in importance relative to cycling as age increases (Figure 1).

The transportation aspects of walking and pedestrian movements can be examined using transportation survey data, and relevant results of such analyses are given in the following sections. Australian data for Canberra in 1975 and Launceston in 1976 (*1*) contained only 12 to 14 percent of nonmotorized trips undertaken solely for exercise or recreational purposes.

TRAVEL SPEED

Typical journey speeds by NMT modes are not widely quoted, and it is useful to place each of the modes in a consistent context. Table 1 provides mean travel speeds over the year for both men and women in Australia.

The values in Table 1 are derived from the 1986 Federal Office of Road Safety (ORS) National Survey of Day-to-Day Travel (*3*), which covered travel by 18,000 people over 8 years old sampled from across Australia. The pedestrian trips were of undefined length

TABLE 1 Mean Speeds, Australia 1986

Mean Speed km/h	Men	Women
Pedestrians	**5**	**4**
Bicycles	11	8
Ferry	10	10
Tram	13	10
Bus	24	21
Taxi	28	18
Train	30	29
Motorcycles	35	27
Car Driver	35	30
Car Passengers	39	38
Truck	37	42
Overall	**32**	**28**

in the survey instrument, and the overall values of mean speed provide a broad indication of the relative use of time and distance covered by the two major NMT modes.

These figures are in surprisingly good agreement with detailed studies of pedestrian flows on footpaths: 4.7 km/hr (2.9 mph) is a commonly observed median value for movement in uncongested areas (*4–8*).

Figure 2 shows the effect of age. The elderly walk slowly, but mean walking speeds are surprisingly stable by age. Women walk slower than men at all ages.

People living in larger cities tend to walk faster than those living in small cities (*9*). This study also confirmed that age, gender, and weather conditions affected walking speeds in Australia and the United Kingdom.

SAFETY, SECURITY, AND CHOICE

Analysis distinguishing between walking trips and the waiting time for other transport modes is often done, and results show different values of time for these two activities of pedestrians. However, motor vehicle–pedestrian crashes are both severe and costly. Records of such incidents are perhaps the most reliable and widely available information on pedestrian activity made regularly available. In a transport sense, the determinants of walking as a travel mode include personal security and perceptions of risk rather than the vulnerability to traffic. The time and effort required to walk also is a significant part of any personal travel time budget. A sense of personal security is a major factor in streetscape design and activity levels in pedestrian areas, especially for children, women, and the elderly. Walking at night is a specific concern of the elderly, one that has been shown to be much greater in the United States among urban than rural dwellers (*10*).

Pedestrian activity in mall areas is undertaken for a number of reasons, including shopping, exercise, and social purposes. However, the feeling of personal security is an important element in this process (*11*). A rising number of studies of the sociology of pedestrians and pedestrian behavior are pertinent to predicting pedestrian behavior, location choice, and the characteristics of successful design of pedestrian areas (*12*).

Pedestrians' perceptions of safety have a strong gender element. Women have valid concerns about walking unaccompanied in urban centers and parks (*13*) (an active walking issue) and about being unaccompanied in transportation terminals in the evening and at night (in addition to pedestrian/waiting time issues). Personal security is an issue in the use of public transport—more in terms of rail than bus travel, but significant in both cases.

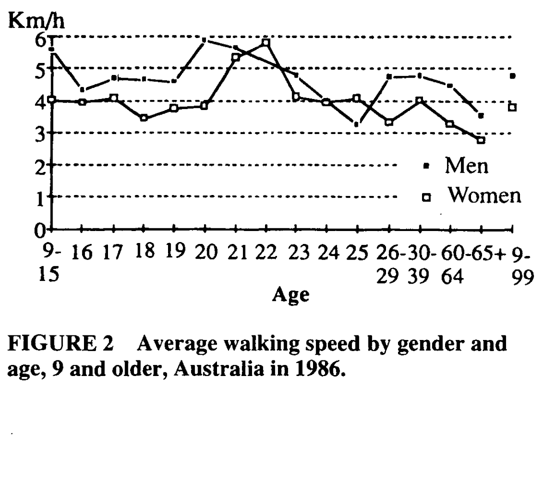

FIGURE 2 Average walking speed by gender and age, 9 and older, Australia in 1986.

Walking as a social, recreational, or health occupation is not universally popular: many of those who walk most like it least, generally as a function of constrained resources and a means of mobility for the elderly (*14,15*).

Such customer perspectives of personal safety and security as mobility constraints are common to several countries, and they contrast with the road safety, crash-oriented view of pedestrian-vehicle conflicts and accidents as the issue requiring most attention. Both safety issues need attention, but the injury area refers mainly to costs and actions familiar to traffic engineering, whereas personal concerns relate to travel demand estimation and time, mode, route, and location choice decisions by individuals in various categories and to a different group of policy makers.

Several studies of walking and cycling on road footpaths have yielded travel exposure values for walking on footpaths and cycling for children (*13*). This type of study does not affect the significance or level of walking in overall transportation terms, and it collects no information on the travel choices available.

WALKING IN AUSTRALIA

Treating walking as just another mode of transportation requires some care. The discussion of walking speeds suggests that travel time rather than distance or trip frequency should be considered. The 1986 ORS study (*3*) contains information only on people 9 years old and older. This has a greater effect on walking than on any other mode, as walking is of great importance to young people. Only walking trips of at least 400 m (440 yd) are reported.

Figure 3 shows the trip rates per day (the full weekday plus weekend period) by gender and status. Women report more walking than men in every category but part-time work and unemployed. Students display the highest levels of walking, and retired people the lowest.

The trip rates are standard population trip rates (SPTR). SPTR is defined as the number of trips by a group divided by the number in that group. Consequently, SPTR does not show the levels of walking activity undertaken by people who actually do walk, and the values are diluted by the numbers of people who do not. This distinction between participation (i.e., at least one walk trip) and activity rate (i.e., the number of trips per day made by those reporting at least one trip) has been shown to be important in person travel analysis (*1*). Expressing walking time as a percentage of total daily travel time goes some way to correct this effect and give a clearer view of the importance of walking to people of each gender and in each age group.

Figure 4 shows that women spend much more time walking than men at all ages. Walking time is 10 to 20 percent of all travel for women of all ages, with a mean value of about 15 percent. Men do less walking, at about 10 percent. The omission of people below 9 years old and the open-ended definition of a walking trip ensure that these are conservative values.

Figure 5 shows the numbers of walking trips in Australia during 1985–1986 as a function of age and gender for people 9 years old and over. Women still walk more than men, but walking is a substantial fraction of all trips made across the whole range of age and for both genders.

The combination of walking and cycling (Figure 6) shows a closer match between the genders, as cycling is more popular with

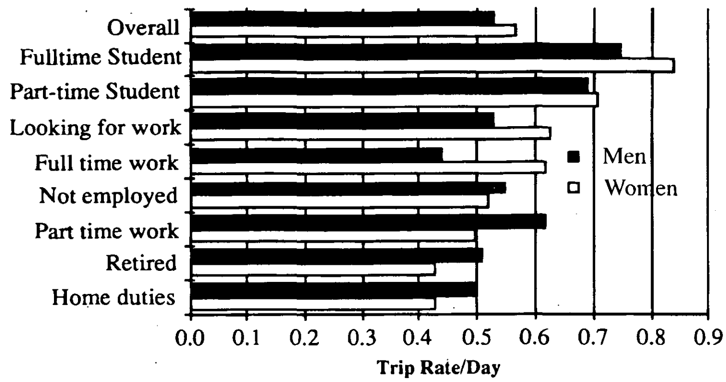

FIGURE 3 Walking trips per day, Australia in 1986 (ages 9 and older).

men. This might appear to favor treating NMT as a mode, but the strong gender differences are disguised by such aggregation.

Walking appears to be more important in Sydney (the largest and densest metropolitan area) than in Australia as a whole. Figure 7 shows the differences between weekday and weekend travel as a percentage of all trips reported. It is difficult to ignore the high percentage of walking trips in both periods. Even if the lowest values are used, walking accounts for 20 percent of all reported trips. The percentages of travel time in Sydney spent walking in 1981 are shown in Figure 8 and may be compared with the 1986 nationwide figures in Figure 4. The importance of walking time in Sydney on weekdays is greater than for the nationwide figures, which are more comparable to the weekend Sydney ratios.

SHOPPING

One area where walking is crucial is in shopping trips, which are increasingly made within major enclosed centers and pedestrian-only malls.

The length of walking trips made in the course of shopping trips is affected strongly by any omission of pedestrian travel within such enclosed areas—and such movements are not sought in transport surveys, only in activity surveys. Most transportation and traffic analyses concentrate on peak-hour, work-related travel, and it is necessary to shift this emphasis in order to understand pedestrian travel better.

The 1986 ORS study (*3*) showed shopping second only to work commuting in importance in terms of the numbers of trips made. Shopping was 57 percent of the number of trips to work for men and 157 percent for women. The work force participation rates for women were considerably lower than those for men, but the relative importance of the contribution of shopping trips to overall travel by gender was certainly considerably higher for women than men in 1986.

The pedestrian component of shopping trips is important for several reasons:

- Impacts on accessibility,
- Demands for car parking,
- Constraints on luggage carrying,
- Concentrations of pedestrian flows, and
- Vehicle-pedestrian conflicts.

The individual stages within a shopping trip often are lumped into a single trip and may contain personal business and service calls. The movements between retail outlets, personal business, and services within an area are usually by foot within a shopping area of reasonable scale. Models of such trips are rare (*16*).

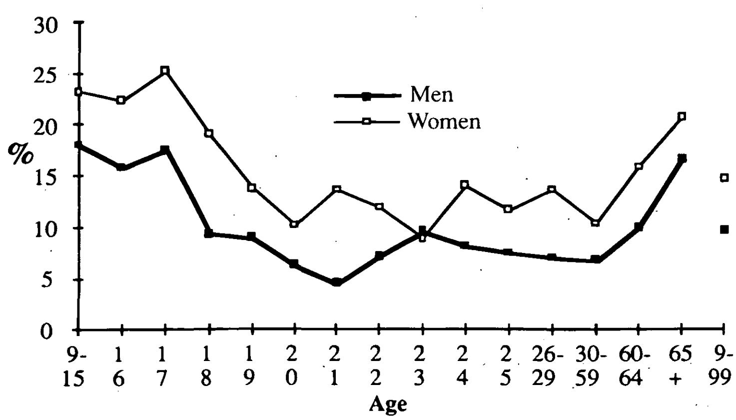

FIGURE 4 Walking time as a percentage of all travel time/head in Australia in 1986 (ages 9 and older).

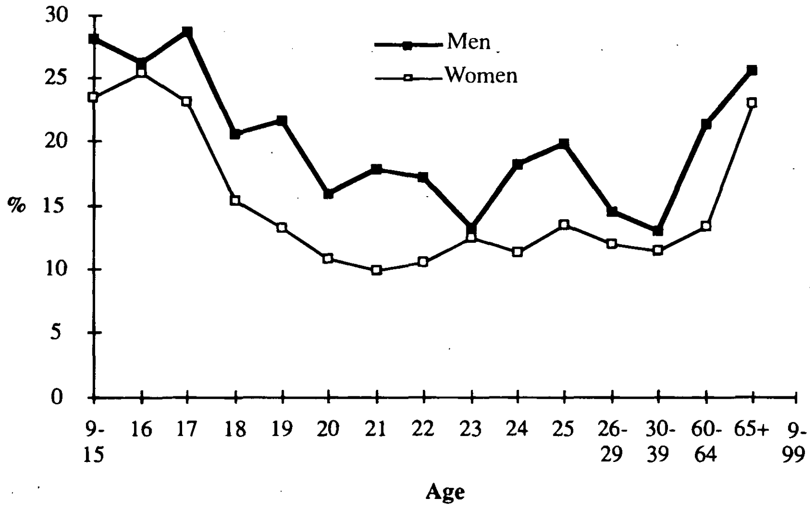

FIGURE 5 Walking trips as a percentage of all trips in Australia in 1986 (ages 9 and older).

Such complex trips are often non-home-based and underreported. They play a significant and increasing role in personal travel, and shopping and personal business travel have risen at several times the rate of travel-to-work trips in recent years in both France and the United States. As these travel purposes continue to grow in importance, the detailed structure of the shopping and personal business trips becomes more significant.

The high density of daytime pedestrian trips in city commercial centers offers an opportunity for estimating the concentrations of pedestrian journeys as a function of commercial and retail shopping space in the area, which was done in Milwaukee in the early 1970s (*17*). The resulting pedestrian flow equations for both non-daytime and overall daytime average pedestrian flows showed the highest weighting to retail commercial floor area, followed by office space, including banks and other personal business destinations.

Those who walked to the city centers of Calgary (a large city with only 2 percent walking to work) and the small city center of Halifax (where about 10 percent walk to work) (*18*) then went on to walk a considerably greater distance (600 m, or 650 yd) *within* the center than did those arriving by other modes [225 m (250 yd) by bus and 325 m (360 yd) by car]. The influence of walking as a mode of choice is clearly significant.

REFORMULATING MODELS OF PEDESTRIAN MOVEMENT

The treatment of pedestrian travel as a variant of vehicle flow modeling is well established, and levels of service for sidewalks and pedestrian routes form a useful section of the standard transportation engineering handbooks (*19*). This aspect of pedestrian travel is the equivalent of highway capacity analysis and traffic management. The concentration on the interference between pedestrian movements and vehicle movements over shared space

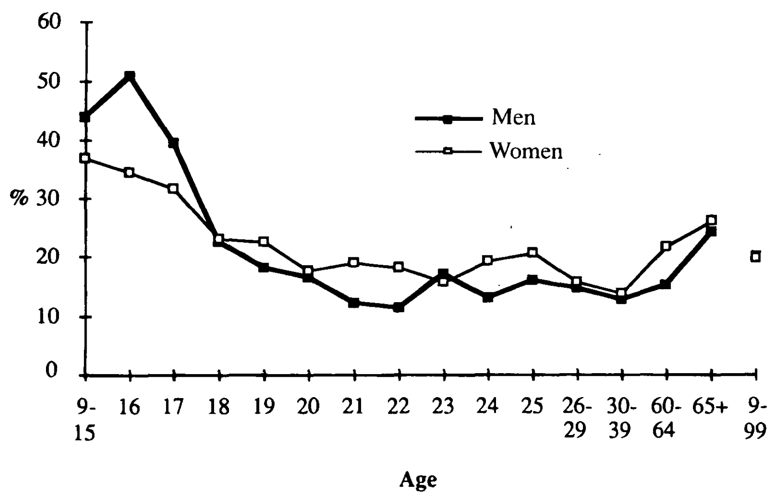

FIGURE 6 Combined walking and cycling trips, percentage of all trips, Australia in 1986 (ages 9 and older).

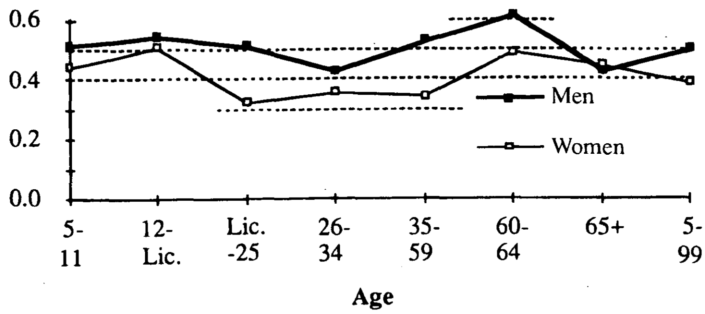

FIGURE 7 Ratios of weekend to weekday walking trip rates, Sydney in 1981.

such as roads is treated again as a traffic management and safety problem.

Analysis of walking movements as pedestrian travel by a full travel mode requires a greater concentration on route and destination choice and on assessing the quality of pedestrian routes and the influence of factors such as environmental quality, visual design, and shopfront activity attractiveness to predict who will go where and how they will travel to and around the areas concerned.

This approach would bring the economic importance of access by foot into the transport analysis mode and destination choice approach and give a greater weight to the nonwork trips (shopping, in particular) that now comfortably exceed work trips in number.

Collection and analysis of large-scale pedestrian movements and route choice are beginning to occur. Such data should be extended to treat pedestrian stop frequency and destination choices using the stated and revealed preference analysis that is now proving so effective for other modes of transportation (*20*).

CONCLUSIONS

Pedestrian behavior, demand, and policy are integrated poorly. Social space design and pedestrian movements as a special form of traffic flow do not need to consider overall needs and determinants of personal travel. Traffic conflict issues are addressed consistently, but the impacts of pedestrian movements and constraints on specific groups are less well monitored or understood, and the effective tools of travel choice analysis are still applied only rarely.

Walking is a major transport mode, of crucial importance to several large groups in the community and a contributor to reducing motor vehicle emissions. It is not clear who is responsible for planning and providing services to these groups, and by default it is the road safety area that has paid most attention and produces most of the public information. The contribution of nonmotorized travel to fitness and the maintenance of mobility for the elderly should be added to mobility and accessibility to achieve balanced evaluations (*21*).

The numbers and proportions of trips to, from, and within retail and personal services areas are increasing around the world. Design within the retail and terminal areas is now likely to influence both mode and frequency of travel and activity in these growing areas of personal travel.

Walking and pedestrians need better understanding and information and more consistent policies if mobility and accessibility are to be maintained for the community as a whole. It is clear that a considerable amount of movement takes place that is not counted in the assessments of travel, and thorough understanding of these nonmotorized movements will permit more balanced allocations of resources and improvements to overall access and mobility. Such efforts have already occurred to some extent for the mobility handicapped, but the rest of the population makes up a much larger group whose interests should not be ignored.

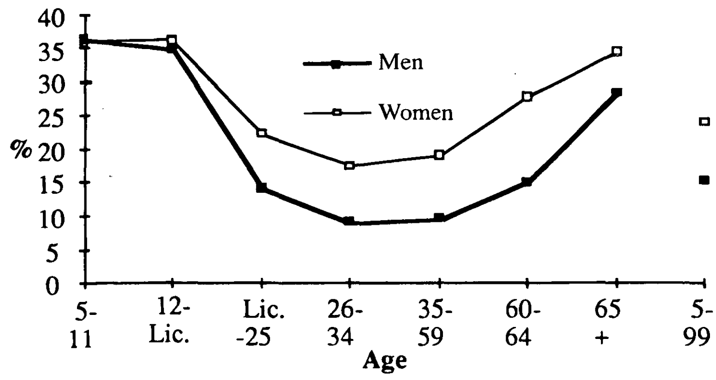

FIGURE 8 Walking time as a percentage of all travel time by age and sex, Sydney weekdays in 1981.

ACKNOWLEDGMENTS

The work was part of a Joint ITS-RTA Study of Non-Motorized Transport funded by the Roads and Traffic Authority of New South Wales. The Federal Office of Road Safety provided access to the 1986 Survey of Day-to-Day Travel.

REFERENCES

1. Wigan, M. R. *Australian Personal Travel Characteristics.* Australian Road Research Board, Vermont, Victoria, 1987.
2. *Sports Participation in 1988 (USA Series).* National Sporting Goods Association, Mt. Prospect, Ill., 1993.
3. Adena, M. A., and H. J. Montesin. *Day to Day Travel in Australia 1985-6.* Report CR 69. INSTAT Australia for the Federal Office of Road Safety, Canberra, 1988.
4. Fruin, J. J. *Pedestrian Planning and Design.* Metropolitan Association of Urban Planners and Designers and Environmental Planners Inc., New York, 1971.
5. Hoel, L. Pedestrian Travel Rates in Central Business Districts. *Traffic Engineering,* Vol. 38, No. 4, 1968, pp. 10–13.
6. O'Flaherty, C. H., and M. H. Parkinson. Movement on a City Center Footway. *Traffic Engineering and Control,* Vol. 13, No. 10, 1972, pp. 434–438.
7. Older, S. J. Movement of Pedestrians in Shopping Streets. *Traffic Engineering and Control,* Vol. 10, No. 4, 1968, pp. 160–163.
8. Tanaboriboon, Y., S. S., Hwa, and C. H. Chor. Pedestrian Characteristics Study in Singapore. *Journal of Transportation Engineering,* Vol. 112, No. 3, 1986, pp. 229–235.
9. Walmsley, D. J., J. Lewis, and J. Gareth. The Pace of Pedestrian Flows in Cities. *Environment and Behavior,* Vol. 21, No. 2, 1989, pp. 123–150.
10. Lee, G. R. Residential Location and Fear of Crime Among the Elderly. *Rural Sociology,* Vol. 47, No. 4, 1982, pp. 655–669.
11. Schnact, S. P., and N. P. Unnithan. Mall Walking and Urban Sociability. *Sociological Spectrum,* Vol. 11, No. 4, 1991, pp. 351–367.
12. Hill, M. R. The Sociology and Experiences of Pedestrians. *Man Environment Systems,* Vol. 17, No. 3–4, 1987, pp. 71–78.
13. Enjeu, C., J. Save, and K. Brown. The City: Off Limits to Women. *Liberation,* Vol. 18, No. 9, 1974, pp. 9–13.
14. Carp, F. M. Pedestrian Transportation for Retired People. In *Highway Research Record 356,* HRB, National Research Council, Washington, D.C., 1971, pp. 105–118.
15. Carp, F. M. The Older Pedestrian in San Francisco. In *Highway Research Record 403,* HRB, National Research Council, Washington, D.C., 1972, pp. 18–25.
16. Wigan, M. R., and E. Richards. *The Analysis of Journey Structure: Linkages Between Different Stages of a Journey.* Internal Report AIR 300-1. Australian Road Research Board, Vermont, Victoria, 1978.
17. Bahman, J., and B. H. Patel. A Method for Estimating Pedestrian Volume in a Central Business District. In *Transportation Research Record 629,* TRB, National Research Council, Washington, D.C., 1977, pp. 22–26.
18. Seneviratne, P., and P. Fraser. Issues Related to Planning for Pedestrian Needs in Central Business Districts. In *Transportation Research Record 1147,* TRB, National Research Council, Washington, D.C., 1987, pp. 7–14.
19. Edwards, J. D. (ed.). *Institution of Transportation Engineers: Transportation Planning Handbook.* Prentice Hall, Englewood Cliffs, N.J., 1992.
20. Hensher, D. A. Stated Preference Analysis of Travel Choices: The State of Practice. *Transportation,* Vol. 21, No. 2, 1994, pp. 107–134.
21. British Medical Association. *Cycling Towards Health and Safety.* Oxford University Press, England, 1992.

Economic Importance of Nonmotorized Transportation

WALTER HOOK

The use of nonmotorized transportation (NMT) is not an indication of underdevelopment. Instead, higher levels of nonmotorized vehicle use can have a positive impact on economic growth. Extensive use of NMT may be one factor explaining higher domestic savings and investment rates in Asia, which in turn are related to the region's superior growth performance. Conversely, the relative lack of nonmotorized vehicle use in Africa may be related to lower levels of domestic savings and immobility among the poor. The availability of intermediate, appropriate transportation technologies has important economic advantages, which is demonstrated. The economic benefits of nonmotorized vehicle use are largely overlooked in most cost-benefit procedures because they ignore nonmotorized modes. The economic benefits of nonmotorized transport are investigated from macroeconomic and microeconomic perspectives.

The use of nonmotorized transportation (NMT) is not an indication of underdevelopment. Instead, higher levels of nonmotorized vehicle use can have a positive impact on economic growth. Extensive use of NMT may be one factor explaining higher domestic savings and investment rates in Asia, which in turn are related to the region's superior growth performance.

MACROECONOMIC PERSPECTIVE

NMT and Underdevelopment

Many people tend to equate the bicycle with underdevelopment, and bicycle use with less developed countries, but this view is statistically insupportable. Using a sample of more than 40 cities around the world (Figure 1), bicycle ownership per 1,000 population rises consistently with increasing incomes, as does car ownership. In other words, the higher the per-capita income, the higher the number of bicycles per 1,000 population. Bicycle ownership and car ownership levels tend to rise and fall together.

Even the United States has an extremely high level of bicycle ownership per 1,000 population. In the Central and Eastern European countries, public transit use has fallen since 1989 but both motor vehicle ownership and bicycle ownership have risen substantially, and growth rates for bicycle ownership are faster than growth rates for private cars in cities such as Budapest, Hungary, and Krakow, Poland (*1*). Bicycle ownership and use also exploded in China after 1989, explaining most of the sharp, recent upsurge in global bicycle use and production (*2*). In sub-Saharan Africa in the past decade both motor vehicle fleets and bicycle fleets fell in the 1980s (*3*). Thus, when countries accumulate more wealth, their residents tend to own more bicycles and more cars, rather than fewer bicycles and more cars.

Bicycle ownership is not necessarily, however, a good indicator of bicycle use. In countries such as the United States, most people who own bicycles use them primarily for recreational purposes. It may therefore be more instructive to look at the degree of correlation between the bicycle's share of total work trips and the gross national product (GNP) per capita (Figure 2). In this case, bicycle and nonmotorized vehicle use vary widely among high-income and low-income countries. The regression line indicates the level of bicycle use predicted by GNP per capita alone. The enormous divergence from this line indicates that there is no statistically significant correlation between GNP per capita and the number of total work trips made by bicycle.

If walking trips are separated from bicycling trips, it is seen that the poorest countries in Africa tend to make very few trips by bicycle (with a handful of exceptions) and many trips by walking. In Asia, by contrast, countries with low per-capita income (e.g., Bangladesh) as well as those with higher per-capita income (e.g., Japan) tend to make many trips by bicycle or pedicab. Pedicabs are used predominantly in the lower income countries, where labor costs are low and crime is a problem, whereas bicycles are used mainly in higher income countries with lower crime rates. Isolating the determinants of variations in bicycle use worldwide would require a much larger and more sensitive data set.

The level of private motor vehicle use, however, can be predicted with greater accuracy. In Figure 3 the mode share of the private motor vehicle in 72 major metropolitan areas is plotted against the national GNP corresponding to those cities. (Mode share data used were the most recent figures available. Most of the figures are from the mid- to late 1980s. This introduces some inaccuracies into the chart, but there is no systemic bias in the age of the data that should distort the significance of the observed correlation.) If the level of GNP were the only variable explaining the level of motor vehicle mode share, all points should fall neatly on the regression line. There is not only significant variation from the regression line, there are significant regional effects. The level of private motor vehicle use in East Asian cities, where GNP grew at 6.1 percent annually between 1980 and 1992, is either roughly consistent with or lower than would be predicted by their GNPs. This contrasts sharply with Africa, where despite negative growth over the past decade, the use of private motor vehicles is considerably higher than would be predicted by GNP. Private motor vehicle mode share is much higher in Lagos, Nigeria, and Dar es Salaam, Tanzania—which are very low-income countries and have been growing at less than 0.5 percent a year since 1965—than in Hong Kong, Shanghai, Singapore, Bangkok, and Tokyo, all of which have averaged over 4 percent annual growth since 1965.

There is a positive but weak correlation between private motor vehicle mode share and increasing GNP per capita, but there is no positive correlation between lower nonmotorized vehicle mode share and higher GNP per capita. Thus, automobile use increases with income, but nonmotorized vehicle use may or may not be the

Institute for Transportation Development Policy, 611 Broadway, Room 616, New York, N.Y. 10012.

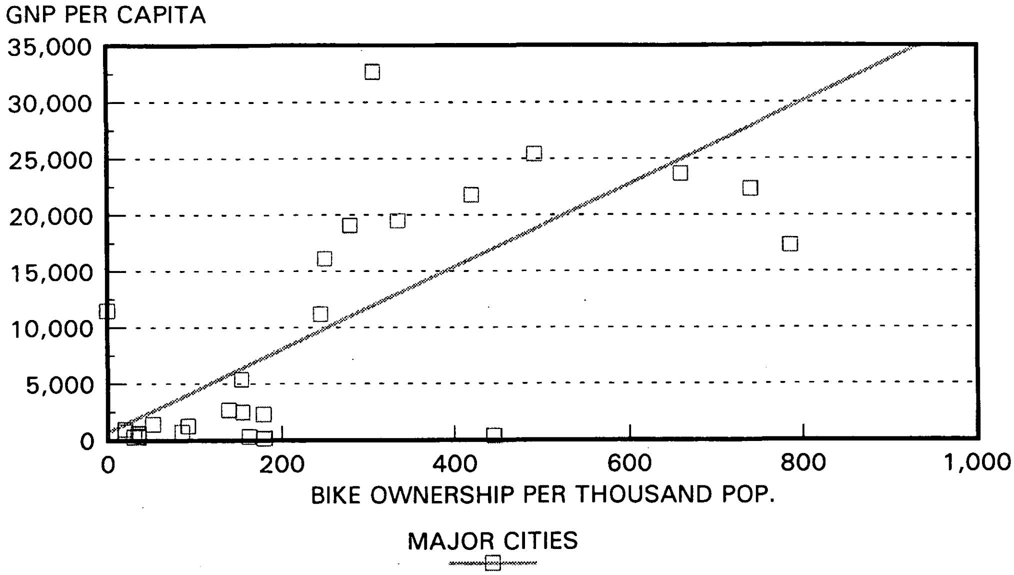

FIGURE 1 Bicycle ownership and income (*10,15*).

mode most likely to be displaced. Anecdotal evidence from around the world indicates that public transit trips, particularly bus trips, are as likely to be displaced by increasing private motor vehicle use as are nonmotorized vehicle trips.

NMT and Macroeconomic Growth

The most dynamic region of the global economy in the past 2 decades has been East and Southeast Asia. In fact, it has been the successful economic rise of Japan, Korea, Taiwan, and most recently China that has forced a fundamental reconsideration of dependency theory and development theory more generally. Many recent studies have tried to identify the key factors in this economic success (*4*).

One common element to this economic success pointed out by theorists from all schools of economic thought is the high level of domestic savings and domestic investment in Japan and the newly industrializing countries (NICs). As Barrett and Chin point out, "by world standards the East Asian NICs were outstanding in their ability to increase rates of domestic savings and reinvestment during this period of rapid industrialization" (*4*). These higher savings rates not only reduced the cost of capital, which acted as an incentive for firms to invest in new technology, but also reduced the dependence on foreign capital. With the possible exception of Indonesia, the other NICs all managed to avoid the debt trap of the 1980s that killed economic growth in much of Latin America and Africa.

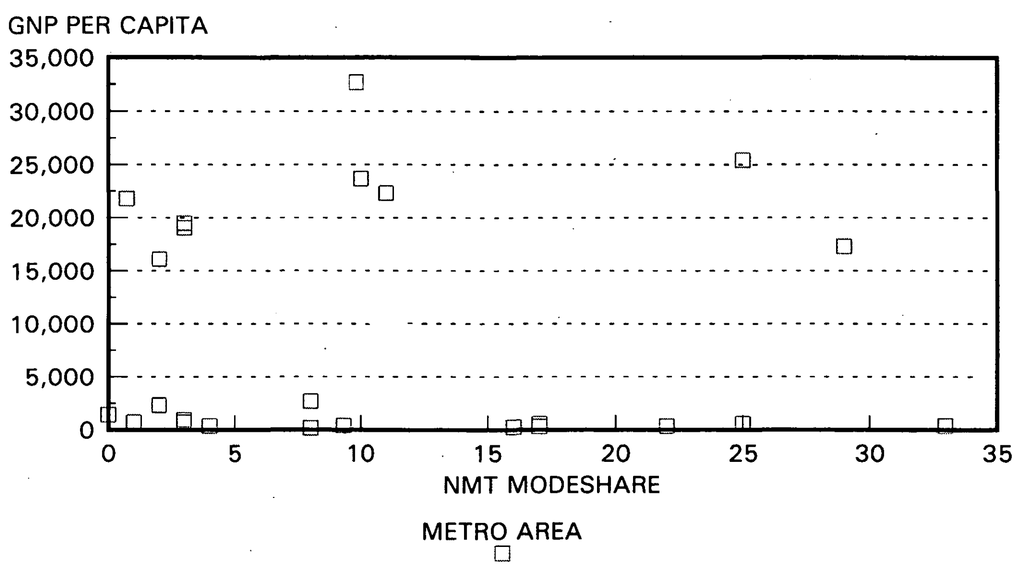

FIGURE 2 NMT mode share and GNP per capita (World Bank, *15,16*)

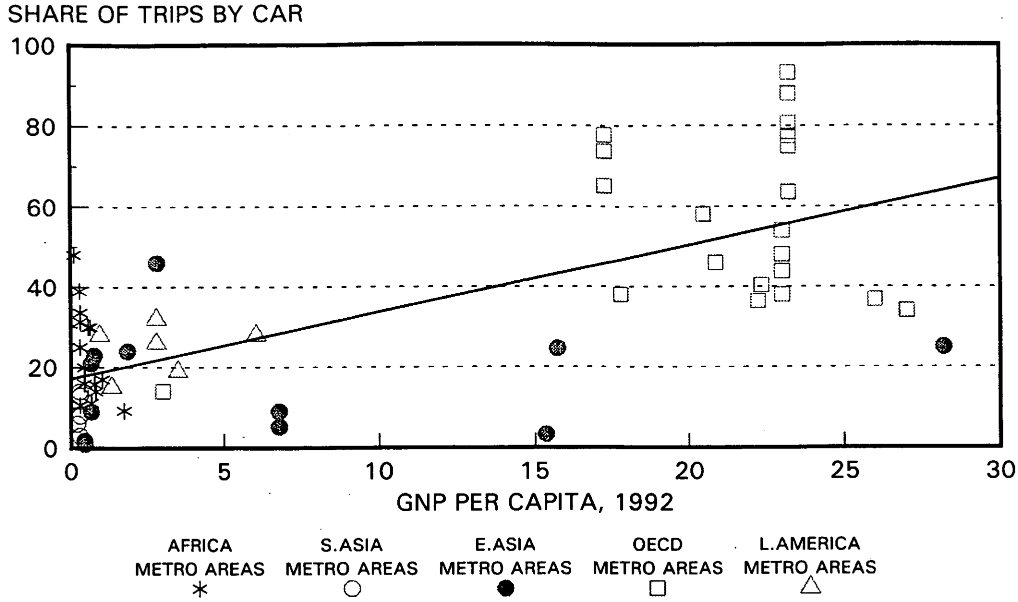

FIGURE 3 Car mode share by GNP per capita by region, 1992 (World Bank).

There is considerable debate in the literature as to what caused this high level of domestic savings. Many authors argue that high savings rates result from a cultural propensity to save, but this appears unlikely given that these savings rates are an entirely post–World War II phenomenon—for most of the NICs, a post-1960 phenomenon. It is unclear why cultural factors would have suddenly changed in East Asia after 1960.

One possible, often overlooked factor that may have influenced the propensity to save was the nature of urbanism in East and Southeast Asia. Urban policy in some East Asian countries such as China, Singapore, and Hong Kong played an important role in constraining consumption and encouraging savings while at the same time minimizing domestic labor costs. These two factors may have facilitated the competitiveness of East Asian exports. In other words, the high levels of bicycle use, low levels of motorized vehicle use, dense urban areas, cramped housing, and congested streets typical of Asian cities are not a sign of underdevelopment; they are, instead, the spatial manifestation of the so-called export-oriented growth model, which lies at the heart of the NICs' economic success.

As negative growth in Africa and Latin America in the 1980s has been attributed largely to the debt crisis that led to a net capital outflow from many of these countries for nearly a decade, it is significant that more than half of low- and lower-middle-income countries import more than 90 percent of their commercial energy. Low-income developing countries, excluding China, spent an average of 33 percent of their merchandise export earnings in 1985 on energy imports, and many of them spent more than 50 percent (*5*). East Asia's transportation systems are less dependent on private motor vehicles, and NMT is far more important there than in other parts of the developing world. This insulated them from the shocks of the oil crisis and the related debt trap.

Firms need to pay their employees sufficient wages to cover the costs of living and commuting to their jobs. These costs of living and commuting, however, vary widely between countries. In the United States, 86 percent of the labor force commutes by private car, but more than 40 percent of these commuters claimed that they would commute by an alternative means if it were practicable for them (*6*). Under such conditions, each employee must be paid more than $4,700/year for the purchase and maintenance of an automobile to carry him or her back and forth to work each day (*7*). Furthermore, taxes must be collected to pay an estimated $2,400/passenger car of public subsidy to make automobile transportation viable (*8*). These costs are reflected in the costs of goods produced in the United States, albeit indirectly. Meanwhile, in a country like China, where most of the population can commute to work by walking or bicycling, all of a worker's commuting costs can be covered by a one-time $100 investment in a bicycle and less than $25/year in maintenance. These cost differences will be reflected in the relative costs of U.S. and Chinese products.

Moreover, the U.S. has sacrificed some 60 percent of its urban land to road and parking infrastructure to accommodate motor vehicle traffic, compared with about 15 percent in most East Asian countries (*9*). The United States has considerable land available per person, but if China were to have as many automobile operators per capita as the United States, China would have to pave over 40 percent of its arable land to accommodate all the cars (*10*).

Japan, which has been growing faster than the United States throughout the postwar period, possesses the best, most extensive public transportation system among the countries of the Organization for Economic Cooperation and Development, and by far the lowest level of automobile use, at about 50 percent of total trips nationally compared with 86 percent in the United States. As a result, the Japanese spend only 10 percent of their GNP on transportation, compared with 18 percent in the United States (*11*).

When high-density urban form, high user fees for automobiles, low levels of investment in road infrastructure, and other policies are used to discourage the consumption of private cars, people tend to save their money rather than spend it on luxury cars. Dedicating road space to buses and low-cost bicycles instead of to private cars and motorcycles encourages savings instead of consumption, allowing for much higher levels of investment and hence faster economic growth.

Automobile-based transportation systems, such as the ones in the United States, tend to undermine the realization of agglomeration economies, or returns to scale in the provision of transportation and other basic services, whereas the rail- and bicycle-based transportation systems more typical of Japan and other NICs have led to the development of higher-density clusters both in central cities and around rail stations. The low-density U.S. pattern imposes important inefficiencies in the provision of many other forms of infrastructure and public service, such as telecommunications, electricity, water, sewerage, postal service, and drainage. A recent study by Phillips and Gnaizda (*12*) and an older study by the U.S. Department of Housing and Urban Development (*13*) indicated that the cost of providing housing in low-density, unplanned suburban areas was 60 percent higher than that of providing the same number of units in planned, higher-density areas. More than half of these costs are underwritten by taxpayers. In low-density sprawling human settlements, the costs of providing roads and streets are 4 to 15 times higher, the costs of copper pipe and utility pipe for water supply 5 times higher, the costs of providing postal delivery 300 times more expensive, the costs of heating five times greater, and the amount of water and electricity consumed were double (*12*). Because of the ability to rely on walking, bicycling, and commuter rail, residents in Tokyo use a seventh of the gasoline consumed by residents in large U.S. cities.

The macroeconomic implications of these cost differences, which are reflected ultimately in the costs of U.S. products, are disturbing. In Asia, agglomeration economies realized through increasing returns to scale in the transportation sector tend to be captured in the form of higher rents. The land intensity of economic activity in Japan in large measure explains the high rents in Japan. These rents, many of which are captured by Japan's largest industrial firms, constitute an interest-free pool of investment capital that has been used to finance Japan's industrial expansion. High rents in turn encourage investment into the built environment, increasing the efficiency of Japanese cities as sites of production. This way, higher density encourages a higher level of gross domestic investment.

Furthermore, countries with higher domestic savings rates do not need to borrow as extensively from foreign countries. One of the major reasons that countries became trapped in the debt crisis of the 1980s was to pay for imported oil and imported private cars. For example, 43 percent of Brazil's total import bill is for oil, 30 percent of which is consumed entirely by private automobiles that are used by only the wealthiest 10 percent of the population (*5*). The debt crisis in Brazil, which basically halted growth for a decade, was brought on by the rapid rise in oil prices and the rapid increase in interest rates on loans to pay for imported cars and oil.

One of the major reasons that the U.S. economy is hemorrhaging is its trade deficit. U.S. dependence on the automobile also is exacerbating the trade deficit. In 1989 Japan produced 9,052,000 passenger cars but consumed only 4,404,000. In the same year the United States produced only 6,823,000 passenger cars but consumed 9,853,000 (*14*). According to the U.S. Commerce Department, 65 percent of the United States' annual trade deficit is related directly to imported automobiles, which is why they have been the ongoing focus of U.S.-Japanese trade talks.

Though insufficient data were available to test the specific macroeconomic impact of nonmotorized vehicle mode share on economic growth, and urban density indicators also proved to be unreliable indicators of agglomeration economies, a path diagram was developed to indicate the strength of various effects on car mode share and economic growth (Figure 4).

Figure 4 maps the results of three regressions: the dependent variable is first economic growth, then gross domestic investment, then motor vehicle mode share. Data on urban density (people per hectare) and the percentage of total trips made by private automobile in 72 major cities around the world were assembled from various sources (*15–19*) and added to World Bank development report data and other indicators used by Barro (*20*) to predict economic growth rates. (The data tables are available from ITDP, 611 Broadway, Room 616, New York, N.Y. 10012.) As possible determinants of car mode share, the national annual output of oil, presence or lack of motor vehicle manufacturing facilities, and other variables were compiled and tested. That data from several cities in certain large countries such as the United States, Germany, and China have been used is probably for the better, as greater weight is given to countries with large populations than ordinary growth tables for which data from each country are given equal weight.

The regression of economic growth indicated that 80 percent (adjusted R^2) of the variation in economic growth from 1965 to 1990 can be explained by the following variables: average level of gross domestic investment from 1965 to 1990 (GDI6590 = .82), level of government expenditure as a percentage of GNP (GOVEXP = .26), literacy rate in 1960 (LIT60 = .29), car mode share (CARSHARE = −0.16), and location of the country (whether in Asia) (ASIA = −0.15), indicating regional growth dynamics. Car mode share and Asia were not quite significant (T = 1.62 and 1.81, respectively). GNP in 1992 had no significant direct correlation with economic growth, nor did a host of other variables. Urban density had no significant direct correlation with growth rates. (The density indicator, people per hectare, does not quite capture the desired concept, as it is driven primarily by the location of the municipal boundaries. Data sets with more sophisticated indicators of variations in urban density are needed.)

Consistent with the author's theory, growth is driven primarily by the level of investment. Savings and investment data run roughly parallel. There is considerable debate in the economics literature as to whether investment determines the savings rate or savings determines the investment rate. The author's inclination is toward the former view, but because the two are roughly equivalent, it will not disrupt the model.

The determinants of gross domestic investment proved harder to predict, with only 47 percent of the variation being explained by these variables. The strongest predictors of gross domestic investment proved to be the location of the country (ASIA = .62) and the level of oil production (OILPROD = .62). Again, Asia reflects the level of investment driven by Japanese investment and other regional effects. A high GDP in 1992 (GDP = −0.44) had a negative impact on investment, which may indicate some validity of the neoclassical view of diminishing returns to capital (*20*). Barro's political instability indicators—the average number of assassinations per million people per year (ASSASS = −0.43) and average number of coups d'état and revolutions on average from 1960 to 1985 (REVCOUP = −0.45)—proved to be strong predictors of investment levels. Each of these variables was significant ($t > 1.96$). The next strongest predictor of investment levels was car mode share (CARSHARE = −0.36). This result indicates that money not spent on cars is more likely to be invested. The variable was not quite significant at the 95 percent level, however ($t = -1.4$). Government expenditure was correlated positively with

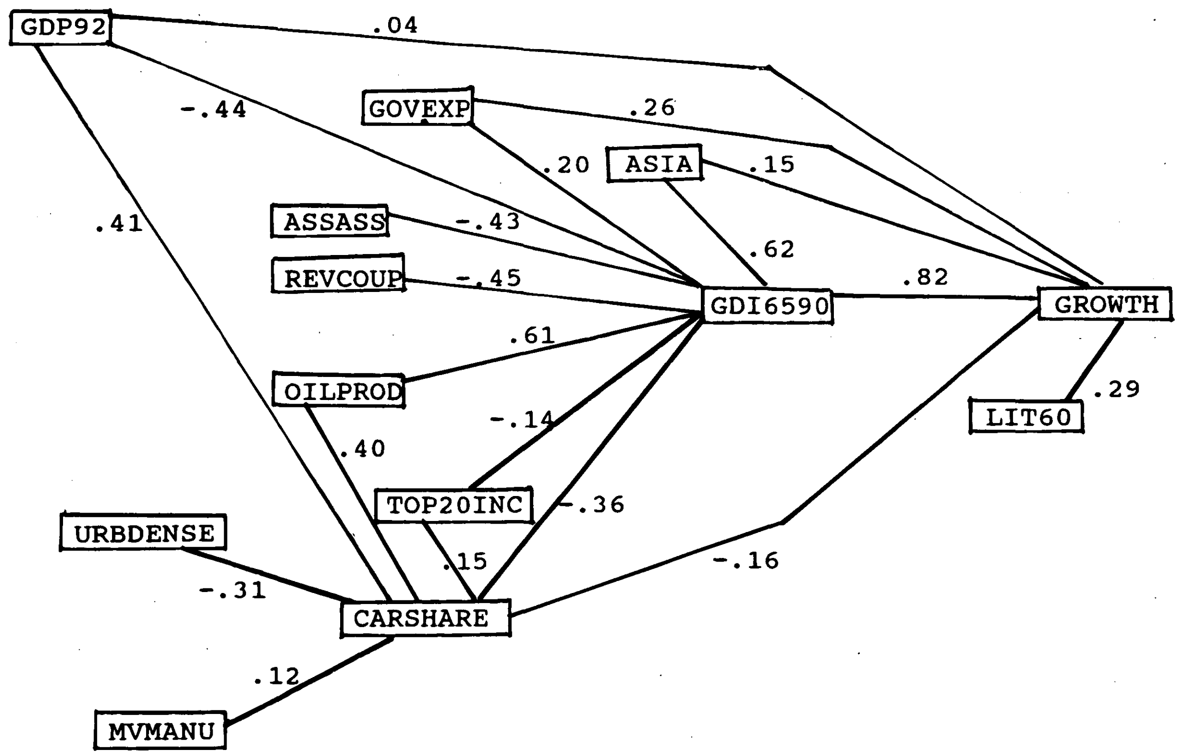

FIGURE 4 Causal path diagram of impact of automobile dependence on economic growth.

gross domestic investment (GOVEXP = .20), and income inequality was correlated negatively with domestic investment (TOP20 = −0.14) but neither was significant ($t > 1$, but < 1.96). Indicators for urban density and for deviations in the exchange rate from purchasing power parity were not significant, nor was the level of oil consumption. (The author tried to demonstrate negative growth effects by showing that car use was correlated with higher levels of oil consumption, and higher levels of oil consumption with lower levels of domestic investment, and higher debt, but could not demonstrate any significant set of relationships here. What this may indicate is that except in times of oil shocks, the effect of automobile dependency on the economy is less a result of its relation to oil consumption than of the consumption of the vehicles themselves and their effect on the efficiency of urban form. The data on oil consumption were not complete, however, so it would be worth testing these relationships again with better data.)

The regression predicting car mode share explained some 75 percent of the observed variation. By far the strongest predictors of car mode share were GNP per capita in 1992 (GDP92 = .41) and the amount of oil produced in the country (OILPROD = .40). The level of oil produced in the country affects car mode share both through the price of gasoline in the country and the political power of the domestic oil industry to push for urban policies that support private motor vehicle users. Getting comparative data from a significant number of countries that could act as proxies for these policies would be an area for further research. The next most powerful predictor of motor vehicle mode share is urban density (URBDENSE = −0.31). Perhaps with better data this would be higher. Each of these variables was significant ($t > 1.96$)

The income inequality indicator (percentage of total income going to the top 20 percent of the population) was also a good predictor of car mode share (TOP20 = .15), and the variable is almost significant ($t = 1.92$). Because in developing countries only the wealthiest people can afford motor vehicles, it follows that elite consumption of motor vehicles would be greater if the elite had more money. This elite consumption is potential investment capital.

The presence of motor vehicle manufacturing in the country is also a good predictor of car mode share (MVMANU = .12), although the variable is not quite significant ($t = 1.3$). This variable again captures the power of the domestic highway lobby over domestic transport and land use policy.

National density proves to be a weak and insignificant indicator of car mode share. There is no evidence that low car mode shares in Japan and the NICs are being driven by higher national population densities.

From Figure 4 one can conclude that car mode share has a total effect of −0.46 (direct plus indirect effects). Of this, .19 is the result of the correlation between higher GNP, higher car mode share, and slower growth. Thus, it can be concluded that the total effect of car mode share on economic growth not caused by higher GNP is −0.27. These conclusions are tentative because neither of the car mode share variables is significant with 95 percent assurance.

Thus, doing simple regression and correlation analysis of a data set from 40 major cities around the world from developed and developing countries lends statistical support to the notion that encouraging bicycle use and discouraging automobile use will encourage rapid economic growth, largely because of its effect on the investment and savings rate but also because of its effect on urban form and the level of oil dependency.

Microeconomic Evidence

Though there is considerable macroeconomic evidence that promoting nonmotorized vehicles and constraining the consumption of private automobiles is likely to encourage economic growth, there is also considerable microeconomic evidence that a major obstacle to development is extremely low productivity in the movement of goods and low-income people. Furthermore, these low productivity levels are not primarily the result of insufficient road infrastructure but the result of the fact that people with very low incomes cannot afford to use available vehicle technologies. The importance of nonmotorized vehicles from an economic perspective is that they provide an intermediate technology that can improve transport productivity levels dramatically at a cost more affordable to a far greater percentage of the world's population than are alternative, motorized technologies.

Unfortunately, the infrastructure focus of most governments and major development organizations such as the World Bank has resulted in minimal attempts to develop methodologies to quantify these economic benefits. Left unquantified, these benefits until recently have been left out of most cost-benefit analyses. World Bank cost-benefit analyses of road projects in developing countries increasingly estimate the value of passenger travel time saved, but these benefits are restricted to road users in motorized vehicles. Until the recent initiative by the World Bank, the benefits and costs to nonmotorized road users—such as pedestrians, bicyclists, informal cart vendors, and rickshaw drivers—had *never* been measured, nor had a methodology for their measurement been developed.

For example, in recent economic assessments for a highway and traffic realignment project in Shanghai, China, which planned to ban bicycle use on major downtown streets, only a minimal attempt was made to estimate the economic impact of the project on bicyclists and pedestrians, despite the fact that 71 percent of all trips in the area are made by these modes (*21*).

New road projects can have severe negative impacts on nonmotorized vehicles, either as a result of banning them from the new road or by creating severance problems in which people wishing to cross the road have to travel long distances or cross awkward overpasses to reach their destinations. Although these severance effects are now included in World Bank environmental impact assessment guidelines (*22*), they are ignored in all economic assessments, even though they have serious travel time and hence economic implications for what are in some cases the users of the predominant mode.

On the other hand, the important positive economic effects of the inclusion of lanes for slow-moving vehicles, nonmotorized vehicle parking at public transit stations, and other infrastructure investments are also ignored, not to mention their enormous impact on road safety.

Not valuing these factors has been justified in part by the fact that it is administratively very difficult and expensive to collect data on nonmotorized vehicle users, data that are highly dependent on local conditions. However, as long as these factors remain exogenous there is no way to estimate their economic significance.

Some have argued that travel time is not important in countries with high levels of underemployment, but recent analysis of labor patterns in less developed countries indicates that the problem is less *under*employment than it is *very low–productivity* employment. Transportation is an important part of this low productivity. In Beira, Mozambique, women involved in primarily subsistence agriculture spend as many as 3.36 hr/day transporting agricultural materials and produce and another 3.6 hr/day transporting water and firewood for the household (*23*). Spending 7 hr/day on transport-related tasks on top of child rearing and education and household maintenance tasks can hardly be called underemployment, but it is certainly an example of low-productivity employment. This low productivity in transportation can greatly inhibit the ability to dedicate labor to agricultural or supplementary income-generating activities.

A similar study in Tanzania indicated that women spend 1,648 hr and men spend 531 hr/year on transporting basic necessities. In Ghana, women spent roughly 980 hr/year on transport, with 30 percent related to marketing crops, 30 percent related to direct agricultural production, and 40 percent related to household maintenance activities, mostly collecting water and firewood (*24,25*). Whether or not these production activities are in the modern sector of the economy, it is clear that these people are not underemployed so much as their productivity level is very low, largely because of the lack of proper mobility.

Whether the level of an individual's production is generating enough surplus to produce goods for trade in the market or not, the time it takes to generate sufficient economic output for survival should have a value roughly equivalent to the subsistence wage. Therefore, whether the time of the person saved by a transport improvement is remunerated, it should be valued at roughly the equivalent of at least the subsistence wage. Unless these economic activities, which are critical to the economic development of almost all developing country populations, are given much greater value in cost-benefit procedures, the emphasis of World Bank lending on infrastructure projects that may have minimal impact on most of the population will continue.

Another reason that economic impacts on nonmotorized road users have long been ignored is that many of the factors affecting nonmotorized vehicle use will be policy issues rather than infrastructure issues, and economic evaluation methods until recently have been less than adept at measuring the economic effects under a diversity of policy regimes. It may be the case that increases in motorized traffic speeds alone will act as a barrier to the use of road infrastructure by nonmotorized modes. Bicyclists may fear for their safety in the absence of lanes to separate nonmotorized from motorized vehicle users. Banning nonmotorized vehicles from using or crossing high-speed roads will obviously have a serious negative impact on nonmotorized road users, but again this results from a policy decision, not from the improvement of the infrastructure per se. Cost-benefit analysis, if it is to measure real economic costs, must be able to measure the economic costs and benefits of these policy options. Many policy decisions besides the build/no build options are all too often ignored.

Until recently, the only way that nonmotorized vehicles enter World Bank cost-benefit analysis is as a negative externality on motorized traffic (*26*). In other words, it treats slow-moving vehicles in the same way it treats low pavement quality, as a factor considered only in light of its negative impact on the travel time of motorized vehicles. This negative impact is real, and should be incorporated into the model, but in the same sense, the presence of too many motorized vehicles could be argued to be a major cost to nonmotorized users. These costs must also be calculated. Thus, the economic impacts of a change in road policy (such as segregating traffic into motorized and nonmotorized lanes or banning nonmotorized vehicle traffic) or a road investment (widening or straightening the road) on all vehicles must be considered, not just the impact on motorized road users. Otherwise, the economic impact of a policy such as banning nonmotorized vehicles will have a higher economic return than providing a slow-moving vehicle lane, as the roadside friction would be removed at what would be measured as zero cost, ignoring the harm done to the nonmotorized road users themselves.

The economic costs and benefits of the impact of road projects and policies on nonmotorized road users can be estimated in the following way. Transportation services do not offer an infinite number of trade-offs between travel time, trip cost, trip comfort, and trip safety. As a result, people taking one mode may actually have been willing to pay more or less to take a slower or faster mode were it an option.

Thus, the impact of a change in road quality, road policy, or other transportation-related investment could have the following effects on nonmotorized transport:

- It could induce people to switch between bicycling or walking and a more expensive mode (bus, paratransit) that may or may not be faster,
- It could induce people to switch between bicycling and a more or less expensive and slower mode such as walking or animal or pedicab, or
- It could speed or slow the travel time and affect the maintenance costs of all current nonmotorized users.

When a slow-moving-vehicle lane is added to a road, for example, the benefit of such a change can be measured by taking the net present value of a stream of benefits into eternity calculated by adding

- The money saved in a particular period by all generated nonmotorized road users who formerly used a more expensive mode *minus* the value of any time lost related to switching modes,
- The value of the time saved by all new nonmotorized road users who used to walk *minus* the increased costs of the trip related to bicycle ownership and maintenance, and
- The value of the increased or decreased travel time costs for all current nonmotorized users.

It is important to point out that the nature of the road infrastructure, whether there are lanes for slow moving vehicles or not, is often less important as an issue than the availability of nonmotorized vehicles. Often the lack of up-front capital for low-income people to buy the vehicles, lack of facilities to rent nonmotorized vehicles, and an underdeveloped private sector engaged in nonmotorized vehicle production or importation are larger problems than the nature of the infrastructure. This is an important point because it may be that World Bank projects focusing on these projects will show a higher rate of return than projects focused specifically on infrastructure.

Example of Shift from Bus to NMT

In one area of Masaya, Nicaragua, for example, the average person spent \$442/year to commute to a job downtown by bus. At the time, shortages of oil and spare parts resulted in buses that were overcrowded, moved very slowly, and broke down often. With a bicycle one could make the trip in roughly the same amount of time, or slightly less time, for the cost of a \$99 bicycle and \$24 in annual maintenance. The savings in 1 year of using the bicycle rather than the bus were \$319. In this case the obstacle to bicycle transportation was not the nature of the infrastructure but the lack of up-front capital to purchase the bicycle. It should, however, be possible in the case of a change in road infrastructure to study the impact of the change on generated nonmotorized vehicle traffic. Though predicting the impact on nonmotorized vehicle traffic levels of a particular investment is likely to have a wide margin of error, this problem is endemic in cost-benefit analysis in the transportation sector. The bigger problem is that there are very few studies (perhaps none) on which to develop a predictive model.

Example of Shift from Walking to NMT

In many poor countries, the inclusion of nonmotorized vehicle lanes (assuming nonmotorized vehicles are available) may lead to a shift from walking to NMT. The benefit is primarily in the form of travel time. Changes in travel time should be measured at some fixed fraction of at least the minimal survival wage rate in the country. In the studies in Beira, Mozambique, NMT was able to decrease the travel time by 50 percent over walking. Given total travel time, residents were able to save some 72.9 hr/month. The average subsistence wage in the area was roughly \$0.10/hr, which gives an estimated economic value of the time saved at \$7.29/month. Whether this value is justified could be determined by a study of the impact of the saved travel time of total aggregate personal income, but such studies do not exist. The costs of vehicle ownership and maintenance then must be deducted from this value.

Economic Development Impacts

Measuring the economic development benefits of an infrastructure project is complex. Economic development benefits for motorized vehicle users are rarely included in economic assessment procedures, and are not included in the HDM model. If economic development benefits to motorized users are included, however, some effort to measure the economic development impacts to nonmotorized users should also be made.

One economic benefit of making NMT options viable is that it allows microenterprises to expand the market area for their goods. In the case study in Beira, Mozambique, the introduction of nonmotorized modes allowed local fishermen to bypass middlemen, with an enormous impact on their income. During the fishing season (6 months a year), the ability of fishermen to use nonmotorized vehicles to take their goods directly to market and bypass middlemen increased their income by \$90.05/month. From an aggregate economic perspective, however, the economic benefit would have to be calculated using welfare economics, adding the new income to the fishermen and the increased consumers resulting from a fall in the price of fish in the market minus the fall in income of the middlemen.

It must be again pointed out that the benefit came not from changing the road infrastructure or road policy but from overcoming market failures inhibiting the access to vehicles. Nevertheless, the same methods could be used to measure the economic effects of infrastructure by looking at the impact of the project or policy on generating or inhibiting nonmotorized vehicle traffic.

CONCLUSION

Although NMT has been seen by many policy makers in developed and developing countries as a sign of underdevelopment, the most rapidly growing economies in the world are turning more often to nonmotorized transportation. Not only does bicycle ownership increase with income, contrary to popular belief, but even such labor-intensive vehicles as pedicabs have begun to reappear in countries as diverse as the United States, the Philippines, and Holland, just as they are being driven out by hostile public policies in developing countries. Private motor vehicle technologies have been around since the 1860s, roughly contemporaneous with the advent of the rickshaw in Japan in 1868. Motorized as well as nonmotorized vehicles have been significantly modernized since then, although developing countries have ignored important improvements in their productivity levels that could be achieved easily and inexpensively by modernizing their human-powered vehicle fleets and production facilities, many of which are still operating with technology that has been outmoded for decades. Bicycle use and ownership has risen and fallen and risen again in most developed countries, paralleling the rise and fall of the mass production economy. Motor vehicle sales are stagnant in the developed world, which explains the efforts to develop markets in developing countries. Planners should consider leapfrogging to the most modern transport technologies of extremely lightweight and low-cost electric powered and nonmotorized vehicles rather than becoming a dumping ground for vehicles that in developed countries may soon be outmoded.

REFERENCES

1. Pettinge, A. Ujpest Pilot Project: Bicycle-Friendly District in Budapest. Final report on Dutch technical assistance. Grontmij Consulting Engineers, Zeist-Amersfoort, The Netherlands, 1995.
2. Brown, L., and E. Ayres. Bicycles Surpassing Automobiles as Leading Form of Personal Transport. Vital Signs Brief No. 6. Worldwatch Institute, Washington, D.C., 1992.
3. Howe, J., and R. Dennis. The Bicycle in Africa: Luxury or Necessity? Presented at velocity conference, The Civilized City: Responses to New Transport Priorities, Nottingham, U.K., 1993.
4. Deyo, F., ed. *The Political Economy of New Asian Industrialism.* Cornell University Press, Ithaca, N.Y., 1987.
5. *World Energy Statistics and Balances 1971–1987.* International Energy Agency, OECD, Paris, 1989.
6. Bicycle Federation of America. *Bicycling Reference Book: Transportation Issue.* Bicycle Institute of America, Washington, D.C., 1994.
7. *Facts and Figures of the U.S. Automobile Industry.* Motor Vehicle Manufacturers Association, Washington, D.C., 1990.
8. Renner, M. Rethinking the Role of the Automobile. Paper 84. Worldwatch Institute, Washington, D.C., 1988.
9. Lowe, M. Alternatives to the Automobile. Paper 98. Worldwatch Institute, Washington, D.C., 1990.
10. Heierli, U. *Environmental Limits to Motorization.* Swiss Center for Appropriate Technology, St. Galen, 1993.
11. Hook, W. The Role of Nonmotorized and Public Transportation in Japan's Economic Success. In *Transportation Research Record 1441,* TRB, National Research Council, Washington, D.C., 1994.
12. Phillips, M., and R. Gnaizda. New Age Doctrine is Out to Lunch on Three Issues. *CoEvolution Quarterly*, summer, 1980.
13. *The Costs of Sprawl.* U.S. Department of Housing and Urban Development, Washington, D.C., 1974.
14. *World Motor Vehicle Data, 1991.* Motor Vehicles Manufacturing Association, Washington D.C., 1991.
15. Replogle, M. *Non-Motorized Vehicles in Asian Cities.* The World Bank, Washington, D.C., 1992.
16. Barrett, R. Satisfying Urban Public Transport Demands. World Bank Urban Transport Working Group, Yaounde, Cameroon, 1990.
17. Armstrong-Wright, A. *Urban Transit Systems.* The World Bank, Washington, D.C., 1988.
18. Newman, P., and J. Kenworthy. *Cities and Automobile Dependence.* Gower, Melbourne, Australia, 1989.
19. Bertaud, A. Land Markets, Urban Form, and the Environment. Presented at 2nd Annual World Bank Conference on Environmentally Sustainable Development, Washington, D.C. 1994.
20. Barro, R. Economic Growth in a Cross Section of Countries. *Quarterly Journal of Economics*, Vol. 106, 1991.
21. *Shanghai Metropolitan Transport Project.* World Bank Staff Appraisal Report. The World Bank, Washington, D.C., 1993.
22. *Environmental Assessment Sourcebook.* The World Bank, Washington, D.C., 1991.
23. Overton, K. Women Take Back the Streets: Overcoming Gender Obstacles to Women's Mobility in Africa. *Sustainable Transport*, July 1994.
24. Dawson, J., and I. Barwell. *Roads Are Not Enough.* Intermediate Technology Publications, London, 1993.
25. Howe, J., and D. Bryceson. Rural Household Transport in Africa: Reducing the Burden on Women? African Studies Center, Leiden, Holland, 1993.
26. Hoban, C., and R. Archondo-Callao. HDM-Q: Highway Design and Maintenance Model HDM-III with Congestion Analysis Capabilities. The World Bank, Washington, D.C., 1992.

Enhancing Nonmotorized Transportation Use in Africa—Changing the Policy Climate

JOHN HOWE

There is a growing realization of the interrelation between immobility and poverty. In the least developed countries, enhanced personal mobility necessarily implies the greater use of nonmotorized means of transportation, including the freedom to walk in safety. Motorized transportation is too scarce, expensive, and—in urban areas—polluting to provide a universal means of movement for the masses. This is especially the case in sub-Saharan Africa (SSA), which is dependent on vehicular transport manufactured outside the continent. Although SSA exhibits both the least incidence of and greatest need for cheap forms of nonmotorized transportation (NMT), paradoxically it has one of the most hostile policy climates for its use. A lack of physical infrastructure in the urban areas and negative attitudes among decision makers and influential members of the public discourage NMT usage. The damaging policy constraints on the promotion and use of NMT are illustrated through an examination of the recent history of the bicycle in Africa. The roles of import and pricing policies are outlined, demonstrating that governments have tended to suppress ownership by overtaxing imports. The conclusions make proposals for policies to encourage wider use of NMT by seeking a new, international basis for their production and finance, and by removing all taxes to stimulate demand.

To determine policies toward nonmotorized transport (NMT) in Africa it is first necessary to consider the rationale for developing the transportation sector in general, motorized transportation in particular. Measuring progress is hampered by the lack of commonly agreed upon and specifically stated objectives for the transportation sector. These must be implied from patterns of investment over the past three decades of national plans and internationally aided development.

Planned investment has overwhelmingly favored road transportation—which accounts for more than 80 percent of all freight and passenger movements (*1*)—with the focus on the creation, largely by government, of physical infrastructure. Starting with generally skeletal road networks and poor intercountry land connections, there has been a perhaps understandable preoccupation with improving physical access. The emphasis has been on extension of the road network to all potentially productive parts of each country, and on connections with neighboring countries so as to facilitate trade, although officially this aspect remains limited. The notion of accessibility has, however, been very restrictive, with investment directed almost exclusively to enhancing access by motor vehicles. Little formal consideration appears to have been given as to how such policies would facilitate any change in the mobility enjoyed by the mass of the population through either better footpaths and tracks or enhanced vehicular means of moving people and goods.

Department of Transportation Engineering, International Institute of Infrastructural, Hydraulic, and Environmental Engineering, Westvest 7, 2611 AX Delft, The Netherlands.

Implicit in this pattern of investment has been a sort of unwritten understanding that the private sector could and would provide the necessary vehicles. There have been few attempts in sub-Saharan Africa (SSA) to even assemble motor vehicles from completely knocked down kits, and the contraction of the market in the 1980s had its greatest impact on local assembly operations, which have been reduced to near shut-down levels in many countries (*1*). Whereas there have been a few, relatively unsuccessful, attempts to mass produce and market nonmotorized vehicles—most notably, Raleigh bicycles in Nigeria and the Swala bicycle in Tanzania—the primary role of the state has been as the regulator rather than the facilitator of investments to enhance mass mobility.

The public/private division of transportation investment is a classically Western notion of responsibilities that has been exported unaltered to the great majority of developing countries. In the developed world, governments have traditionally provided only the physical transportation infrastructure, although this is ending rapidly with an avalanche of initiatives to secure private-sector financing for major infrastructure works, such as the $15 billion railway tunnel connecting the United Kingdom and France. Vehicle provision has been a virtual private-sector monopoly for almost a century, and the arrangement has worked very efficiently. Manufacturers are even able to finance research and development for their own products.

For a few decades the rapid increase in motorization exhibited by a number of developing countries appeared to suggest that the unwritten relationship could be transferred easily. For SSA, this was an illusion. The institutional infrastructure failed to develop sufficiently to produce a sustainable transfer of vehicular technology. Africa urbanized without industrializing: the process was more in the nature of a poorly understood deagrarianization (*2*). One consequence was that motor vehicle operation in SSA has remained expensive, and this is not attributable just to its poorly developed infrastructure (*1*). Recently published research indicates that long-distance freight transport—where, because of competition, efficiency is normally fairly high—in three African countries (Cameroon, Cote d'Ivoire, and Mali) is more than four times as expensive as comparable operations in Pakistan (*3*).

ROAD NETWORK AND MOTORIZATION PROGRESS

Road Networks

The apparent growth in the road network in most of Africa is impressive, but it has been bought at a high price. The World Bank's

1988 and subsequent reports on road deterioration showed that inadequate attention to maintenance has left most countries facing massive investments to prevent the loss of existing assets (*4*). The World Bank has estimated that partial rehabilitation of only the existing rural road network will require an outlay of $3 billion (U.S.), which compares with the $1.7 billion (U.S.) of World Bank–funded rural road rehabilitation over the past 25 years. Africa appears to have overreached. The situation is so grave in most countries that there is little if any economic justification for investment in new facilities. Resources must be concentrated on network stabilization programs and, in a number of cases, on only 20 to 30 percent of core economic networks, with the implicit acceptance that major portions of the existing road system will have to be, albeit temporarily, abandoned (*6–9*).

Zero road network expansion may make economic sense, but it is politically very difficult to accept. A country such as Ethiopia has experienced more than a decade of internal war. The new unification government is understandably anxious to reduce the isolation of the 70 to 75 percent of the population estimated to live more than half a day's walk from the nearest all-weather road (*10*). But it is likely to find little international support for the necessary investments while the bulk of its existing road system exhibits massive and continuing deterioration and is indeed in danger of needing total reconstruction at a far greater cost than if all available resources were devoted to stabilizing the current situation.

Motor Vehicle Development

Motor vehicle development has fared little better than the road networks, but for a different reason. The impressive increase in the stock of motor vehicles in the 1960s and 1970s halted and then declined in the 1980s (*1*). The main cause was the ending, in the 1970s, of the free market in foreign exchange, which was triggered by the first oil crisis in 1973 and consolidated by the second in 1979. Consequently, the total stock of motor vehicles in SSA fell in the 1980s from slightly more than to just below 7 per 1,000 population (*11*). Not even a major oil producer like Nigeria was spared. Its vehicle stock is estimated to have fallen from some 615,000 units in 1984 to a third of that figure today (*12*). Thus for more than a decade there has effectively been no free market in vehicle purchases. The overwhelming majority have been financed from foreign aid projects and nongovernmental organizations (NGOs). Only in the past few years, under structural adjustment policies, has the freeing of foreign currency markets allowed a wealthy few to reactivate some form of free market in motor vehicles. Commonly these are secondhand vehicles that will have greatly reduced lives because of age and parts problems (*13*). Indeed, the encouragement of such purchases, by suitable policy reform, is an official objective under the Second United Nations Transport and Communications Decade for Africa (*1*).

At the end of 1988, SSA's population of about 443 million shared 1.9 million light vehicles. With an average household size of 5.9 persons and assuming that only 40 percent of such vehicles are available for private use—the rest being used by international organizations and their representatives, companies, NGOs, and government—then about 1 percent of households may have had access to a private motor vehicle. This figure clearly would vary between countries and would be substantially higher in some urban areas, but it is evidently insignificant in addressing the travel needs of most of the population.

Of course public transportation provides additional access, but its extent has been modest and in recent years supply has not been able to keep up with population growth even for the limited proportion of people who can afford its services (*14*). In the larger urban areas, the level of service is low and the average expenditure on transport is high, forcing many poorer commuters—usually the large majority of the population—to walk. Because of the low level of incomes, in the smaller towns "traffic" cannot support a public transportation system for internal trips, and the only alternative is to walk or cycle. Research from Ghana indicates that public transport services become practicable only once the population exceeds a threshold of 60,000 to 80,000.

To complete the picture it is apparent that continental capacity for goods movement by road has at best stagnated. In 1981 Africa received more than 31,000 new trucks of 16 T or more capacity. In 1990 it was only 6,500 units, with a near continuous decline in the intervening period (*15*). With such a record it is inconceivable that the continent was able to maintain the goods-carrying capacity of its long-distance roads.

Today, market liberalizations carried out under structural adjustment policies have resulted in a surge in vehicle imports in several countries. However, the volumes appear to be small and it is too soon to judge whether this will reverse the downward trend in vehicle stocks. For most countries the effects of the 1970s-initiated foreign exchange crisis is a blow from which they have still not recovered since their economies remain in recession.

The current situation calls into question the implicit strategy of increasing mass mobility and accessibility primarily through the promotion of motorized transportation. Private-sector provision of vehicles has been frustrated by foreign exchange rationing. This situation is easing under structural adjustment, but future supplies are likely to remain restrained and probably below the rate of growth in population. The terms of international trade have turned against any rapid growth in motor vehicle ownership. Up to the mid-1970s, many middle-income earners could afford motor vehicles, but in the 1980s economic problems and devaluation of local currencies drove up vehicle prices. In most of the region, a medium-sized car that cost 1.5 to 2 years' average salary of a middle-income earner in the 1970s now costs 12 to 15 years' salary (*16*). This situation should have increased the demand for bicycles, and there is indeed evidence that this has happened in a few countries in the last 3 or 4 years. However, cars are predominantly urban vehicles, and safety and attitudinal factors appear still to restrain bicycle use for commuting or commercial purposes.

Nigeria provides an example of this. Its private car population has declined from an estimated 150,000 units in 1983 to 42,000 in 1992 (*12*). There is no evidence that this decline has led to any dramatically increased use of bicycles—indeed, its major bicycle factory is reported to have closed. As in most West African countries, bicycle use is popular only in the dryer north of the country and is shunned in the south and center for a mixture of climatic, safety, and prestige reasons. People who have had to forgo car, or even new motorcycle, ownership have preferred to buy secondhand motorcycles, which can cost between two and four times the price of a new bicycle, currently $110 (*10*).

There is a hidden danger in this trend toward low-cost motorization. The substitution of motorcycles for cars or bicycles carries with it the threat of a drastic increase in urban air pollution. Precisely this phenomenon has been observed in Indian cities, such as Bangalore, for almost identical reasons (*17*).

NMT

Given the bleak prospects for increased access and mobility by motorized road transport, it is legitimate to consider how NMT has been performing and can be expected to perform. Have the declining fortunes of the motorized sector been reflected by NMT? Have they fared better or worse, or have they been given more emphasis as a means of enhancing access and mobility, and to compensate for the decline of motorized transport?

It is a difficult assessment to make because NMT is rarely mentioned in official documents and information is fragmentary. Moreover, few large-scale and systematic attempts to promote their use have been made. For example, Ethiopia, with a potential working population of some 9 million animals and a centuries-old tradition of farming with animal power, has no more than a few hundred animal-drawn carts (*10*). Such situations reflect a generally patronizing and dismissive attitude among decision makers toward promoting NMT.

However, there are some indications that attitudes are changing. Much of the initiative has come from outside Africa and finds its locus in the growing appreciation that the U.S.-style notion of a car-dominated society has severe limitations. European countries, such as The Netherlands and Denmark, have rejected this notion on environmental grounds (*18*). Countries as diverse as China and Japan have demonstrated that it is not essential to achieving rapid and sustained rates of economic growth (*19,20*). In the United States itself, there is growing disenchantment with the legacy of divisive social problems that have resulted from automobile dependence (*21,22*).

In Africa the issue of NMT has come into public prominence within only the last few years, although there have been isolated initiatives over a somewhat longer period. However, unlike most other continents, NMT activities in Africa are more of a rural than an urban phenomenon. Following a general survey of prospects for intermediate means of transport (IMT) (*5*), the World Bank recently strengthened the basis for its policy formulation by completing major research studies of NMT in Burkina Faso, Uganda, and Zambia (*23*). [IMT is defined as "those means of transport which are intermediate, in terms of initial cost and transport characteristics—payload, range speed of travel and route requirements—between the traditional methods of walking and headloading, and conventional motor vehicles . . . [and] . . . intermediate in time," i.e. they are a stage in the process of developing from a traditional to a modern transport system (*24*)]. The governments of Ethiopia and Tanzania have gone a stage further by formulating new rural travel and transport strategies in which the promotion of NMT is a key element.

Complementary to the foregoing has been the World Bank's initiation, in 1993, in conjunction with the Economic Commission for Africa, of a major study of NMT in selected East and West African cities. The program marks a watershed in the development of Africa's urban areas and has the long-term objectives of

- Encouraging the development of a balanced and cost-effective urban mobility system that supports an efficient internal urban economic market and is affordable to the entire urban population;
- Stimulating a choice of construction and maintenance technologies for transportation infrastructure and vehicles that realistically reflects the economic and social conditions in SSA cities, such as the need to generate local employment and to restrict unproductive consumption of scarce financial and land resources by a small minority; and
- Supporting an urban development model that allows acceptable environmental conditions to be maintained in SSA cities: reasonable air quality, noise levels, safety, and tree cover.

It is too soon to envisage the likely outcome of these studies, but the issue of NMT will be given much greater prominence than in the past since it is central to the achievement of these objectives.

These developments are long overdue: issues associated with NMT have simply been excluded from past transportation policy formulation in most SSA countries. Some of the resulting problems can be illustrated by the recent history of the bicycle. Doing so is possible only because the bicycle is almost entirely imported and so it is the best documented of the different forms of NMT. It is also used widely throughout the continent, although popularity is subject to variation due to climate, culture, and terrain, among other things.

Bicycle Trends

Perhaps unsurprisingly, given the generally hostile climate of opinion among decision makers, the bicycle has fared badly in most of SSA for much of the past two decades. In most countries there was a catastrophic decline in the imports both of bicycle kits and spare parts throughout the late 1970s and much of the 1980s. Malawi, whose rural population traditionally has been a strong user of bicycles, saw imports plummet from some 39,000 units in 1970 to just 390 in 1985 (*10*). Imports had only "recovered" to fewer than 1,000 units in 1990. More generally, United Nations Conference on Trade on Development data on bicycle and parts imports, as reported by national customs departments from 28 SSA countries, which include all the traditionally largest importers, show that on aggregate the real value of imports fell by about 60 percent between 1980–1982 and 1989–1991. On a per-capita basis the fall was about 74 percent (*10*). Furthermore, it should be borne in mind that the base period, 1980–1982, was not boom years. Many countries were already experiencing the full effects of the second oil price shock in 1979. Furthermore, 1989–1991 were not years of deep economic depression, as were the mid-1980s. According to mainstream economic thinking, they represent a period of economic improvement with structural adjustment programs already well under way. Hence, whereas available evidence does not permit the precise measurement of the amount that bicycle stocks declined over the past decade, indications are that it must have been considerable.

Since the late 1980s there have been signs of a recovery in the market for bicycles in a few countries, most notably Ghana, Kenya, and Tanzania. In each case imports have exhibited a dramatic increase—with the bulk of vehicles destined for rural areas, the main area of use for the bicycle in Africa—and the apparent causes have been the freeing of foreign exchange markets and a significant reduction in price as a consequence of the abolition of traditional taxes and duties.

For import purposes the bicycle traditionally has been classified in Africa as a luxury, sports good, or child's toy and taxed accordingly. The accumulation of import duties and various other taxes has not infrequently inflated the purchase price to several hundred percent above the landed price at port of entry. There is a well-documented example from the mid-1980s of a large aid-donated consignment (50,000 units) being surcharged between 400 and 500 percent of the landed price (*25*), but mark-ups of several hundred percent were the norm. It was only when some countries had the foresight to abandon such punitive rates of duty that their effect in suppressing demand became apparent.

Foreign exchange rationing clearly emerges as the binding constraint and main cause of the decline in imports, but other factors were at work. In urban areas, worsening safety conditions for cyclists were an additional cause of the decline in their use. Special route and junction facilities for cyclists are almost unheard of in African cities, and with the increased motor traffic cycling became so dangerous that many owners of bicycles abandoned them for commuting purposes (*10*).

In rural areas it is hypothesized that disincentive taxation, imposed largely and misguidedly by governments, exacerbated the effect of foreign exchange shortage on the demand for and supply of bicycles. The mechanism of price restraint on the demand for bicycles is thought to have operated as follows:

1. Taxation-inflated prices for would-be users suppressed effective demand.
2. Low demand reduced pressure for foreign exchange allocations for purchase.
3. As long as latent demand remained unrecognized, foreign exchange was the binding constraint on supply.

The government in Kenya appears to have been the first to recognize that taxes on bicycles were suppressing demand and slashed the taxes progressively from 80 to 20 percent during 1986–1989. This caused a real retail price reduction of 35 percent and a 1,500 percent increase in imports, showing that demand is highly elastic (*10*). Both Ghana and Tanzania experienced a similar phenomenon. This suggests that two conditions are necessary to reverse the recent trend in the decline of bicycle stocks: first, reduce, and preferably abolish, taxation on all bicycle imports; second, raise the foreign exchange prioritization for bicycles.

WHY A NEW DEAL FOR NMT?

It is a case that has been stated often, but it bears repetition because the alternatives have never appeared so unattractive. A new deal for NMT makes sense from the perspective of poverty reduction, energy conservation, and economic and environmental conditions. For the great majority of Africans, rural or urban, enhanced mobility and access through the mechanism of motorized transportation is a most unlikely prospect. A series of mutually reinforcing constraints, dominated by limited economic prospects, makes that outcome a near certainty. Yet enhanced mobility and access are a prerequisite for reducing poverty. Since the reduction of poverty is a universally accepted objective, the issue ought to be not whether the use of NMT should be enhanced but how? However, the case is as strong in economic as in social equity terms.

There is conclusive evidence from SSA that ownership of NMT conveys benefits on a household (*24*). Bicycles are used for personal travel, predominantly by men, to facilities outside the village, to a place of employment, and for social reasons. Using a bicycle to travel to and from work was found to be economically efficient.

NMT was also found to have an important role for load-carrying tasks. Bicycles are used, and are economically effective, for small-enterprise activities such as trading in crops, beer, and other goods, and in one area for passenger-carrying services. Animal-drawn carts perform two main functions: movement of agricultural inputs from a depot to the fields, and transport of harvested crops back to the store. They are also used to carry bulk quantities of marketed crops to a local point of sale such as a buying point. There is significant hired use of carts for these tasks, so the benefits extend much more widely than the cart owners. Carts typically generate a high return on the investment by the owners.

CONCLUSIONS

Something has evidently gone badly wrong with the transportation strategy adopted in Africa. It is not just that road network investments have been enormously wasteful or the accidental consequences of the international crises in the price of motor fuel. Instead, it is the absence of a vision of the purpose of transportation in the first place. The connection between these investments and the prosperity of the mass of population has always been vague. Were the investments ever intended to provide access or mobility to the impoverished population? Certainly it was never specified how the people were supposed to benefit.

Notwithstanding any restrictions based on concern for the environment or conservation of scare and expensive energy resources, SSA countries' low level of income—GNP per capita in 1993 was $350, and grew at an annual average of just 0.2 percent in the period 1965–1990—places personal ownership of any form of motorized transportation far out of reach of the majority (*26*). In the period 1980–1991 the annual average growth rate of GNP per capita was, at −1.2 percent, actually negative (*27*). How then, if not by NMT, can its people be made more mobile and given access to the services necessary both to reduce poverty and increase the quality of life?

Many examples, from the very richest and the most proletarian countries, show that given an enabling policy framework, NMT can play an important role in enhancing the economic and social activities of significant numbers of people. Recent research has emphasized the complexity of such a framework (*28*). It is also a policy framework that is largely absent in SSA (*29*).

The most binding constraints are those on the supply of NMT that appear to be regulated as much by accepted norms of institutional behavior in judging which activities are suitable for investment as they are by the immutable laws of economics. A few years ago it would have been regarded as very unconventional for the private sector to be involved in a significant scale in the financing of infrastructure investments. Similarly, relatively few motor vehicle producers ventured outside their own national borders to manufacture. Both of these actions are now commonplace.

Enhancing the supply and use of NMT in Africa will require as radical a change as either of the foregoing. There appears to be little prospect that the market will address the problem since few markets are really free, and most reflect Western, car-oriented values. The first requirement is industrial vision and skill of the type most developed countries have forgotten: efficient mass production for the poor masses. Leadership in this respect appears most likely to come from the developing world itself. Where better than in India or China? Why should there not be Chinese bicycle factories in SSA in just the way that there are Japanese car factories in Europe and the United States? It evidently has the industrial expertise, but can it rewrite the laws of marketing in the way that Japan did? If the markets are too fragmented, can regional agreements be negotiated with the Economic Community of West African States, the Southern African Development Coordination Conference, or the emerging East African common market to enlarge the economic scale of production? And should it have to finance such risk alone?

A second requirement is, therefore, likely to be innovative financing. If, as it declares, poverty alleviation is the central mission of the World Bank, then why should it, and the other large development institutions, not provide the lead by changing past practice of lending predominantly for the physical infrastructure of transportation? The World Bank could intervene directly in the process of low-cost mobility and access enhancement by financing the mass production and improvement of NMT.

SSA governments have it in their immediate power to boost the supply of NMT by ensuring the lowest possible purchase price. In many parts of Africa the bicycle, for example, with prices as high as $220 (U.S.), remains the choice of the relatively affluent (*30*). As this paper has demonstrated, this effectively dampens demand and supply. Prices can be lowered by exempting NMT, the components and raw materials for their manufacture, and spare parts from all taxes as is commonly the case for agricultural implements.

REFERENCES

1. *Road Sub-Sector Working Group Strategy Paper.* Second United Nations Transport and Communications Decade, United Nations Economic Commission for Africa, Dec. 1990.
2. Bryceson, D. F. *Deagrarianization and Rural Employment Generation in Sub-Saharan Africa—Process and Prospects.* Working Paper. Vol. 19, Afrika-Studie Centrum, Leiden, The Netherlands, 1993.
3. Hine, J., and C. Rizet. Halving Africa's Freight Transport Costs: Could It Be Done? *Proc., International Symposium on Transport and Communications in Africa,* Brussels, Belgium, Nov. 1991.
4. *Road Deterioration in Developing Countries—Policies and Remedies.* World Bank, Washington, D.C. 1988.
5. Riverson, J. D. N., and S. Carapetis. *Intermediate Means of Transport in SubSaharan Africa: Its Potential for Improving Rural Travel and Transport.* Technical Paper 161. Africa Technical Department Series, World Bank, Washington, D.C., 1991.
6. *Republic of Ghana—Rural Road Sub-Sector Strategy Paper.* Infrastructure Operations Division, West Africa Department, Africa Region, World Bank, Washington, D.C., June 1991.
7. *Republic of Madagascar—Rural Road Sub-Sector Strategy.* Report 9555-MAG. Infrastructure Division, Technical Department, Africa Region, World Bank, Washington, D.C. May 1991.
8. *Federal Republic of Nigeria—Road Sector Strategy Paper.* Infrastructure Operations Division, Country Department IV, Africa Region, World Bank, Washington, D.C., Jan. 1991.
9. *The United Republic of Tanzania: Integrated Roads Project.* Staff Appraisal Report 8367-TA. World Bank, Washington, D.C., 1990.
10. Howe, J. *Aspects of Rural Transport Infrastructure in Ethiopia.* Rural Road and Transport Strategy Seminar, Institute of Highway Engineers, Addis Ababa, Ethiopia, May 1992.
11. Howe, J., and R. Dennis. The Bicycle in Africa: Luxury or Necessity? *Proc., Velocity Conference: The Civilised City: Responses to New Transport Priorities.* Nottingham, England, Sept. 1993.
12. *Nigeria—Urban Transport in Crisis.* Report 8974-UNI. West Africa Department, Infrastructure Division, World Bank, Washington, D.C., Feb. 1991.
13. Mutonya, N. Imports of Old Cars a Deluge. *Daily Nation,* Oct. 6, 1993, Nairobi, Kenya.
14. Satisfying Urban Public Transport Demands. *Proc., Sub-Saharan Africa Transport Program, Urban Public Transport,* World Bank, Washington, D.C., March 1991.
15. Trucks for Developing Countries. *Development Journal Issues,* 1991.
16. Davidson, O. R. Opportunities for Energy Efficiency in the Transport Sector. In *Energy Options for Africa: Environmentally Sustainable Alternatives,* 2nd ed. (S. Karekezi and G. A. Mackenzie, eds.).
17. Heierli, U. *Environmental Limits to Motorisation: Non-Motorised Transport in Developed and Developing Countries.* SKAT-DEH-DA, St. Gallen, Switzerland, 1993.
18. *Bicycle Master Plan: Structured Scheme for Traffic and Transport.* Ministry of Transport, Public Works and Water Management, The Hague, The Netherlands, June 1991.
19. *China's Economic Reforms.* Briefing Paper. Overseas Development Institute, London, Feb. 1993.
20. Hook, W. Role of Nonmotorized Transportation and Public Transport in Japan's Economic Success. In *Transportation Research Record 1441,* TRB, National Research Council, Washington, D.C., 1994, pp. 108–115.
21. Waller, P. F. Transportation Redefined: Broadening the Vision. Presented at 72nd Annual Meeting of the Transportation Research Board, Washington, D.C., 1993.
22. Grieg, G. From Motown to No Town. *The (London) Sunday Times.* March 20, 1994.
23. Barwell, I. *Local Level Transport in Sub-Saharan Africa: Final Synthesis Report of Findings and Conclusions from Village-Level Travel and Transport Surveys and Related Case Studies.* I.T. Transport/ILO; Rural Travel and Transport Project, World Bank Sub-Saharan Africa Transport Policy Program, Sept. 1993.
24. Bryceson, D. F., and J. Howe. An Investigation into the Potential for the Wider Use of Intermediate Means of Transport in Ethiopia. I.T Transport Consultancy; World Bank, Washington, D.C., April 1989.
25. Cooksey, B., C. Kwayu, and A. Fowler. *Netherlands Commodity Support to Tanzania: The Provision of Bicycles as Incentive Goods to Farmers in Mwanza and Shinyanga Regions (1985–87).* Final Project Report and Evaluation. Consultants for Management of Development Programmes, Nairobi, Kenya, Sept. 1987.
26. *Development and the Environment.* World Development Report 1992. World Bank, Washington, D.C., 1992.
27. *Investing in Health.* World Development Report 1993. World Bank, Washington, D.C., 1993.
28. Kuranami, C., B. P. Winston, and P. A. Guitink. Nonmotorized Vehicles in Asian Cities: Issues and Policies. In *Transportation Research Record 1441,* TRB, National Research Council, Washington, D.C., 1994, pp. 61–70.
29. *Non-Motorized Urban Transport Studies, Eastern and Southern Africa.* Preliminary Assessment Report. Sub-Saharan Africa Transport Program, World Bank; UN Economic Commission for Africa, Nov. 1993.
30. Keita, B., and J. R. Carre. What Future for Bicycles in West Africa? Bicycle Use and Industrial Development Perspectives. *Proc., Velocity Conference: The Civilised City: Responses to New Transport Priorities,* Nottingham, England, Sept. 1993.

Road Transportation in India: Major Problems and Issues

RIYAJ A. SHAIK

Transportation in developing countries is of great significance because of its contribution to national and regional economic, industrial, social, and cultural development. However, most developing countries are facing problems related to traffic and transportation. Inadequate transportation facilities retard the process of socioeconomic development in a country. Especially in a heavily populated country such as India, managing different aspects of transportation is a difficult task. The most important problem concerning highway/transportation professionals in India is that of highway safety. Ministry of Transport figures show that approximately 60,000 people died in road accidents in 1992. The fatality rates are high in many cities in the subcontinent. India has the dubious distinction of accounting for 6 percent of the world's road deaths while having just 1 percent of the world's vehicles. There is also a growing concern over the high degree of air pollution in Indian cities. It is evident that most pollution is caused by motor vehicles. The present lead content in gasoline is 0.54 g/L. The government is attempting to lower the lead content to 0.15 g/L, which is nowhere near the world average lead content of 0.013 g/L. The growing trend toward private transportation increases congestion. The way to avoid congestion is to travel by mass transport or railways. India has the third largest rail system in the world after United States and the former Soviet Union. Despite the efforts of the government, the numbers of accidents and fatalities are increasing year by year, and the environment is becoming more polluted without any strict environmental regulations. Roads are getting congested because more vehicles travel on them. India's government should pass legislation to control vehicles on roads and enforce tougher environmental regulations. With the majority of World Bank funds allocated toward transportation and highways, the government should adopt the latest technology and introduce mass rapid transit to reduce congestion and accidents on roads.

Transportation in developing countries is of great significance because of its contribution to national and regional economic, industrial, social, and cultural development. Transportation is vital for the economic development of any region since every commodity needs transportation at all stages from production to distribution. However, most developing countries are facing problems related to traffic and transportation. The transportation system of a country indicates its economic and social development; inadequate transportation facilities retard the process of socioeconomic development of a country. Especially in a heavily populated country such as India, managing different aspects of transportation is a difficult task. At the moment India is the second most heavily populated country in the world, after China. Figure 1 shows the population growth of India and China during 1984–1991. Indian population has grown from 730 million in 1984 to 886 million in 1991, and if present trends continue the population will reach 1 billion by the turn of the century. With this increase in population, changes in the occupational structure habitat, and requirement of leisure, the demand for passenger transportation services increases.

Central Artery/Tunnel Project, Bechtel/Parsons Brinckerhoff, One South Station, Boston, Mass. 02110.

Development of any region follows the lines of transportation. People have always settled along river shores and roadsides and near railway stations. Attempts are being made to decentralize the population centers away from the sides of the main transportation routes. Planning patterns are changing rapidly. To avoid congestion around the populated areas, suburban and satellite towns acting as counter magnets should be linked with rapid transit systems. All the advantages of transportation in developing countries may be summarized as follows:

- Transportation is for the advancement of community.
- Transportation is essential for economic prosperity and general development of a country.
- Transportation is essential for strategic movement in an emergency for defense of the country and to maintain law and order.

With over 75 percent of the population of India living in the villages, development in urban centers alone does not indicate the overall development of the country. Only improved transportation facilities in rural areas can speed the development of rural centers. When facilities for education, health care, and other social needs are improved in the villages, the urge to migrate to urban centers decreases, thus helping to balance the development of the country as a whole.

DEVELOPMENT OF ROADS IN INDIA

It was proved during the Mohenjo-daro and Harappa excavations that roads existed in India as early as the 25th century B.C. The ancient archives refer to the existence of roads during 4th century B.C. The ancient literary piece titled *Arthasastra* mentioned rules about regulating the depth of roads for various purposes and different kinds of traffic. Mention has been made of punishment for obstructing roads. In the 19th century, road conditions deteriorated. Instability in the economic and political sectors caused damage to the maintenance of roads. Before the introduction of railways, British military engineers built roads to connect important cities and business centers. In 1865 the Public Works Department was formed by the British Governor General Lord Dalhousie. The first assignment undertaken by the Public Works Department was the construction of the Grand Trunk Road. After the first World War, the number of motorized and nonmotorized vehicles using the roads increased. The existing roads were not capable of handling the mixed traffic conditions, and in an effort to improve the road condition, the Indian Legislature appointed the Jayakar Committee in 1927. The Central Road Fund was formed in 1929, the Indian Roads Congress was established in 1934, and the Central Road Research Institute was started in 1950.

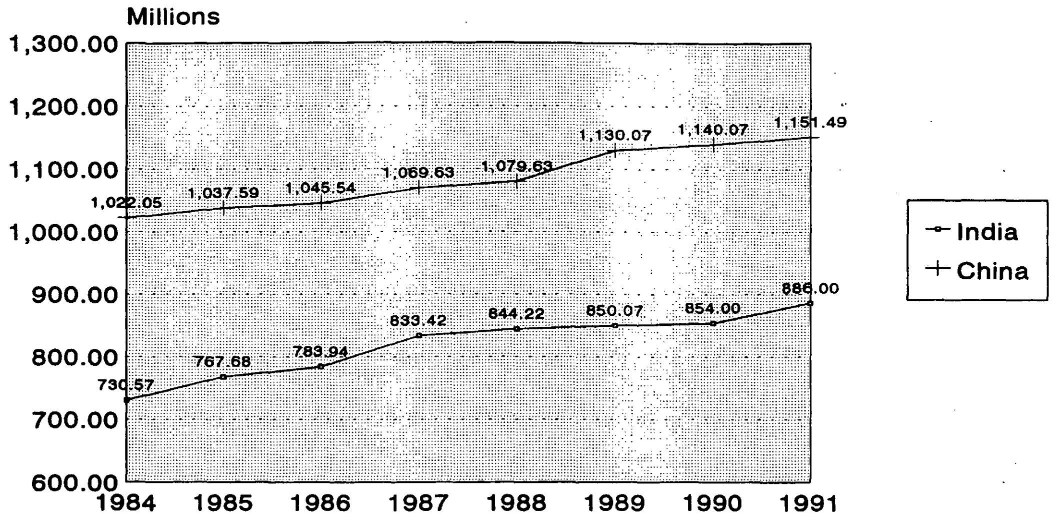

FIGURE 1 Population growth, 1984–1991 (*source: Motor Vehicle Manufacturers Association*).

Economic hardship during the 1930s delayed road development in India. During this period funds from the Central Road Fund were the only source of highway financing. During the second World War, efforts were made to improve the road network; such projects were substantially supported by the defense service funds. After World War II the number of vehicles using Indian roads grew rapidly, so existing roads began to deteriorate. In an effort to regulate traffic, the government of India introduced the Motor Vehicle Act in 1939; the act has been revised several times since then.

ROAD DEVELOPMENT PLANS

In 1943 the first road development plan was approved by the government of India. This landmark in road development in India was a 20-year plan known as the Nagpur Road Plan. The target road length was 16 km/100 km^2 area of the country (*1*).

The second 20-year road development plan was for the period 1961–1981; it was known as the Bombay Road Plan. This plan considered both the developments taking place and the developments that should take place. The target road length was almost twice the Nagpur Road Plan, that is, a total road length of 1,057,330 km or 32 km/100 km^2 area (*1*). The construction of 1600 km of expressway was also included.

The third and current road development plan, for the period 1981–2001, is known as the Lucknow Road Plan. This 20-year plan aims at a road length of 2,702,000 km by the year 2001, or a road density of 82 km/100 km^2 (*1*). Under the third plan the roads in India were classified as follows

1. Primary system
   –Expressways, and
   –National highways (NH).
2. Secondary system
   –State highways (SH), and
   –Major district roads (MDR).
3. Rural roads
   –Other district roads (ODR), and
   –Village roads (VR).

CURRENT PROBLEMS AND ISSUES

Even though there are many problems and issues related to road transportation in India, this paper looks only at the recent major problems of the transportation section. This limitation is due mainly to lack of data. The three major problems that the country faces right now are accidents, air pollution, and congestion.

Accidents

The most important problem for any highway or transportation professional is that of highway safety. Ministry of Transport figures show that approximately 60,000 people died in road accidents in 1992, which is one person killed in a traffic accident every 9 min, and half a million over the past 15 years. The fatality rates are high in many cities in the subcontinent. India has the dubious distinction of accounting for 6 percent of the world's road deaths while having just 1 percent of the world's vehicles. Table 1 gives the accident and fatality rates in four major cities in India for 1991. Even though the accident rate is highest in Bombay, "the Hollywood of India," fatality rates are highest in the national capital, Delhi. It is more likely that a person involved in an accident will be killed in Delhi than in any other city in India.

One reason for high accident and fatality rates in these four cities is the increase in the number of vehicles on roads. Table 2 presents the number of registered vehicles in these four cities from 1984 to 1993: the number of vehicles grew a staggering 360 percent in Madras, and 180 percent in Delhi. Vehicle density on roads in Delhi increased almost four times in the past 20 years. Table 3 gives the vehicle density on roads in Delhi during 1972–1991. But more important is the number of vehicles. In 1993 more than 2,097,000 vehicles were on roads in Delhi, compared with 641,000 in Madras. The increase in Bombay during 1984–1993 was 35 percent, and that in Calcutta was 85 percent.

Figure 2 shows motor vehicle production in India during 1984–1992. The number of vehicles produced increased steadily until 1990 and then experienced a steady drop. But the latest study released by International Finance Corporation indicates that auto-

TABLE 1 Traffic Accidents in Major Cities, 1991

City	Population (millions)	Vehicles (millions)	Total Accidents	Persons Killed	Rate of Accidents[a]	Rate of Fatalities[b]
DELHI	9.37	1.813	8065	1651	86.07	17.62
MADRAS	3.89	0.544	5242	481	134.75	11.52
BOMBAY	10.5	0.629	25477	339	242.63	3.23
CALCUTTA	10.7	0.475	10017	448	93.61	4.19

[a] Accidents per 100,000 population [b] Fatalities per 100,000 population

Source: Directorate of Transport, New Delhi

mobile production in India is on the rise (*2*). Most vehicles produced in India are for domestic use, therefore the number of registered vehicles has also increased steadily over the period 1984–1992. Figure 3 shows the growth in vehicle registration for that period.

The high fatality rates in Delhi prompted many transportation officials and researchers to look at the causes of accidents. Table 4 gives the causes of accidents in Delhi for 1991. The first and foremost cause is the driver. Most of the drivers in India are not well educated. Unlike in the West, occupants of automobiles in India account for a very low percentage of fatalities. The main victims are pedestrians, cyclists, and occupants of other slow-moving vehicles. Proper training and effective licensing are two of the basic prerequisites of a

TABLE 2 Number of Registered Motor Vehicles

(in thousands)

YEAR	DELHI	MADRAS	BOMBAY	CALCUTTA
1984	750	139	404	285
1985	841	166	441	311
1986	961	228	480	339
1987	1112	328	524	370
1988	1284	485	557	397
1989	1466	***	588	424
1990	1638	505	610	449
1991	1813	544	629	475
1992	1963	604	647	497
1993	2097	641	546	517

*** Not available

Source: Ministry of Surface Transport, Government of India

TABLE 3 Vehicle Density in New Delhi, 1972–1991

YEAR	Motor Vehicle Population (thousands)	Road Length in Kilometers (thousands)	No. of Veh. per Kilometer of road length
1972	214.05	8.38	26
1973	260.61	8.95	29
1974	279.23	9.58	29
1975	312.1	10.01	31
1976	346.95	10.38	33
1977	381.35	11.33	34
1978	449.10	11.60	39
1979	479.27	12.96	37
1980	521.46	13.85	38
1981	573.32	14.32	40
1982	648.82	15.49	42
1983	724.50	16.36	44
1984	750.00	16.68	45
1985	841.00	17.18	49
1986	961.00	18.05	53
1987	1112.00	18.07	62
1988	1284.00	18.08	71
1989	1466.00	19.41	76
1990	1638.00	20.49	80
1991	1813.00	21.67	84

1 Kilometer = 0.621 Miles

Source: Directorate of Transport, Delhi

good driver, but most drivers in India have hardly any formal training. Skills of the drivers are poor, especially of the estimated 1.4 million truck and 300,000 bus drivers, many of whom have graduated to driving from being cleaners and mechanics (*3*). Many of them are color-blind or have serious eyesight problems, and their abilities to respond to events on the roads are extremely limited. It is also estimated that an increase in the number of such drivers accompanies the increase in the number of vehicles (*3*). Recent efforts have encouraged drivers to receive proper training. The Motor Vehicle Act has been amended to make it compulsory for bus and truck drivers to have at least a diploma before they begin driving.

In Delhi, which has both the highest accident rates in the country and the most vehicles, police have put up billboards and banners advising drivers to follow the traffic rules and to think about the safety of other road users as well as their own (*4*). Another major factor behind the high fatality rates is the lack of prompt action by people near an accident victim. Public participation, which is common in the West, is lacking in India, and quick medical attention may substantially lower fatality rates. However things have begun to improve after the amendment of a law that discouraged people from extending help to an accident victim and the creation of an emergency accident control room to attend exclusively to accident victims.

Air Pollution

There is a growing concern over the high degree of air pollution in Indian cities. It is evident that most pollution is caused by motor vehicles. The emissions are hydrocarbons, carbon monoxide, and nitrogen oxide; other pollutants are airborne lead and sulphur dioxide. The pollution emissions of two- versus four-wheeled vehicles are given in Table 5. Two-wheeled vehicles constitute a greater percentage of emissions than buses. To control the level of air pollution, which can cause cancer and brain damage, the government is trying to lower the lead content of gasoline, which is now 0.54 g/L. The target level is 0.15 g/L, which is nowhere near the world average lead content of 0.013 g/L (*4*). To improve gasoline quality, Indian refineries—all of which are owned by the govern-

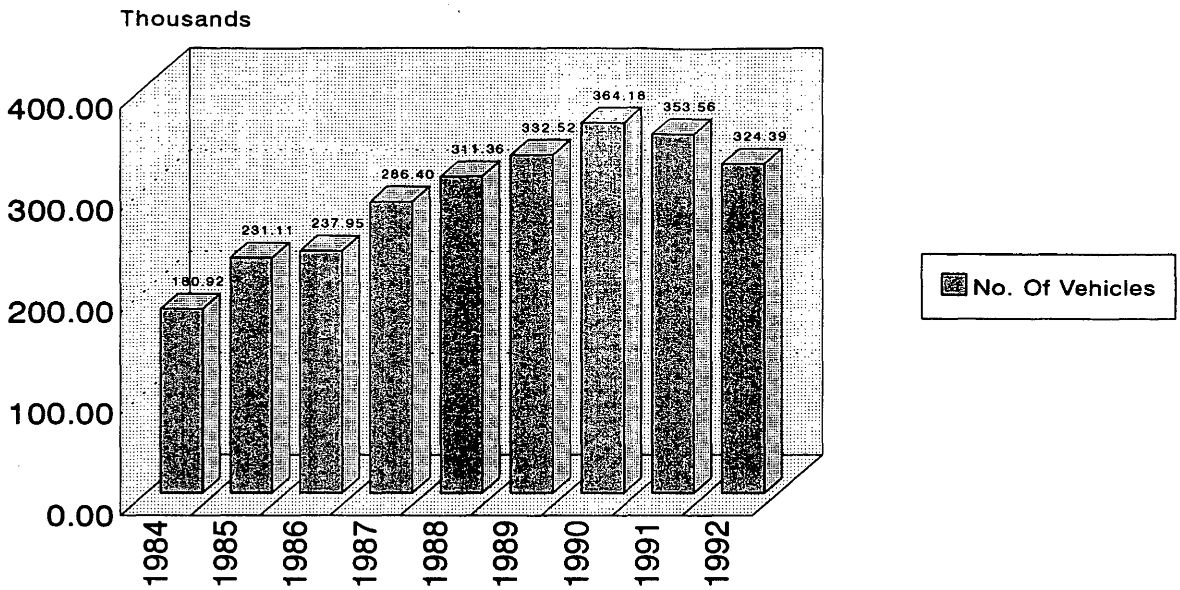

FIGURE 2 Motor vehicle production in India, 1984–1992 (*source: Motor Vehicle Manufacturers Association*).

ment—must upgrade process technology. Doing so will cost 30 billion rupees ($1 billion), an amount that the government cannot find easily. Daily automobile emissions in Delhi, one of the 10 most polluted cities in the world according to World Health Organization, generated 808.9 T of carbon monoxide, 12.74 T of particulate matter that hung in the air, 157.04 T of nitrogen oxide, 310.05 T of hydrocarbon, and 7.47 T of sulphur dioxide (*4*). More than 80 percent of the pollution comes from gasoline-driven vehicles, mainly motorized scooters with two-stroke engines that leave unburnt in the air 20 percent of the gasoline. This reacts with nitrogen in the air to produce cancer-inducing chemicals. New vehicles coming out of the Indian factories have reduced emissions by 80 percent from 1989 to 1992 (*4*). The availability of unleaded gasoline should be the government's priority, because without cleaner fuel the automobile industry cannot produce greener (less-polluting) vehicles.

Congestion

The growing trend toward private transportation increases congestion. Private transport uses the road less efficiently than mass transport. Table 6 gives the road space utilization for various vehicles. The main reason for congestion on Indian roads is the increase in the number of vehicles on the road. Table 2 presents the number of registered vehicles in the four major cities of India. Vehicle density on roads has grown as a result of the increase in vehicles. Figure 2 shows the motor vehicle production in India from 1984 to 1992. Over this period the number of vehicles produced grew steadily until 1990. Vehicles produced in India are for domestic use, therefore, the number of registered vehicles has also increased steadily over the same period. Figure 3 shows the growth in vehicle registration for that time. The increase in vehicle density is also due to

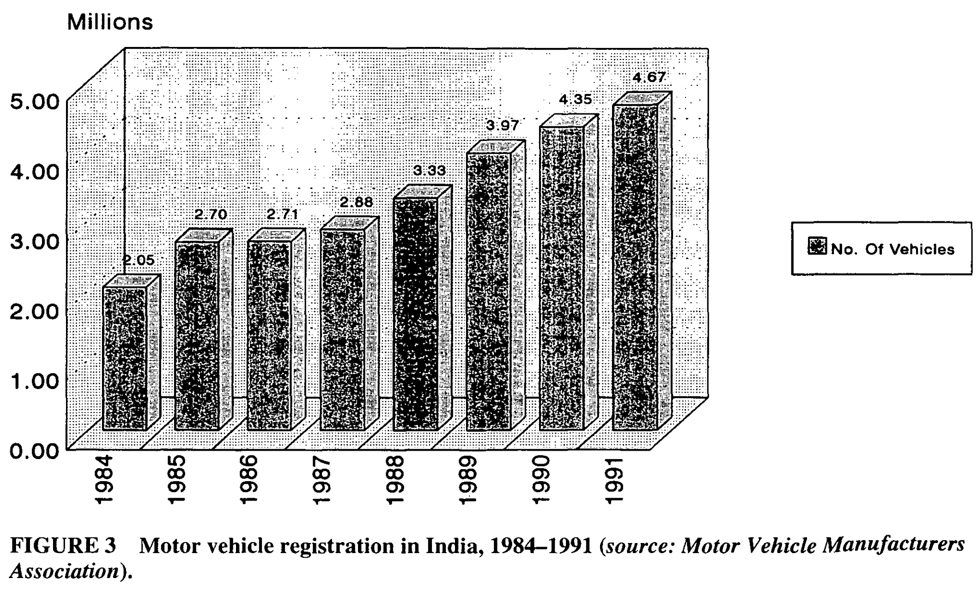

FIGURE 3 Motor vehicle registration in India, 1984–1991 (*source: Motor Vehicle Manufacturers Association*).

TABLE 4 Accident Causes in New Delhi, 1991

CAUSES OF ACCIDENTS	PERCENTAGE
Fault of driver of motor vehicle	74.70
Fault of driver of vehicle other than motor vehicle	2.27
Fault of cyclists	4.40
Fault of pedestrians	7.32
Fault of passengers	3.71
Defective mechanical condition of vehicles	2.51
Defective roads	0.81
Bad weather condition	0.18
Other causes	4.10
TOTAL	100.00

Source: Delhi Traffic Police, Delhi

lack of growth in road network or lack of infrastructure. Especially in Delhi, the national capital, vehicle density increased four times in the past 20 years. Table 3 gives the vehicle density on roads in Delhi for the period 1972–1991.

The way to avoid congestion is to travel by mass transport or railways. India has the third largest rail system in the world after the United States and the former Soviet Union. Table 7 presents the rail networks in selected countries. Railways handle 41 percent of the passenger travel in India. If more and more people use rail for their travel needs, congestion, accidents, and pollution will be reduced in India. Lack of infrastructure plays an important role in alleviating any of these problems. Recently the World Bank agreed to fund sev-

TABLE 5 Proportion of Pollutants

Vehicle	Emission of Pollutants (in Kilograms)	Proportion of Pollution
2-wheelers	1355000	0.36
3-wheelers	626000	0.17
Cars	1234000	0.33
Buses	518000	0.14
Total	3733000	1.00

1 Kilogram = 2.2026 Pounds

Source: Proceedings of workshop on Energy Conservation in Road Transport, India, 1989.

TABLE 6 Road Space Utilization

Vehicle Type	Area (Square meter)	Average Occupancy	Occupancy/ Square meter
Buses	27.5	37.5	1.36
Cars	12	2.2	0.18
Taxis	12	2.63	0.22
Autorickshaws	7.5	1.95	0.26
Scooters	5	1.62	0.32
Mopeds	5	1.62	0.32
Motorcycles	5	1.62	0.32

1 Meter = 3.2787 Feet

Source: Ministry of Industry, Government of India

eral infrastructure projects in India, with most of the funds allocated to the transportation sector (*5*). Figure 4 shows the sector-wise commitment of the World Bank: transportation and highways receive the majority of the funds. It is hoped that using these funds to build infrastructure will mitigate some of the problems facing the country.

CONCLUSION

Despite efforts by the government, the numbers of traffic accidents and fatalities in India are increasing year by year. The environment is becoming more and more polluted because of a lack of strict environmental regulations, and roads are becoming more and more con-

TABLE 7 Rail Networks in Selected Countries, 1990–1992

COUNTRY	Length of Rail Network (Kilometers)	Share of Total Freight Traffic	Share of Total Passenger Traffic
United States	187,691	37	0.4
Former Soviet Union	147,359	79	45
India	61,976	51	41
China	54,083	80	56
France	33,446	24	9
Former West Germany	27,028	22	6
Japan	24,412	5	31
United Kingdom	16,896	7	5
Italy	16,138	11	6
Czechoslovakia	13,115	78	30
Switzerland	5,108	40	13
Netherlands	2,780	3	5

1 Kilometer = 0.621 Miles

Source: Worldwatch Report, Back on Track: The Global Rail Revival

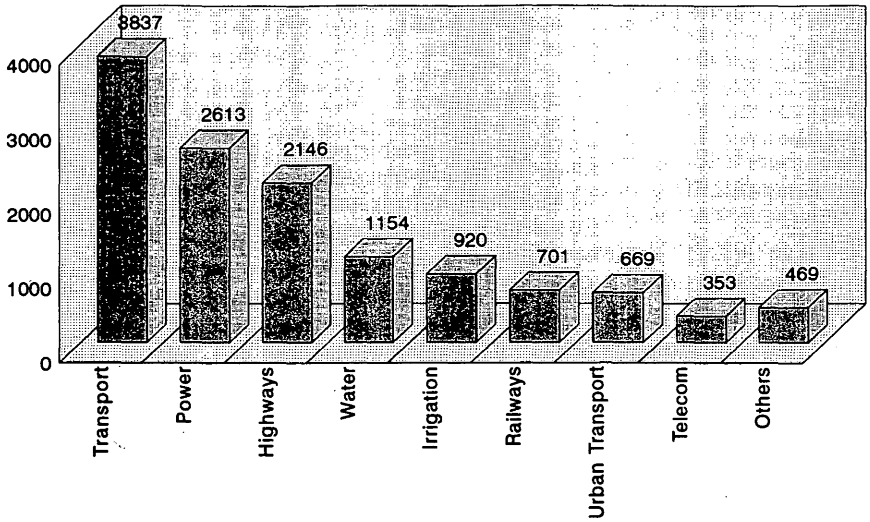

FIGURE 4 World Bank commitments ($ millions, U.S.) (5).

gested because more vehicles are on the roads. The government should bring legislation to control vehicles on roads and enforce tougher environmental regulations. With the majority of World Bank funds allocated toward transportation and highways, the government should use the latest technology and introduce mass rapid transit to reduce congestion and accidents on roads. But in the next few years, the situation will probably worsen before it becomes better.

ACKNOWLEDGMENTS

The author is grateful for the efforts of Suneel K. Wasan, Project Coordinator, National Transportation Planning and Research Center, New Delhi; and A. K. Wadhwa, Section Officer, Indian Roads Congress, New Delhi, in helping to gather data for this paper. The author gives special thanks to the editor of *India Abroad* for help in gathering data published in previous issues of *India Abroad.* The author extends his gratitude to a number of other people who contributed at various stages of this paper.

REFERENCES

1. Khanna, S. K., and C. E. G Justo. *Highway Engineering,* 7th ed. Nem Chand & Bros., Roorkee, India, 1991.
2. Transport Chaos Takes Huge Toll. *India Abroad,* Vol. 23, No. 34, May 21, 1993, p. 24.
3. Indian Auto Market's Swift Growth. *India Abroad,* Vol. 24, No. 37, June 10, 1994, p. 20.
4. Lower-Lead Gasoline Set for 1995. *India Abroad,* Vol. 24, No. 36, June 3, 1994, p. 37.
5. World Bank Eyes Public Sector. *India Abroad,* Vol. 24, No. 42, July 15, 1994, p. 26.

The views presented in this paper and any errors are the responsibility of the author.

Role of Nonmotorized Transportation in the Major Highway System in China

XIAOMING LIU, L. DAVID SHEN, SHANGHE CHEN, AND JIAN HUANG

The National Major Highways of China (NMHC) is the name of the major highway system in China, which is the backbone of the country's highway transportation. A variety of transportation modes share the NMHC, including motor vehicles, bicycles, and man-powered and animal-drawn vehicles. In 1992 the total percentage of nonmotorized transportation in China was 13.2 percent. As such, nonmotorized transportation modes must be considered in developing future strategies for the NMHC. The characteristics of nonmotorized transportation are discussed using statistical traffic data for the NMHC between 1988 and 1992. In addition, recommendations are made for the future planning of the NMHC, with special consideration given to bicycle traffic.

Economic reform policies over the past 15 years have resulted in the rapid development of highway construction in China. From 1978, an average of 10 000 km/year has been added to the highway system, totaling 1 075 000 km and including 1145 km of expressway. According to the initial plan from the Communication Ministry of China, China will have 1 250 000 km of highways by the year 2000.

Highways in China have been classified into three categories: the National Major Highways of China (NMHC), the provincial major highways of China, and the local highways. NMHC highways are assigned numbers according to their point of origination: those originating from Beijing are numbered "1xx" and total 12 in number, those having north-south orientations are numbered "2xx" and total 28 in number, and those with east-west orientations are numbered "3xx" and total 30 in number. By 1993 the total length of the NMHC had reached 111 000 km, 10.3 percent of the total highway length in China. Moreover, 24 percent of the total kilometer tonnage was produced from transported goods. In addition, these highways link more than 80 percent of the cities having populations greater than 500,000.

As a developing country, China lags behind industrial nations in economic power. As such, transportation facilities are inadequate and insufficient. And most NMHC highways accommodate a mix of motor vehicles, tractors, bicycles, and man-powered and animal-drawn vehicles. The existence of nonmotorized transportation increases the difficulty in managing the traffic on these highways.

NONMOTORIZED TRANSPORTATION ON NMHC

China is known as the bicycle kingdom of the world. At the end of 1992, bicycle ownership in China's urban areas had reached two bicycles for every three persons. Therefore, bicycle traffic inevitably will interfere with motor vehicle traffic on the NMHC highways.

China is an agricultural country with one-fifth of the world's population. The transport of agricultural goods by man- and animal-drawn vehicles is predominant for short-distance transportation in most areas of China, especially those areas that are undeveloped.

Motorized and nonmotorized vehicles need to be normalized for comparative analysis. The conversion factors in Table 1 for motorized and nonmotorized vehicles are calculated on the basis of their roadway capacities. The standard motor vehicle is defined as a two-axle, six-wheeled truck, called the standard Jiefangpai truck by Chinese transportation engineers. Table 2 indicates that all the annual percentages of nonmotorized transportation from 1988 through 1992 exceeded 13 percent (*1*). Although the annual percentage declined gradually from 15.7 percent in 1988 to 13.2 percent in 1992 with an average annual declining rate of 0.65 percent, this is still an exceptional transportation phenomenon in the world's highway transportation systems. Moreover, the nonmotorized traffic volume has continued to increase.

A comparison of Figures 1 and 2 shows that the percentage of bicycle traffic declined from 8.9 percent in 1988 to 6.8 percent in 1992 (*2*). Although the percentage of bicycle traffic has been decreasing gradually, it is still higher than that of many industrial nations and is not anticipated to change much over the long term. It is noteworthy that the percentage of man- and animal-drawn vehicle traffic has increased from 6.0 percent in 1991 to 6.4 percent in 1992, which is an unusual phenomenon in the world (*3*). The reasons leading to the current situation on the NMHC highways can be described as follows:

- China is a developing country, and for most people, the bicycle is the primary choice of transportation.

TABLE 1 Conversion Factors for Motor and Nonmotorized Vehicles

Vehicle	Conversion Factor
Motor Vehicle	1.0
Mini Bus	0.5
Bus	1.0
Trailer	1.5
Tractor	1.0
Bicycle	0.1
Man-drawn Vehicle	0.5
Animal-drawn Vehicle	2.0

X. Liu and S. Chen, Department of Civil Engineering, Beijing Polytechnic University, Beijing 100022, China. L. D. Shen and J. Huang, Department of Civil and Environmental Engineering, Lehman Center for Transportation Research, Florida International University, State University of Florida at Miami, Miami, Fla. 33199.

TABLE 2 Percentages of Nonmotorized Traffic on NMHC Highways

	Percentages (%)[a]		
Year	Bicycle Traffic	Man-drawn and Animal-drawn Vehicle Traffic	Total Nonmotorized Traffic
1988	8.9	6.8	15.7
1989	8.4	6.5	14.9
1990	8.2	6.1	14.3
1991	7.7	6.0	13.8
1992	6.8	6.4	13.2

[a] Calculation based on motor vehicle equivalents

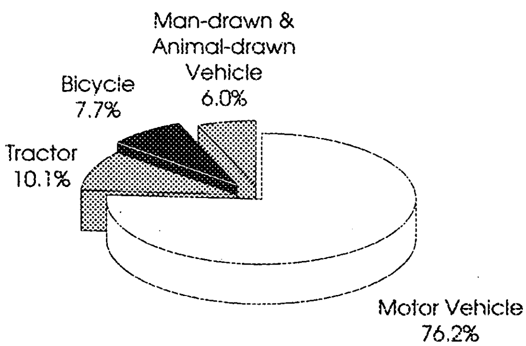

FIGURE 1 Transportation modes on NMHC highways in percentage of traffic volume, 1991.

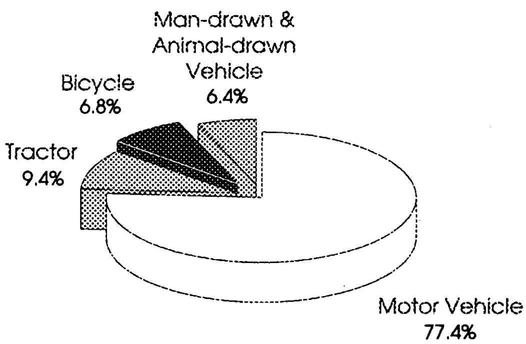

FIGURE 2 Transportation modes on NMHC highways in percentage of traffic volume, 1992.

- Man- and animal-drawn vehicles are used as low-cost modes of transportation and are used widely for short-distance and low-weight transportation.
- In China, towns are usually surrounded by villages less than 10 km away. Such short distances make the use of nonmotorized transportation modes physically possible.
- Nonmotorized transportation is affordable and practical and therefore is used widely in China.

LOCATION CHARACTERISTICS OF NONMOTORIZED TRANSPORTATION

Location characteristics of nonmotorized transportation on the NMHC highways are very complicated, not only because China is a big country and the roadway conditions vary significantly but also because they are related to social and economic levels and geographic environments, such as local economic levels, population densities, and geographies and environments. In the following sections, traffic volumes and percentages of nonmotorized transportation are analyzed to identify the location characteristics of nonmotorized transportation.

Five provinces having the highest nonmotorized traffic volumes in 1992 on the NMHC highways are presented in Table 3 in motor vehicle equivalents. Five provinces having the lowest nonmotorized traffic volumes in 1992 are also given. Bicycle traffic volumes and man- and animal-drawn vehicle traffic volumes on the NMHC highways are given in Tables 4 and 5, respectively.

Table 3 indicates that nonmotorized traffic volumes are much higher in Jiangsu, Guangdong, Shanghai, Tianjin, and Beijing, where the economic levels and population densities are greater than those of most other areas in China. Guangdong and Jiangsu

TABLE 3 Nonmotorized Traffic Volumes in Motor Vehicle Equivalents, 1992

Highest Five Provinces in Volume	Nonmotorized Traffic (AADT)	Lowest Five Provinces in Volume	Nonmotorized Traffic (AADT)
Jiangsu	1,163	Qinghai	45
Guangdong	975	Ningxia	78
Shanghai	825	Guizhou	107
Tianjin	764	Gansu	162
Beijing	619	Xinjiang	177

NOTE: AADT = annual average daily traffic.

TABLE 4 Bicycle Traffic Volumes, 1992

Highest Four Provinces in Volume	Bicycle Traffic (AADT)	Lowest Five Provinces in Volume	Bicycle Traffic (AADT)
Guangdong	8,293	Qinghai	180
Jiangsu	5,492	Guizhou	292
Tianjin	5,477	Ningxia	470
Shanghai	8,673	Xinjiang	705
		Heilongjiang	704

NOTE: AADT = annual average daily traffic.

TABLE 5 Man- and Animal-Drawn Vehicle Traffic Volumes, 1992

Highest Five Provinces in Volume	Man-drawn Traffic (AADT)	Animal-drawn Traffic (AADT)	Lowest Five Provinces in Volume	Man-drawn Traffic (AADT)	Animal-drawn Traffic (AADT)
Jiangsu	341	85	Ningxia	27	7
Neimeng	278	69	Qinghai	30	8
Jilin	272	68	Guizhou	82	21
Hubei	231	58	Gansu	90	22
Tianjin	217	54	Xinjiang	106	27

NOTE: AADT = annual average daily traffic.

are the two provinces having the highest economic levels in China. After the economic reformation and the opening of China to the rest of the world, the economic power in these two provinces has been greatly increased. At the same time, labor demand is increasing so greatly that the number of people moving into these provinces from other parts of China is rising yearly. Therefore the combination of all those mentioned above has led to high nonmotorized traffic volumes. Beijing, Tianjin, and Shanghai, the three municipalities directly governed by the central government, are the political, economic, and cultural centers of China. Because of the high transportation demands, population densities and transportation efficiencies of nonmotorized vehicles, forms of nonmotorized transportation, especially bicycles, are widely accepted by the citizens.

Tables 4 and 5 reveal that the distributions of bicycle transportation and man- and animal-drawn vehicle transportation among these cities are basically consistent with those of nonmotorized transportation as a whole.

TABLE 6 Five Provinces with Highest Percentages of Nonmotorized Transportation, 1992

	Percentages (%)		
Province	Bicycle Transportation	Man-drawn and Animal-drawn Transportation	Total Nonmotorized Transportation
Neimeng	6.43	20.94	27.37
Jilin	7.03	13.01	20.03
Hubei	7.71	9.33	17.04
Anhui	13.58	3.44	17.02
Guangxi	14.79	1.86	16.65

TABLE 7 Five Provinces with Lowest Percentages of Nonmotorized Transportation, 1992

	Percentages (%)		
Province	Bicycle Transportation	Man-drawn and Animal-drawn Transportation	Total Nonmotorized Transportation
Ningxia	2.83	1.50	4.32
Shandong	0.90	5.46	6.36
Fujian	5.29	1.47	6.76
Tianjin	4.55	2.48	7.03
Hunan	7.13	1.47	8.60

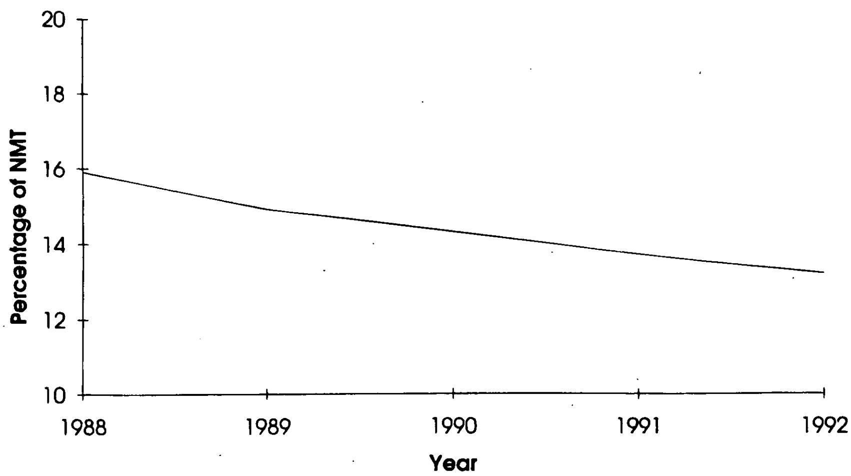

FIGURE 3 Percentage of nonmotorized transportation (NMT).

Table 6 presents the five provinces having the highest percentage of nonmotorized transportation. Table 7 gives the five provinces having the lowest percentage of nonmotorized transportation.

The five provinces having the highest percentages of nonmotorized transportation all have a medium economic level, even geographic environment, and lower-than-average population density. The reasons are as follows:

- Limited local economic development leads to a slow growth in motorized transportation.
- Nonmotorized transportation is more suitable for areas with high population densities and even geographic environments that require shorter traveling distances and have a sufficient labor force.

Provinces with the lowest percentages for nonmotorized transportation include comparatively developed areas, such as Fujian, Shandong, and Tianjin, as well as underdeveloped areas such as Hunan and Ningxia. In economically developed areas, motorized transportation has grown faster than nonmotorized transportation. Areas with low economic levels have a limited development of both motorized and nonmotorized transportation.

Nonmotorized transportation varies in location because of different local economic levels and the various geographic environments. Most of the areas with the higher nonmotorized traffic volumes lie along the coast of China and in the municipalities of Beijing, Shanghai, and Tianjin. The distribution of nonmotorized traffic volumes declines from east to west with the exception of the Heilongjiang and Jilin provinces.

TIME CHARACTERISTICS OF NONMOTORIZED TRANSPORTATION

As shown in Figure 3, the percentage of nonmotorized transportation declined gradually from 1988 to 1992; this decline is anticipated to continue well into the future. The three forecasting models developed to display this trend are as follows (*4*):

1. Linear regression:

$$Y = -1248.16 - 0.62X \qquad R^2 = 0.905$$

2. Polynomial regression:

$$Y = 0.0428571X^2 - 171.191X + 170967 \qquad R^2 = 0.912$$

3. Exponential regression:

$$Y = 2.46976 * 10^{38} * 0.95783^x \qquad R^2 = 0.895$$

where Y is the percentage of nonmotorized transportation for the forecasting year and X is the forecasting year.

The nonmotorized traffic volumes from 1993 to 2000 on the NMHC highways are projected using the three forecasting models and are presented in Table 8. The average values for the traffic volumes of nonmotorized transportation from 1993 to 2000 are also displayed in Figure 4.

Table 9 indicates that nonmotorized traffic volumes have been increasing gradually but that their percentages have been declining slowly. This is happening because motor vehicle traffic volumes and their percentages have been increasing with the growth of the gross national product (GNP) as given in Table 10.

TABLE 8 Projected Traffic Volumes of Nonmotorized Transportation (%)

Regression Model	1993	1994	1995	1996	1997	1998	1999	2000
Linear	12.50	11.88	11.26	10.64	10.02	9.40	8.78	8.16
Polynomial	12.85	12.53	12.29	12.14	12.07	12.10	12.21	12.40
Exponential	12.60	12.07	11.56	11.07	10.60	10.16	9.73	9.32
Average	12.65	12.16	11.70	11.28	10.90	10.55	10.24	9.96

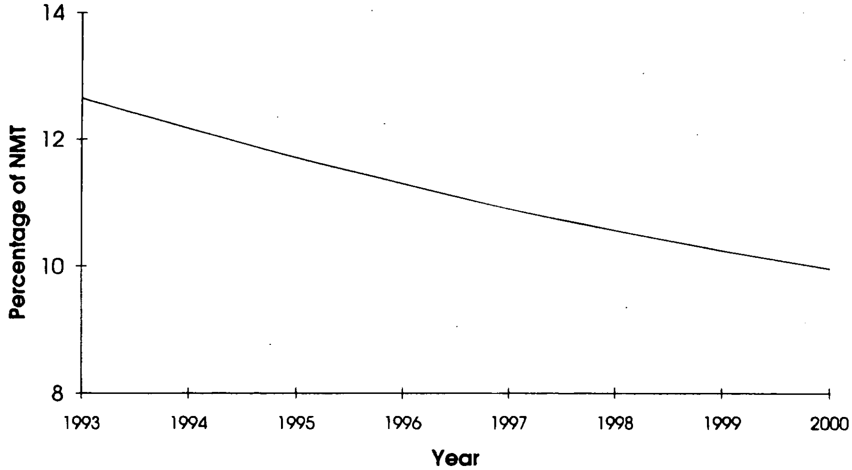

FIGURE 4 Average percentages of traffic volumes of nonmotorized transportation (NMT).

TABLE 9 Nonmotorized Traffic Volumes

	Annual Average Daily Traffic (AADT)		
Year	Bicycle	Man-Drawn Vehicle	Animal-Drawn Vehicle
1988	2,118	41	162
1989	2,157	42	167
1990	2,226	40	166
1991	2,295	45	179
1992	2,290	54	215

RECOMMENDATIONS

The following recommendations for future planning and management are made as a result of the preceding analysis of nonmotorized transportation on each mode of the NMHC highway system.

1. Because nonmotorized transportation will be used for a long time, interference with motor vehicle operations from nonmotorized vehicles should be examined while the capacities of NMHC highways are evaluated.
2. Although nonmotorized traffic volumes will rise continuously, their percentages will decline slowly. Since percentages for traffic volumes of motorized and nonmotorized vehicles will change, their conversion factors should be recalculated.
3. As NMHC highways are replaced with new highways, expressways, and freeways, the old roadways should be maintained for nonmotorized transportation to use. The nonmotorized traffic situation in most areas of China will not change much over the next 20 years. Therefore, in the rehabilitation of old NMHC highways, it is recommended that separated lanes for nonmotorized transportation be used.
4. For Beijing, Shanghai, Tianjin, and other economically developed areas, more attention should be paid to nonmotorized traffic planning and management.
5. China is a country with one-fifth of the world's population. There is a big gap in purchasing power between China and industrial nations. Therefore, bicycles will continue to be the primary mode of private transportation in the future and must be taken into account when NMHC highways are planned.

CONCLUSIONS

As a developing country, China lacks the economic power of industrial nations. Most Chinese people will be unable economically to purchase motor vehicles in the coming years. Therefore, the number of nonmotorized vehicles will remain, and may even rise, as low-cost transportation modes. Because of the variety in

TABLE 10 Relationship Between GNP and Annual Average Daily Traffic (AADT) Growth

	Percentages (%)		
	Average Yearly Growth (1986-1990)	Yearly Growth from 1990 to 1991	Yearly Growth from 1991 to 1992
GNP	7.8	7.0	12.8
AADT	8.3	8.4	12.8

economic levels and geographic conditions throughout China, non-motorized traffic is distributed unevenly on the NMHC. This situation is not anticipated to change quickly in the near future. Therefore, further research and practice should be implemented to develop a strategy for accommodating both motorized and non-motorized transportation on the NMHC highways for the present and near future.

ACKNOWLEDGMENTS

The authors wish to thank Caijun Luo for helping to compile the data and Allison C. Smith for editing this paper.

REFERENCES

1. *A Collection of Traffic Volumes in the NMHC Highways.* Institute of Highway Planning and Design, Ministry of Communication of China, Beijing, 1988–1992.
2. Chen, S., and X. Liu. Overview of Bicycle Traffic of the NMHC. *Proc., International Symposium on Non-Motorized Transportation,* Beijing, China, May 1994.
3. Liu, X., L. D. Shen, and F. Ren. Overview of Bicycle Transportation in China. In *Transportation Research Record 1396,* TRB, National Research Council, Washington, D.C., 1993.
4. Liu, X., and F. Ren. Ideological System of Transport Forecasting in Highway Network Planning. *Journal of Highway and Transport,* No. 3, 1994.

Transportation Modeling for Energy and Environment: U.S. Experience and Relevance to the Developing World

P. CHRISTOPHER ZEGRAS, DHARM GURUSWAMY, AND HENRY MALBRÁN ROJAS

Recent developments in travel demand modeling and their potential for application in the developing world are examined, with a specific focus on energy, air pollution, and land use impacts. Practices in North America, where transportation and air quality modeling were pioneered, are emphasized, and potential in the developing world, where North American paradigms were often applied and where current trends suggest that future urban transport costs will be large, are explored.

For the developing world, the need for transport system improvements is intense, perhaps nowhere more than in the rapidly growing urban areas. Even though they already allocate from 15 to 25 percent of annual spending on urban transportation, developing countries, estimates suggest, must increase their abilities to supply and manage urban infrastructure by 75 percent simply to maintain the current, often unacceptable conditions (*1*). The challenges of accommodating demand for transport in the developing world are compounded by rapid growth in motor vehicle fleets and its associated effects on congestion, energy, environment, equity, and safety. Estimates project that the motor vehicle fleet in the developing world will increase by 220 percent between 1988 and 2000 (*2*). Already, developing world cities face dire congestion problems; in Bangkok, estimates suggest that $15 billion in transport investments over 15 years will speed up snarled traffic conditions by a mere 1 km/hr (*3*). Transportation oil consumption is also rising rapidly, often outstripping growth in gross domestic product (*4*) and straining the capital reserves of oil-importing countries and reducing export earnings for oil exporters. The environmental implications are all too well known, the most notable being air pollution. In some of the world's most polluted cities, transportation is responsible for between 70 and 86 percent of total airborne pollutants (*5*). Safety concerns in the developing world also are growing, as road accident deaths are commonly the second largest cause of death for economically active age groups (*6*).

Facing these large and growing problems, developing countries require innovative urban transport solutions as well as analysis tools—or models—that can measure the broad-ranging impacts of those solutions. Unfortunately, it remains unclear what role traditional transport models can play in addressing the unique challenges facing cities in today's developing countries. Transportation models essentially were developed in the post–World War II United States, an environment of seemingly unlimited financial and natural resources. These models were designed to analyze the need for new highway facilities. Today, however, urban transportation models must effectively analyze a wide variety of transport measures—from alternative land use development to promotion of nonmotorized transport modes. In addition, models must be able to measure energy and air pollution impacts of different transport options and strategies.

P. C. Zegras, International Institute for Energy Conservation, 750 First Street, NE, Suite 940, Washington, D.C. 20002. D. Guruswamy, Graduate City Planning Program, Georgia Institute of Technology, Atlanta, Ga. 30332. H. M. Rojas, Lota 2257, Office 401, Providencia, Santiago, Chile.

MODELING IN NORTH AMERICA

Travel Demand Models

The urban transportation planning process follows a straightforward methodology evolved over four decades of development and refinement. The process was made possible by the advent of computers, which enabled the translation of theoretical constructs into practical application and analysis. Travel modeling was pioneered in the United States as the federal government attempted to establish a uniform method of priority ranking road investment decisions (*7*). In the standardized process, which came to be known as the urban transportation modeling system (UTMS) or the urban transportation planning process, travel demand is derived from the daily activities of individuals and businesses. The goal of the process is to find the amount, type, and location of travel in the designated study area. The process has a number of requirements that basically are universal (*8*):

1. Gather the data at the lowest possible level of aggregation;
2. Develop (or use other sources of) future projections for population, income, fuel price, transit fares, and so on;
3. Develop a model that accurately forecasts travel behavior; and
4. Apply the models to produce travel forecasts.

Most conventional travel forecasting models include some common elements. First, the primary inputs into the model are land use data (sometimes itself derived from a model) on housing and employment distributions, which are typically not sensitive to changes in the transport system. From this land activity distribution, the travel demand forecast is derived, in a "four-step" method, sequentially estimating

1. *Trip generation*, describing the number of trips originating and ending in each zone;
2. *Trip distribution*, mapping the number of trips between each origin-destination (O-D) pair;
3. *Mode split*, dividing the total number of O-D flows into modes (automobile or transit); and

4. *Assignment,* assigning the automobile O-D flows and transit O-D flows to specific paths in their respective networks.

The conventional four-step travel demand modeling process will produce travel times, speeds, costs, distances, volumes, and volume/capacity ratios (which represent traffic density) by mode. These results are available for individual network links and for O-D pairs. This basic data can then be used to derive information such as total vehicle distances traveled or transit ridership by line (*9*).

A transportation model requires a large volume of data for calibration and validation. Typically, these data come from surveys designed specifically for estimating travel demand and the nature of that demand. The most common form of survey is the O-D survey, normally conducted by interviewing people, representing sample demographic segments, within a given travel area. The survey can help determine specific travel patterns in the study area, whether that be a single neighborhood, a subdivision, a commercial development, or an entire metropolitan area (*10*). Means of conducting such surveys vary from direct interviews, phone interviews, mail surveys, or some combination. Other information needs that also are necessary to transportation modeling and complementary to O-D surveys are traffic counts, cordon counts, vehicle occupancy counts, and transit inventories. In the United States, a study of metropolitan area travel surveys revealed that different urban areas varied greatly in the extent and frequency of surveys; they include household surveys conducted on a 10-year cycle, 15-year (or more) cycle, a continuous cycle, and not currently conducting surveys (*11*).

Transportation Emissions Modeling and Air Quality

Outputs from the travel demand modeling process can be used as inputs into a mobile source emissions model to generate estimates of aggregate motor vehicle emissions in an urban area. These emissions estimates can, in turn, be input into a dispersion model, which attempts to predict ambient air quality by simulating pollutants' interaction within a given meteorological and topographical situation in order to estimate future ambient air quality levels under different possible transportation (as well as other emissions source) scenarios (*12*). Ambient air quality levels represent the actual pollution concentration in an urban area's air shed and are crucial for determining emissions impacts on human populations, vegetation, and buildings.

In many of the world's cities that suffer from poor air quality, such as Los Angeles; Mexico City; São Paulo, Brazil; Manila, the Philippines; road transport accounts for between 70 and 86 percent of all pollutant emissions (*5*). To model transportation emissions accurately, and thereby determine impacts on air quality, these emissions should be disaggregated into their components. Motor vehicle emissions can be categorized as exhaust emissions (direct from tailpipe during operation), evaporative emissions (due to fuel evaporating from engine or ambient air temperature), and running loss emissions (evaporative emissions during vehicle operation) (*13*). The rate at which motor vehicles emit pollutants depends on a variety of factors, including vehicle type, age, and maintenance level; driving habits; and ambient air temperature.

A mobile source emissions model is used to determine transport contribution to ambient air pollution. California first developed a mobile source emissions model, EMFAC, to predict emissions factors (emissions per distance traveled) at a given average speed for different vehicle types. In this way, the data from travel forecasting models, combined with vehicle inventories, could be used to project future transport emissions. The Environmental Protection Agency soon developed a similar model, MOBILE. Both models have been refined continually as knowledge of emissions characteristics evolved and vehicle technologies and fuels changed. The current versions of the two models are MOBILE5 and EMFAC7F. Since both models produce factors based on average speed, they can be classified as average speed models (*9*).

Although the assumptions and algorithms underlying the two models differ, both EMFAC and MOBILE require similar data inputs and produce similar outputs based on average speed. In the case of the widely used MOBILE model, the vehicle fleet is categorized into seven types: light-duty gasoline vehicles, light-duty gasoline trucks, heavy-duty gasoline vehicles, light-duty diesel vehicles, light-duty diesel trucks, heavy-duty diesel trucks, and motorcycles (*13*). Inputs necessary to determine actual emissions factors include ambient air temperature, vehicle tampering levels, gasoline volatility class (which influences rate of evaporative emissions), vehicle age distribution, inspection maintenance parameters, emissions control technologies, air conditioner use, vehicle load factors, and altitude (*13*). Such data typically require detailed data bases from local departments of transportation. Fleet characteristic data combined with data from the travel forecasting model on the number, length, and average speed of trips that occur in an urban area and the proportion of cold versus hot starts enable average speed models to estimate vehicle emissions (*9*).

Energy Modeling

Road transportation accounts for approximately 72 percent of total global transport energy consumption (*14*) and at least 14 percent of global fossil fuel carbon dioxide emissions (*15*). As global road vehicle fleets and distances traveled continue increasing rapidly, road transportation will most likely become a larger relative consumer of global energy. Because the sector depends on petroleum as its primary energy source, growing energy consumption in road transport is of concern for a number of reasons, including (*a*) increasing risks of oil price shocks as global demand increases; (*b*) growing threats to many nations' balances of payments because of imported oil products; and (*c*) growing contributions to global greenhouse gas emissions.

Within an urban area, transportation energy consumption depends on three primary factors:

1. Vehicle design, including engine technology, transmission, weight, and aerodynamics;
2. Travel conditions, including vehicle speed, stops and starts, road conditions, and driver behavior; and
3. Weather conditions (to a lesser extent).

Ideally, a fuel consumption model should be able to reflect changes in vehicle fuel consumption characteristics and in travel characteristics to estimate current and future urban transport consumption accurately in different scenarios.

The simplest and most commonly applied method of modeling urban transport energy consumption operates in a manner similar to the average speed emissions models discussed earlier. Such models take average vehicle fuel efficiencies (which can be broken down into different vehicle classes, such as those differentiated previously) for a given average speed and, using outputs from the travel forecasting model for number and length of journeys (which should at least be broken down by vehicle type according to the relative proportion of each vehicle type to total urban fleet), can give rough macrolevel estimates of urban transport energy consumption.

Land Use–Transportation Modeling

Land use is of concern to transportation both because land use data is a necessary input for travel forecasting models and because of the intimate relationship between land use patterns and travel behavior. Not only does land use determine trip generation rates, but land use patterns and urban form influence average trip distance and modal split. At the same time, land uses and trip generations are affected, over time, by changes in transport supply.

In most cases, land use data are input into travel forecasting models as exogenous variables, typically drawn from a group of potential land use scenarios. Although this technique is adequate for showing what transport system requirements a specific land use will dictate, its inability to project the impacts that transport system performance will then have on land use presents a serious shortcoming to travel forecasting.

In recent years, increasing attention in North America has been placed on the land use–transportation link, partly because of environmental impact concerns, as typified in the United States by the recent study *Making the Land Use/Transportation/Air Quality Connection* (LUTRAQ). The LUTRAQ study was designed as a national demonstration to "develop methodologies for creating and evaluating alternative land use patterns and design standards that will: reduce dependence on automotive travel; increase mobility for all segments of society; minimize negative environmental impacts, particularly those on air quality; reduce energy consumption; and foster a strong sense of community character" (*16*). In its preliminary survey, the LUTRAQ study found that land use forecasting procedures in most metropolitan areas in the United States have not changed significantly in the past 20 years (*16*). The study found only two urban areas have fully implemented the tools available to predict the ways in which transportation system performance influences land uses and vice versa, and points out that even these two systems have serious deficiencies.

The LUTRAQ documentation provides a good overview of the operating characteristics of mainstream integrated land use transport models judged available for use in the United States, dividing them into two operational groups, ITLUP and MEPLAN (*16*). Most of these models have two distinct subsystems: a land use subsystem, which when given the level of accessibility provided by the transport system, can divide out available space between different types of land use (residential, commercial, and industrial), and a transportation subsystem, which when given the land use patterns and the transportation network can determine the transport system operation and the level of accessibility of a particular travel zone. The resulting accessibilities for each zone can then be used as a new input into the land use subsystem. The timing of the interactions between the two subsystems is uncertain. However, the most common approach used assumes that the transportation subsystem stabilizes within the current period given the land uses. Over time, land uses evolve and are influenced by the past performance of the transportation subsystem.

MODELING IN DEVELOPING WORLD

Travel Demand Modeling

Several middle-income developing countries engage in travel forecasting modeling (i.e., Thailand, Mexico, Chile, and Brazil), but the vast majority of developing cities have almost no indigenous modeling capability. Of 31 major transportation studies (which include modeling efforts) carried out in developing world cities between 1955 and 1984, only one—the 1972 Delhi and Madras study—was completed by a local organization (*17*). Many have criticized these efforts as "hit and run" jobs, making little effort to survey the local circumstances or engage in technology transfer and capacity building. Some have even accused the U.S. Department of Transportation of being slow in transferring more recent portions of the UTMS to the developing world (*17*).

In recent years, trends suggest movement toward greater technical capability in southern countries, especially those countries with rapidly growing economies. For example, in Chile, a partnership between the government, major universities, and consultants developed an urban transport model for use in Chilean cities, specifically the capital, Santiago. In the early 1980s, researchers there determined that the current models available on the commercial market would not effectively address the realities of the transportation system in Santiago, namely, a very congested system and a system in which public transportation satisfied the overwhelming majority of urban trips. Without an adequate commercially available model, the government decided to develop its own model. Known as ESTRAUS, the model uses a simultaneous supply-demand equilibrium equation that solves the two stages of demand (trip distribution and modal split) and supply (network assignment) at the same time instead of the two steps normally required (*18*). In this way, the model ensures that the costs used to estimate travel demand are the same as the costs used in assigning that demand to the transport network, providing internal consistency.

Despite the trend toward more in-country capacity, a large knowledge gap still remains in most of the developing world. History has shown that most cities of southern countries do not start effective modeling until they have reached middle-income status (around $4,000 per capita). Unfortunately, by then the problems of automobile proliferation, air pollution, and large bills for imported oil already exist.

In the developing world, information on the extent and cost of O-D surveys is difficult to obtain, but obviously it is available only in areas where some type of travel modeling has been attempted or considered. In Chile, for example, as part of the development of the ESTRAUS model, relatively comprehensive O-D surveys were conducted. When ESTRAUS was developed in the mid-1980s, it was calibrated with limited data available at the time. In 1991 a thorough O-D survey was conducted, covering a total of 33,000 households (3.3 percent of city households) at a cost of nearly $1.3 million (U.S.). The time necessary to design the O-D survey and collect, process, and validate the data was 18 months. After the 1991 O-D survey was finished, recalibrating the model took approximately 12 months.

Transportation Emissions and Energy Modeling

Attempts to replicate U.S.-style transportation air quality modeling in the developing world introduces complexities due to diverse vehicle fleets, rapid and unpredictable fleet growth rates, and unavailable or inaccurate basic data (i.e., vehicle miles traveled per year and vehicle emissions factors). Nevertheless, studies of various degrees of technical sophistication exist. In Bangkok, Thailand, for example, in 1990 researchers and consultants at the Thailand Development and Research Institute developed a transportation model to help project the growth of travel, energy use, and emissions as well as to evaluate various policy options. The travel data base and projections were drawn, with slight modification, from a study completed in 1990 by the Japan International Cooperation Agency (*19*). Emissions were calculated for all modes of transport, except rail and ferry services, using emissions factors from MOBILE4, EMFAC7, and other models (*19*). Nationally available data were used for calculating energy consumption factors. With these data, the research team developed a spreadsheet model that estimated emissions and energy use for 19 travel zones according to different estimated average travel speeds. Running the model under different future scenarios showed that only a combination of technical improvements to vehicles *and* area road pricing with improved mass transit would improve Bangkok's air quality (although carbon monoxide emissions would continue to increase) (*19*).

Other, more rudimentary attempts at modeling urban transportation and energy use include studies by the International Institute for Energy Conservation of three Asian cities (*20–22*). In these studies, linear extrapolations of current trends in urban growth, motorization rates, trip making, modal use, and trip lengths were combined with estimated emissions and energy consumption factors to project emissions and energy use under different scenarios. The World Bank–conducted Metropolitan Environmental Improvement Program has been examining air quality improvement possibilities, including transportation, in four Asian cities: Bombay, India; Jakarta, Indonesia; Katmandu, Nepal; and Manila, the Philippines. Unfortunately, the available literature does not highlight specific methodologies used (*23*). Other known studies include a European-backed effort to model the air quality of Tehran, Iran, using the European Union's CORINAIR model.

Land Use Modeling

According to Darbéra (*24*), a Lowry-type (*25*) land use model was used in the French-conducted transport planning study of Santiago, Chile, in the late 1960s—one of the earliest, if not first, computer-based modeling studies in a developing country city. Conducted largely to plan the French construction of the Santiago metro, the modeling and subsequent transportation plan had interesting effects on Santiago's transportation system and planning efforts. Six metro lines were laid out in the plan, two of which are currently operating (a third line is under construction). Line 2 of the Santiago metro has been criticized widely, at least by Chilean planners, as unjustifiable, largely because it never fulfilled the anticipated land use impacts that would have increased ridership to projected levels. Today, Line 2 continues to operate below capacity. The Lowry-type model used in the original French study was not used again in Santiago (*24*). The mixed impacts of the metro in Santiago on land use resulted in a general disenchantment with land use modeling among planners in Chile because, as some believe, the current state of land use–transport models is not sophisticated enough to handle the complex relationship between the two and simply because of the rapid, unrestrained growth of cites in typical developing countries.

At least two of the integrated land use transportation models have been applied to cities in developing countries. MEPLAN was applied in São Paulo, Brazil, where the forecasts produced by the model were validated by surveys over a 5-year interval (*16*). The TRANUS model, developed by a Venezuelan firm, has been used in Venezuela to evaluate urban land use planning on the island of Curaçao and the city of La Victoria, to conduct regional land use planning for a motorway and railway, and to study urban transportation planning in the city of Caracas (*16*).

SHORTCOMINGS OF CURRENT MODELING TECHNIQUES AND POSSIBLE SOLUTIONS

Travel Demand Models

In recent years federal legislation in the United States regarding both air pollution (the Clean Air Act Amendments of 1990) and transportation investment (the Intermodal Surface Transportation Efficiency Act of 1991, or ISTEA) has spurred increased scrutiny and criticism of travel demand modeling and its relation to air quality modeling. In general, criticisms of the traditional approach to travel forecasting focus on three primary areas: the underlying theories behind the models, the data used in the models, and the way in which the models are used (*12*). Detailed technical criticisms of the models are available in a growing collection of literature (*8,9,12,26,27*).

Criticisms of Models

Model Size A fundamental problem of travel demand modeling is the typically large, regional nature of the models used. These models were designed to predict the volume of traffic on major arterials. Smaller streets and localized traffic are most often not represented, thereby overlooking the significant congestion, energy, and emissions impacts of traffic situations on those facilities. Including all network features—high-occupancy vehicle (HOV) facilities, local streets, bicycle and pedestrian facilities, microscale information on intersections, and so on—would be greatly facilitated by a move to geographic information systems (GIS) (*28*).

Time of Day The models typically are designed for examining peak-period (a.m. peak) and sometimes off-peak travel, but they are not very sensitive to time-of-day variations. Time-of-day modeling is important to measure congestion impacts of time-shifting transport measures (peak-period pricing or flexible work schedules) and because air quality is very sensitive to time of day (because of evaporative emissions and photochemical smog formation). Measures to overcome this shortcoming include incorporation of time-of-day modeling possibly through developing time-of-day trip tables after trip generation or adding a fifth time-of-day submodel (*26*).

Travel Speeds Conventional models typically cannot provide average trip speed (not to be confused with link speeds), and even link speeds typically are not validated (*26*). Accurate speeds are critical for estimating emissions and accounting for the effects of congestion on transport, such as modal shifts (*26*).

Automobile Ownership Automobile ownership typically is either an exogenous input to the modeling system or modeled in very simplistic ways, ignoring the role played by gender, age, land use, and transit access (*8*). The process should explicitly incorporate models that relate automobile ownership to such variables (*8*).

Transit and HOV The four-step models typically cannot offer decent representations of measures that attempt to change vehicle occupancy levels (*9*); although most models can measure the impacts of HOV facilities, they need to include more detailed information (such as urban form and density) that might affect transit use.

Model Feedback Loops and Internal Consistency The typical four-step approach occurs in a sequential process—for example, outputs from one stage serve as inputs into the next. But final model outputs themselves, such as travel speeds, directly affect earlier stages of the process, such as land use development, trip generation, and modal split. Model iteration, whereby travel speeds are recycled back into the earlier stages of the process and models are rerun, can help make the models internally consistent so that travel speed outputs from assignment are the same as those used in earlier steps. Iteration has been shown to change future travel and emissions projections significantly (*29*) but may still produce inaccurate results, particularly when congestion is especially high. Another method for addressing internal consistency is through direct demand modeling, which is based on the premise that the decision to travel occurs simultaneously with the selection of destination and mode choice (*7*). Direct demand modeling simultaneously solves the distribution, modal split, and assignment stages in one equation (*30*).

Model Calibration To match model predictions with observed system performance, *K*-factors are used to correct for any differences. Although the use of *K*-factors will help achieve a "fit" between the current system and the model, it may not allow for accurate predictions of the future. The use of *K*-factors should be explicitly recognized, minimized, and quantitatively related to land use and socioeconomic factors (*27*).

Land Uses Attempts at feeding transportation modeling outputs into a transport-sensitive land use model still occur only in a handful of U.S. metropolitan areas. Because of the intimate relationship between transportation and land use, transportation model outputs should, at least, feed into a transport-sensitive land use model.

Nonmotorized Transportation Most models are based on vehicle trips, not person trips, virtually ignoring the role of nonmotorized modes of transport. The large-scale nature of the models also reduces the possibility of modeling the microscale nonmotorized transportation (NMT) network. Because of the lack of information on NMT facilities, amenities, and networks, changes in these cannot be accounted for in modal choice models (*26*). To overcome these shortcomings, trip generation should always be based on person trips, not vehicle trips (*27*). In addition, models should use zones small enough to capture short NMT trips and should include variables that represent NMT accessibility in trip generation, distribution, and mode choice (*27,31*). In Portland, Oregon, the modeling process incorporates a "pre–mode choice" model, which splits modes among walk/bike versus motorized modes. The pre–mode choice model uses the pedestrian environmental factor, which attempts to assess the model's travel zones for NMT-friendliness according to topography, street characteristics, and sidewalks (*32*). After generation, however, the nonmotorized trips are not distributed.

Data Availability and Collection

Relative to the amount of money and effort spent in constructing transportation infrastructure, the costs of data collection are low; still survey data are often neglected in planning because policy makers do not understand their importance to strong technical analysis (*8*). Failure to collect adequate data, however, will result in modeling and transport analysis efforts that will be, at best, subpar. Many urban areas in the United States use survey data that are close to 30 years old (*11*), which cannot accurately measure important demographic changes. Important considerations for data collection include the following:

- Costs have dropped because of technological advances (*8*),
- Surveys should focus on activities instead of trips (*27*),
- Survey data can have useful applications beyond travel forecasting (*8*), and
- A longitudinal panel survey approach (where a series of surveys are conducted with the same group of respondents) can improve data content and flexibility (*8*).

All data collection efforts should include information on walk and bike trips, including facilities inventory, NMT volume survey, speed and travel time survey, household survey, operators' survey, road accident inventory, inventory of costs and fares, an inventory of traffic regulations, and an outer cordon survey (*33*).

Emissions and Energy Models

One crucial shortcoming to both emissions and energy modeling for transportation stems from the fact that the models draw their inputs directly from the travel demand models, so any inaccuracies coming from the four-step model will be transferred into emissions and energy estimates. In that regard, addressing many of the model shortcomings identified here will help improve the accuracy of energy/emissions work. In addition, there are particular aspects of the four-step model that, although they do not necessarily affect the accuracy of the travel forecasting process, have important implications for air quality modeling. For example, the typical 10- to 20-year time frames that transportation planners use require that air quality analysts interpolate shorter-term conditions with often inaccurate results (*12*). Air quality analysis also requires information on the mix of vehicle types using the system, the proportion and time distribution of cold engine starts (which affect emissions levels), and seasonal variation (because different seasons produce different air quality effects)—all of which the typical travel model cannot produce (*28*).

The current generation of emissions factors models themselves also have limitations, in part because they estimate vehicle emissions on the basis of average speeds, whereas actual vehicle emissions depend more heavily on actual driving patterns (stops and starts, accelerations and decelerations). Both EMFAC and MOBILE historically have underpredicted emissions; however, further research is necessary to determine the extent to which the underprediction of motor vehicle emissions on a regional scale is due to the transportation models from which they get their input data or the emissions factors within EMFAC and MOBILE (*34*).

To go beyond average speed emissions models requires developing more detailed network assignment procedures that can generate something more than average link speed estimates and that are more directly integrated with the emissions calculation process. In general, at least two broad classes of more detailed models can be identified (*9*): (*a*) instantaneous speed models, which attempt to simulate in detail speed-time-distance trajectories of individual vehicles, usually on a second-by-second basis; and (*b*) elemental or semi-queueing models, essentially an "intermediate" or "meso" level of model not requiring the extreme detail of the instantaneous approach.

As with emissions models, alternatives to average speed models basically involve microsimulation instantaneous speed models or mesolevel, elemental models (*9*).

Miller and Hassounah (*9*) suggest that mesolevel models may provide the best compromise between model detail (required for credible estimation of emissions), feasibility of generating data inputs required, and computational intensity for the foreseeable future.

Land Use Models

One of the major problems with the travel forecasting process today is the lack of feedback between transportation infrastructure and system performance on land use development. The almost complete absence of integrated land use transportation models throughout the United States reflects both cynicism about the models themselves and the lack of resources required to successfully implement them. Even ITLUP, which was designed to be a "fifth stage" of the traditional four-stage travel demand forecasting process, requires significant effort to implement.

When used, the typical integrated transport land use forecasting models (i.e., ITLUP and MEPLAN) have shortcomings:

- *Limited variables.* Most models operate under the assumption that the major factor determining residential location is accessibility to the workplace, although workplace access represents only one of many factors affecting residential location, with many other factors often dominating the process (price of housing, neighborhood attributes, and such). In addition, designed with the typical central business district–dominated city in mind, the models do not treat multicentered cities well. These models must explicitly represent the housing market and recognize the role that automobile ownership plays in location choices.
- *Equilibrium.* The models assume an equilibrium state, although urban areas rarely, if ever, can be considered to be in a state of equilibrium.
- *Travel models.* The travel demand components of these modeling systems tend to be fairly conventional and similar to four-stage models and thus carry the shortcomings outlined earlier. Advances in travel demand modeling should be integrated into the land use models.
- *Data requirements.* The calibration requirements and data needs of these models are significant. A move to GIS can help here, by allowing for several layers of data to be maintained in very disaggregate forms and aggregated according to need (*35*).

Problems of Developing Countries

When compared with a typical North American application, modeling in the context of a developing country introduces an extended set of challenges. Indeed, many have criticized the relevance of the UTMS to cities in developing countries, including Peter Watson, a World Bank official, who attempted to view the process from the perspective of the poor, saying (*17*), "Do I walk 12 miles and eat an extra bowl of rice or [do I] take a bus? All these fancy parameters that some transport planners are trying to model are absolutely irrelevant to some people."

Certain shortcomings in the UTMS as discussed here have particular relevance to the developing world:

- *Ignoring NMT travel.* Walking and cycling play a critical travel role in developing country cities. In many Asian cities, for example, NMT modes account for up to 80 percent of vehicle trips (*31*). Nonmotorized modes are also most important to the poorest segments of the population; ignoring their role raises serious equity issues. Even in Asian cities, many models now in use typically ignore NMT (*31*), and researchers consider the development of a transportation network model capable of reflecting NMT modes to be an urgent need (*33*).
- *Internal consistency.* The lack of feedback between model stages can produce very unreliable travel (and emissions) forecasts, especially in the face of congestion, which is typical in many cities of developing countries.
- *Value of time.* Travel cost estimates are based on the value of time, which approaches zero for the very poor. The quantification of time does not address equity for the poorest inhabitants of developing country cities (where the poor can compose 40 percent of the population).
- *Lack of data.* As discussed, data collection is critical, yet time- and resource-consuming. The needs of data collection are complicated further in the developing world, because telephone and mail surveys typically will not reach a representative cross section of the population, again raising important equity issues. House-to-house surveys are often the only possible means of collecting accurate data, and high illiteracy rates in some regions may force verbal surveys.
- *Automobile ownership.* With booming automobile ownership rates, cities in developing countries need to explicitly integrate the effects of growing fleets on urban land use and transportation system evolution.

Emissions and Air Quality Modeling

Again, most of the problems concerning emissions modeling apply to the developing world. In the United States, for example, experience suggests large differences in emissions during vehicle tests and actual on-road performance. In the developing world—with its extremely diverse vehicle fleets, increased problems of vehicle maintenance, lack of proper testing facilities, and the increasing phenomenon of "dumping" of secondhand vehicles from the industrialized world—the challenges are heightened.

The Bangkok work discussed earlier is being updated in an attempt to predict air quality for the Bangkok region in 2000. Using an internal travel forecasting model for 1994, the study divides the city into 118 traffic zones and 4 outside zones and sets up a traffic network consisting of arterial and feeder roads (*36*). Three different year 2000 road scenarios were formulated and base-year trip matrices were calculated from a 1989 study and calibrated against 1994 traffic cordon and screenline counts. Year 2000 trip matrices were calculated and emissions were estimated with MOBILE5 modified for Bangkok. The output of MOBILE was then plugged into the Swedish air pollutant dispersion model AIRVIRO (*36*). The results show that under current plans, air quality in Bangkok will continue to deteriorate, unless additional traffic improvement measures and stricter vehicle emissions and inspection standards are implemented. Although not variables in the study, incentives to discourage automobile use and more effective land use planning are highlighted as having a potentially critical role (*36*).

Land Use Modeling

The conclusions of the Bangkok study show that integrated land use transport models have a potentially important role in developing world urban transportation analysis, especially because of the rapid growth in most of these cities. It appears somewhat appropriate, therefore, that one of the most promising recent efforts in the field comes from the developing world, the Five-Stage Land Use–Transport model (5-LUT), developed in Chile. The 5-LUT is a "unified" model in which transportation and location are determined simultaneously, assuming that the consumer makes consistent location and transport decisions based on maximizing utility (*37,38*). The 5-LUT model comprises two submodels, a land use submodel and a transport submodel. The transport submodel provides the accessibility and attractiveness characteristics that consumers consider to be an attribute of the land site. Accessibility and attractiveness both are based on trip costs derived from a trip distribution model (*38*). The transport attributes help determine the land use market equilibrium, which in turn requires feedback and a further iteration of the transport model (*38*). Reportedly, work is under way to calibrate the 5-LUT model for operation in Santiago in 1995 with ESTRAUS as the transport submodel.

CONCLUSIONS

Travel modeling and necessary improvements, such as incorporation of nonmotorized modes and iteration of model runs, involve significant costs at the local level. In addition, travel modeling innovations, such as advanced equilibrium or direct demand modeling, require local technical skills that even experienced professionals typically lack (*7*). More advanced emissions, energy, and land use modeling also require additional resources and expertise. There is much truth to the suggestion by Gakenheimer and Meyer (*39*) that often "significant indications of transport system performance can be found from simple field observations."

Still, as large infrastructure investments rapidly occur to address transport demands throughout much of the developing world, the need to fully consider the broad impacts of these investments is critical. What will be the long-term energy or air quality impacts of such investments? What role can alternative land use development play or how will land uses be affected? These critical questions suggest that cities in developing countries can benefit significantly from recent developments in urban modeling efforts. Indeed, considerable potential to "leapfrog" technological boundaries and learn from the experiences of other nations exists. Multilateral and bilateral agencies, which account for a major portion of infrastructure investment in developing countries, could aid in this technology transfer by dedicating at least a portion of their investments to developing appropriate models, in-country technical capacity, and the data collection necessary for good modeling.

Recent and ongoing developments in emissions and travel forecasting modeling in the United States suggest that resolution of many of the current shortcomings is possible in the foreseeable future. Unfortunately, wide dissemination and implementation of such advances remain a challenge and the optimal level of modeling detail is unclear. What does seem clear, from the experiences of countries such as Chile, is that the most effective modeling efforts will be those developed by local, in-country expertise. So, as models evolve and move from laboratory to practice, it is important that they be shared with other practitioners in the field and implemented where appropriate, but they must have caveats of both strengths and weaknesses. In the end, modeling must be clearly recognized as simply one tool in a transportation planning process that is ultimately and necessarily political.

ACKNOWLEDGMENTS

This paper was supported by a grant from the U.S. Department of Energy. The authors would like to express sincere thanks to Eric Miller of the University of Toronto, Francisco Martínez of the University of Chile, and Glen Harrison of Oak Ridge National Laboratory.

REFERENCES

1. 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.
2. Karmokolias, Y. *Automotive Industry Trends and Prospects for Investment in Developing Countries.* Discussion Paper 7. International Finance Corporation, Washington, D.C., 1990.
3. Tanaboriboon, Y. Demand Management Implementation in Southeast Asia. *ITE Journal,* Vol. 63, No. 9, 1993, pp. 21–28.
4. Birk, M. L., and P. C. Zegras. *Moving Toward Integrated Transport Planning: Energy, Environment and Mobility in Four Asian Cities.* International Institute for Energy Conservation, Washington, D.C., 1993.
5. World Resources Institute. *World Resources 1992–93.* Oxford University Press, New York, 1992.
6. Ross, A., and M. Mwiraria. *Review of World Bank Experience in Road Safety.* World Bank, Washington, D.C., 1992.
7. Shunk, G. Urban Transportation Systems. In *Transportation Planning Handbook* (J. D., Edwards, ed.), Institute of Transportation Engineers, Prentice-Hall, Englewood Cliffs, N.J., 1992, pp. 88–122.
8. Deakin, E., and G. Harvey. *A Manual of Regional Transportation Modeling Practice for Air Quality Analysis.* National Association of Regional Councils, Washington, D.C., 1993.
9. Miller, E. J., and M. I. Hassounah. *Quantitative Analysis of Urban Transportation Energy Use and Emissions: Phase I Final Report.* Joint Program in Transportation, University of Toronto, Ontario, Canada, 1993.
10. Kell, J. H. Transportation Planning Studies. In *Transportation Planning Handbook* (J. D., Edwards, ed.), Institute of Transportation Engineers, Prentice-Hall, Englewood Cliffs, N.J., 1992, pp. 387–409.
11. Purvis, C. *Survey of Travel Surveys II.* Presented at the Mid-Year Meeting and Conference of the Transportation Research Board, Transportation Data and Information Systems, 1989.

12. *Issues and Approaches to Improving Transportation Modeling for Air Quality Analysis.* Office of Air Quality Planning and Standards and Office of Mobile Sources, Environmental Protection Agency, Research Triangle Park, N.C., 1993.
13. Cohn, L. F., R. L. Wayson, and R. A. Harris. Environmental and Energy Considerations. In *Transportation Planning Handbook* (J. D. Edwards, ed.), Institute of Transportation Engineers, Prentice-Hall, Englewood Cliffs, N.J., 1992, pp. 447–477.
14. Pischinger, R., S. Hausberger, and G. Sammer. *Measures to Reduce Greenhouse Gas Emissions in the Transport Sector.* Austrian Ministry of the Environment, Youth, and Family, Graz University of Technology, 1993.
15. MacKenzie, J. J., and M. P. Walsh. *Driving Forces: Motor Vehicle Trends and Their Implications for Global Warming, Energy Strategies, and Transportation Planning.* World Resources Institute, Washington, D.C., 1990.
16. Cambridge Systematics, Inc. *Making the Land Use Transportation Air Quality Connection: Modeling Practices: Volume 1.* 1000 Friends of Oregon, Portland, 1991.
17. Dimitriou, H. T. *Urban Transport Planning: A Developmental Approach.* Routledge, New York, 1992.
18. Fernandez, J. E., and T. L. Freisz. Equilibrium Predictions in Transportation Market: The State of the Art. *Transportation Research B,* Vol. 17, 1983.
19. Buranasajja, S., T. Chongpeerapien, P. Kritporn, Resource Management Associates, and S. Sungsawan. *Energy and Environment: Choosing the Right Mix.* Thailand Development Research Institute, Bangkok, 1990, pp. 39–75.
20. Masud, J. *Assessment of Transportation Growth in Asia and Its Effects on Energy Use, the Environment, and Traffic Congestion: Case Study of Islamabad, Pakistan.* International Institute for Energy Conservation, Washington, D.C., June 1992.
21. Gunawan, W. *Assessment of Transportation Growth in Asia and Its Effects on Energy Use, the Environment, and Traffic Congestion: Case Study of Surabaya, Indonesia.* International Institute for Energy Conservation, Washington, D.C., July 1992.
22. Elangovan, T. *Assessment of Transportation Growth in Asia and Its Effects on Energy Use, the Environment, and Traffic Congestion: Case Study of Varanasi, India.* International Institute for Energy Conservation, Washington, D.C., Oct. 1992.
23. Metropolitan Environmental Improvement Program. Urban Air Quality Management in Asia (URBAIR). *Proc., Asia Technical Department,* World Bank, Washington, D.C., April 1994.
24. Darbéra, R. Use of Models by French Consultants for Urban Transport Planning in Developing Countries. In *Transportation Research Record 1167,* TRB, National Research Council, Washington D.C., 1988, pp. 41–45.
25. Lowry, I. S. *A Model of Metropolis.* Report RM-4935RC. Rand Corporation, Santa Monica, Calif., 1964.
26. Karash, K. H., and C. Schweiger. *Identification of Transportation Planning Data Requirements in Federal Legislation.* John A. Volpe National Transportation Center, Cambridge, Mass., 1994.
27. Johnston, R. A., and C. J. Rodier. *A Critique of Regional Travel Demand Models in California.* Institute of Transportation Studies, University of California, Davis, 1993.
28. Stopher, P. R. Deficiencies of Travel-Forecasting Methods Relative to Mobile Emissions. *Journal of Transportation Engineering,* Vol. 119, No. 5, 1993.
29. Johnston, R. A., and R. Ceerla. *A Comparison of Modeling Travel Demand and Emissions With and Without Assigned Travel Times Fed Back to Trip Distribution.* University of California Institute for Transportation Studies, Berkeley, 1994.
30. Fernández, E., and J. De Cea. *An Application of Equilibrium Modelling to Urban Transport Planning in Developing Countries: The Case of Santiago de Chile.* Department of Transport Engineering, Catholic University of Chile, Santiago (n.d.).
31. Replogle, M. *Non-Motorized Vehicles in Asian Cities.* Technical Paper 162. Asia Technical Department, World Bank, Washington, D.C., 1992.
32. Parsons, Brinckerhoff, Quade and Douglas, Inc.; Cambridge Systematics, Inc.; Calthorpe Associates. *The Pedestrian Environment: Volume 4A.* 1000 Friends of Oregon, Portland, 1993.
33. Kurunami, C., B. P. Winston, and P. A. Guitink. Nonmotorized Vehicles in Asian Cities: Issues and Policies. In *Transportation Research Record 1441,* TRB, National Research Council, Washington, D.C., 1994, pp. 61–70.
34. Austin, B., J. Fieber, and J. Heiken. Characteristics of MOBILE4 and EMFAC7E Models. Presented at the National Conference on Transportation Planning and Air Quality, ASCE, July 1991.
35. Poulicos, P. Integrating GIS Technology in Urban Transportation Planning and Modeling. In *Transportation Research Record 1305,* TRB, National Research Council, Washington, D.C, 1991, pp. 123–130.
36. Kanchit, P., S. Panich, S. Wangwongwatana, O. Paisamutpong, and N. Boonthewara. *Traffic Crisis and Air Pollution: A Case Study of Bangkok.* Thailand Environment Institute, Bangkok, 1994.
37. Wegener, M. Operational Urban Models: State of the Art. *Journal of the American Planning Association,* Vol. 60, No. 1, Winter 1994, pp. 17–28.
38. Martínez, F. *Towards the 5-Stage Land Use-Transport Model.* University of Chile, Santiago, 1992.
39. Gakenheimer, R., and M. D. Meyer. Urban Transport Corridor Planning. In *Transport Planning for Third World Cities* (H. Dimitriou, ed.), Routledge, New York, 1990.

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.

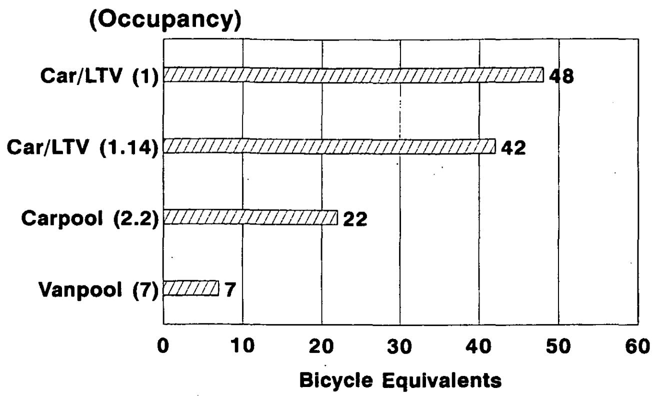

FIGURE 1 Material requirements, United States, 1989; bicycle = 30 kg/person (*1,2,5*).

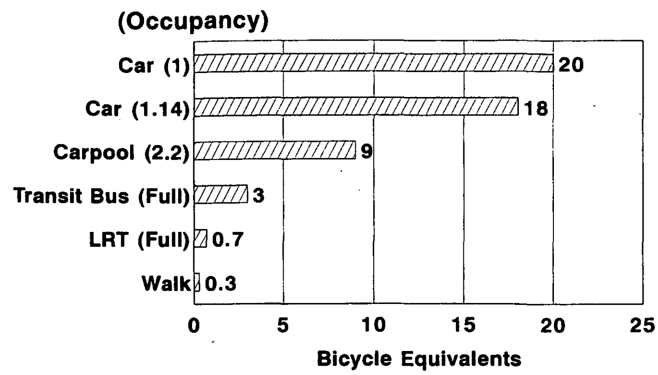

FIGURE 4 Road space requirements; bicycle = 3 m^2/person at 10 km/hr, speed = 40 km/hr for car or carpool, 30 km/hr for bus and light rail transit, and 5 km/hr for walking (*1,3,5*).

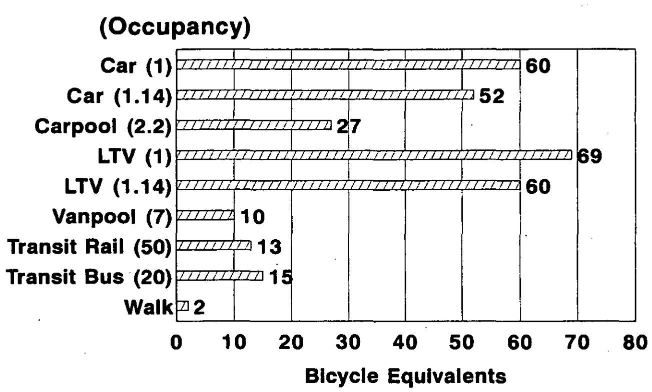

FIGURE 2 Energy use in operation, United States, 1989; bicycle = 92 kJ/person-km, fuel economy = 15.7 L/100 km for car or carpool and 18.1 L/100 km for LTV or vanpool while commuting (*1,5*).

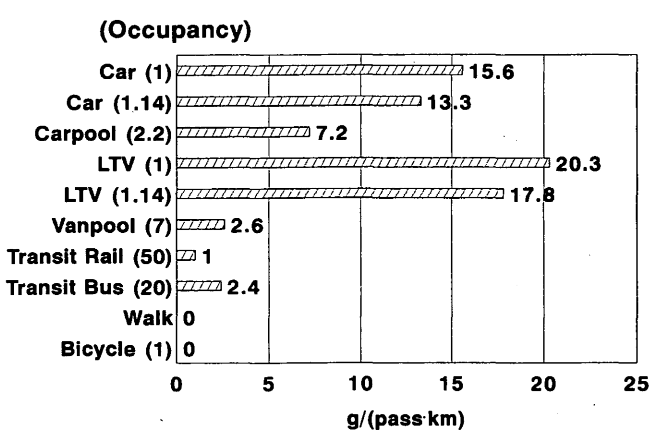

FIGURE 3 Total regulated emissions, United States, 1989 (fuel economy assumptions as in Figure 2) (*1,5*).

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

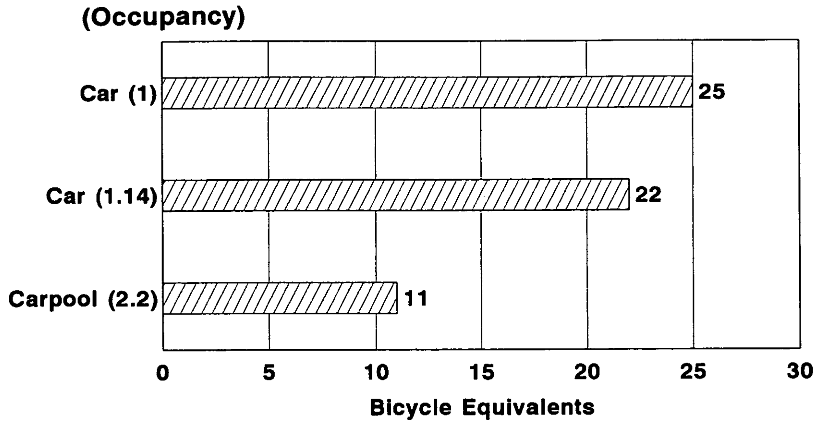

FIGURE 5 Land requirements for parking, United States, 1989; bicycle = 1.1 m²/person (*1,5*).

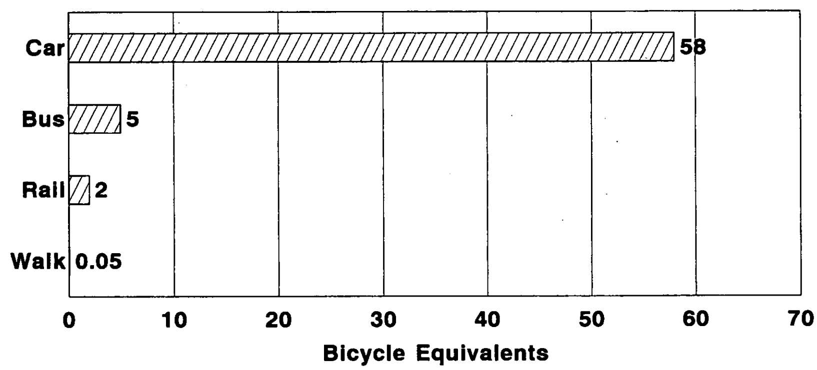

FIGURE 6 Accident risk, Germany, 1989; bicycle = 0.2 hr life lost/person-km (*4*)

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

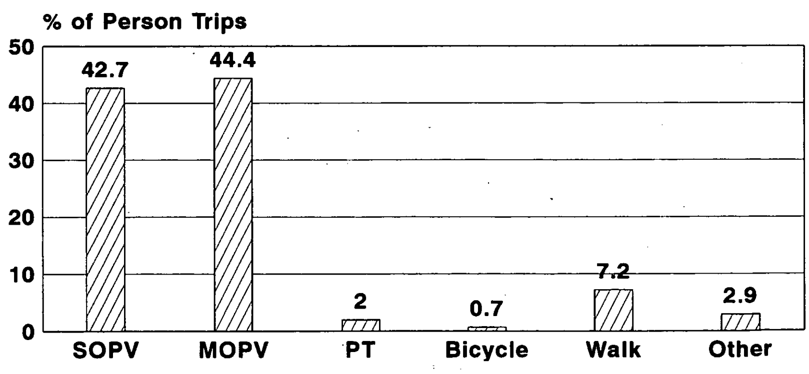

FIGURE 7 Mode choice, United States, 1990 (PT = public transit, SOPV and MOPV = single- and multiple-occupant vehicle) (*5*).

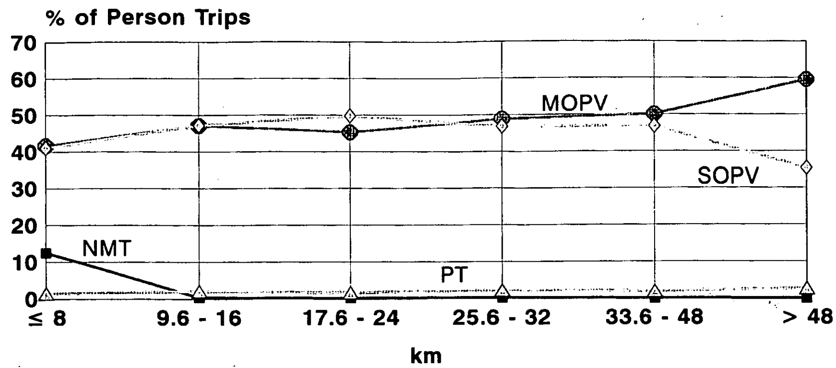

FIGURE 8 Distance and mode choice, United States, 1990; *X*-axis not to scale (*5*).

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

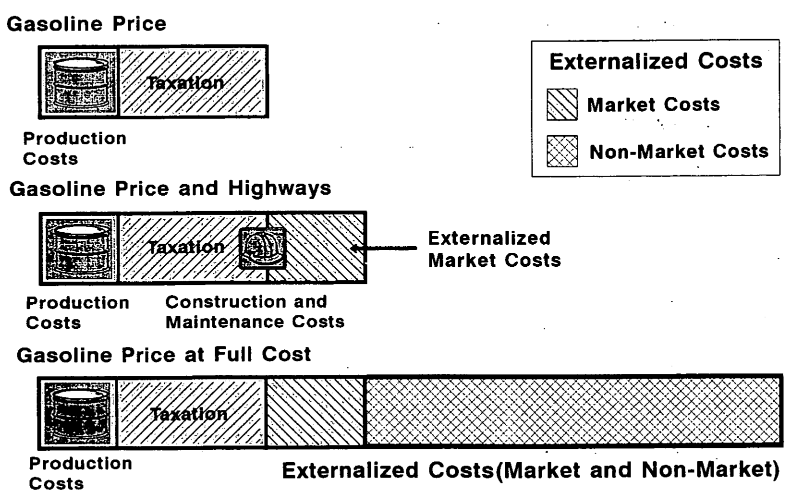

FIGURE 9 Externalization of costs (*3*).

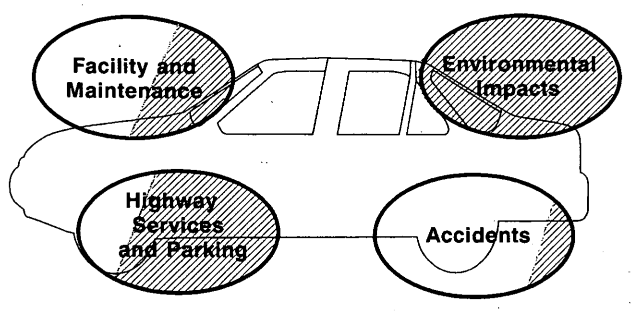

FIGURE 10 Uncovered transportation costs (shaded areas) (*9*).

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

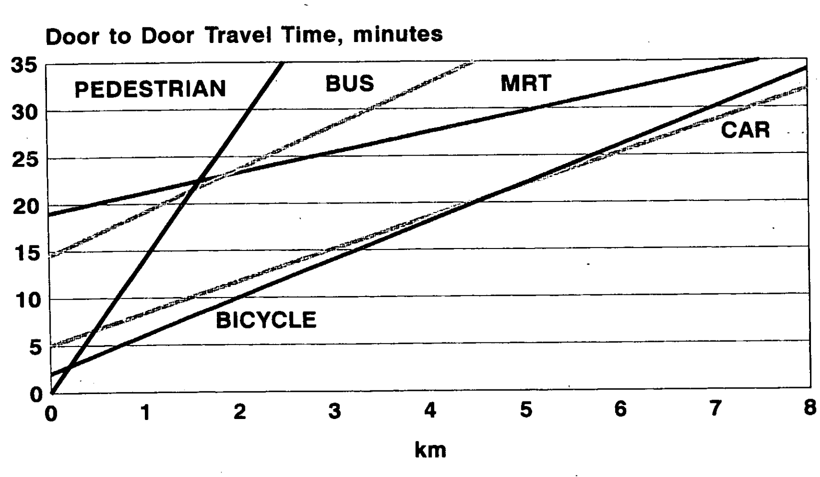

FIGURE 11 Urban travel times, Europe, 1988 (*3*).

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:

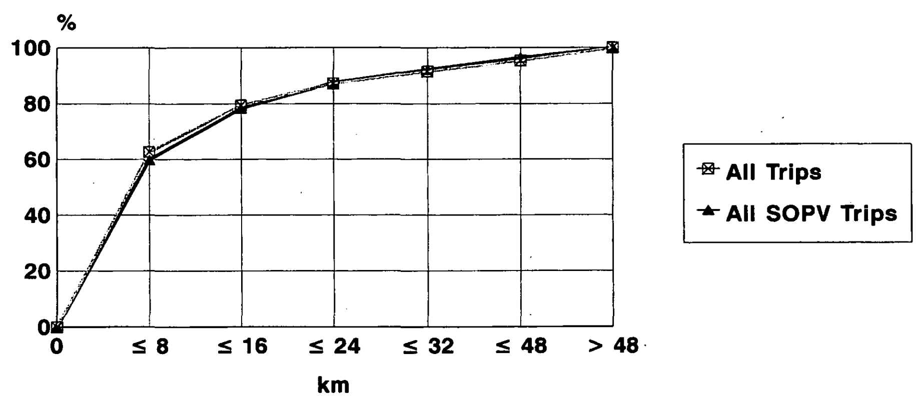

FIGURE 12 Cumulative distribution of person trips by distance, United States, 1990 (*X*-axis not to scale) (*5*).

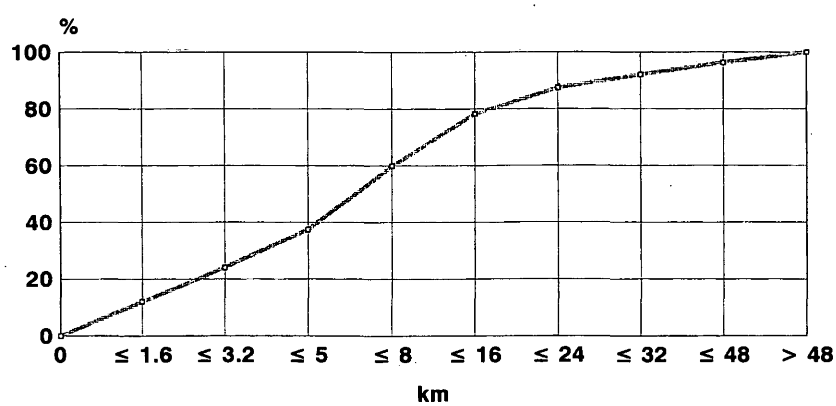

FIGURE 13 Cumulative distribution of SOPV person trips by distance, United States, 1990 (*X*-axis not to scale) (*5*).

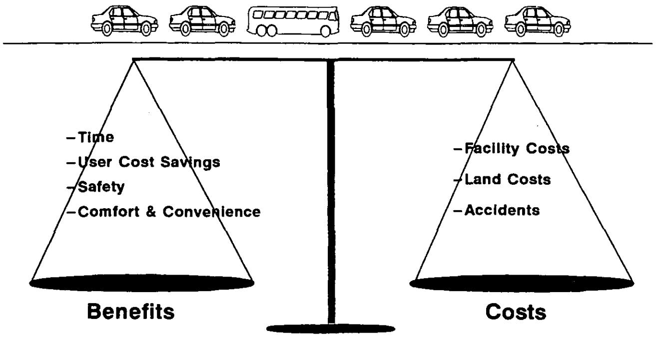

FIGURE 14 Current investment decision matrix.

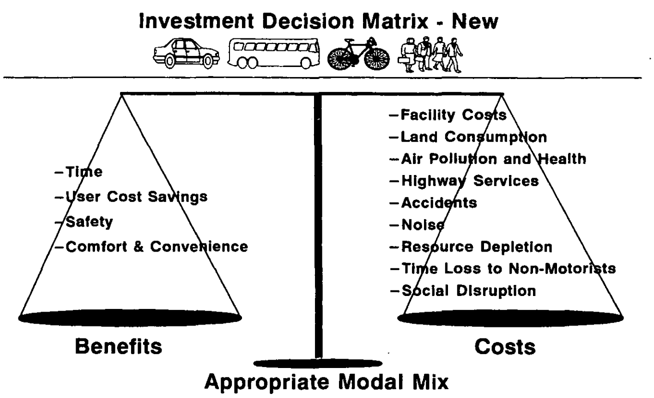

FIGURE 15 New investment decision matrix.

- 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).

Pedestrian Flow Characteristics in Hong Kong

WILLIAM H. K. LAM, JOHN F. MORRALL, AND HERBERT HO

The findings of a study of pedestrian flow characteristics in Hong Kong are described. The objective was to collect walking distance, speed, flow, and density data on indoor and outdoor walkways, signalized crosswalks, light rail transit crosswalks, and stairways. The data collected were used to develop speed-flow-density relationships for each type of pedestrian link. In addition, pedestrian characteristics from various international cities are compared. The data collected and the relationships established could be used as the basis for the development of pedestrian design standards and simulation models for Hong Kong.

Hong Kong, a city of more than 6 million people and a land area of only 1060 km^2, is one of the most densely populated cities in the world, with residential densities of approximately 39,000 persons per square kilometer of developed land. Although pedestrian facilities have always been used intensively, the rapid development of Hong Kong, as well as traffic generators such as the Mass Transit Railway (MTR) and Kowloon-Canton Railway (KCR) stations and great concentrations of people focused in high-rise office and residential buildings, has put tremendous pressure on the pedestrian system. In recognition of the importance of the pedestrian mode, the Hong Kong government has developed a pedestrian action plan as documented in its *Transportation Planning and Design Manual* (*1*), and a pedestrian simulation model (2) is being used to carry out congestion and safety assessments of congested pedestrian networks in an objective and consistent fashion.

INTRODUCTION

High-rise buildings and high occupancy rates of buildings in Hong Kong result in tremendous concentrations of people and a great deal of conflict between the needs of pedestrians and vehicles, imposing noise and air pollution and threatening the lives of the pedestrians. Figure 1 illustrates the pedestrian movements in the urban areas of Hong Kong. Almost half of road accident casualties are pedestrians, and police estimate that pedestrian negligence causes 26 percent of road accidents. To maintain and improve mobility, the Hong Kong government is planning pedestrian facilities as an integral part of new transportation systems in developing areas. There are now more than 1,000 such facilities, which include footbridges, subways, zebra crossings, and signal-controlled pedestrian crossings. The government has selected possible sites for additional grade-separated footbridges and subways and is continuing to provide additional crossings at grade. Pedestrian access to public transportation interchanges such as the MTR and KCR stations, which is particularly important, will be obtained by elevated walkways or tunnels connecting to the nearby bus terminus.

The lack of land in the old, established and highly developed urban areas limits the construction of grade-separated facilities (such as pedestrian footbridges and subways). Experiments in providing pedestrian-only streets have not proved very popular with government, although the scale of their provision has been small because of the difficulties of finding other routes for the displaced traffic. Furthermore, any road or building works take place adjacent

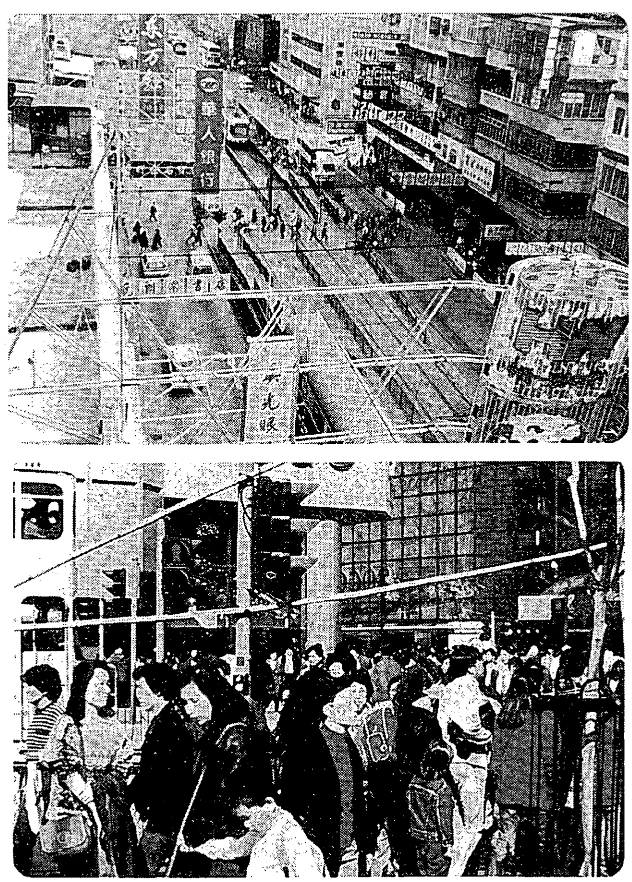

FIGURE 1 Pedestrian movements in Hong Kong.

W. H. K. Lam, Department of Civil and Structural Engineering, Hong Kong Polytechnic University, Hong Kong. J. F. Morrall, Department of Civil Engineering, University of Calgary, 2500 University Drive, NW, Calgary, Alberta, Canada, T2N 1N4. H. Ho, Kowloon-Canton Railway Corporation, KCR House, Shatin, Hong Kong.

TABLE 1 Data Collection Sites and Their Characteristics

STAIRCASES						
FACILITY	LOCATION		RISER HEIGHT (mm)	TREAD WIDTH (mm)	ANGLE (deg)	
MTR	Tsim Sha Tsui & Wan Chai Stations	Up :	158	292	28.4	
		Down :	158	292	28.4	
KCR	Kowloon Station	Up :	152	285	28.1	
		Down :	148	294	26.7	
WALKWAYS						
FACILITY	LOCATION	WIDTH (m)	WALKING DISTANCE MEASURED (m)			
Outdoor	Haiphong Road	2.0	7.5			
	Mody Square	3.5	7.5			
Indoor	Nan Fung	6.0	5.0			
	Tsuen Wan	8.0	5.0			
	KCR Kowloon	10.0	5.0			
CROSSWALKS	LOCATION		CURB-TO-CURB DISTANCE (m)	SIGNAL TIMING CYCLE LENGTH	PHASING	AVERAGE DAILY TRAFFIC (VEHICLES)
Signalized	Yim Po Fong St	5.0	20.5	90 sec.	4	29,710
	Hennessy Road	8.0	17.5	78 sec.	2	21,730
	Cheung Yip Street	3.5	6.7	60 sec.	2	9,920
LRT Signalized	Tai Tong Station	6.5	20.5	72 sec.	2	21,480

to footpaths in the urban area, so the pedestrian loses pavement space and often is forced to walk on the roads. It is clear that the difficulties of pedestrian planning in Hong Kong's limited area are considerable.

For purposes of pedestrian planning and design, pedestrian characteristics in Hong Kong should be well understood. The walking speed of pedestrians is of prime importance in a study of the functioning and design of pedestrian facilities, as it is associated closely with the ability of a walkway to maintain a desired flow of pedestrians along its length. Certain primary factors relating to the pedestrian and his or her environment will have an effect on walking speeds. The incidence of a speed-flow relationship leads one from the consideration of "primary" factors affecting walking speeds to the "secondary" factors, which revolve principally around the effect of flow rate and density.

For this paper, walking speeds were monitored on six pedestrian facilities in Hong Kong. The times and locations were chosen to minimize variation due to physical factors. An outline of the data collection surveys is presented, followed by a discussion of the survey results on walking distances, walking speeds, and maximum observed flow rates. A range of speed-density-flow models have been developed for each facility type. Finally, conclusions are drawn and recommendation is given for further study.

DATA COLLECTION

Data collection surveys were undertaken during peak and off-peak periods in November and December 1991. Six categories of pedestrian facilities were used for data collection; they are presented in Table 1 with their locations and location characteristics. In total, data were collected at 12 sites for the six categories of pedestrian facilities.

Walking speed and pedestrian flow data were collected using a video camera and on-site manual counts. Walking distance information was gathered at three sites using a questionnaire with an area map on which interviewees were asked to trace their actual walking paths. Walking distances were scaled from the survey maps.

SURVEY RESULTS

Walking Distances

Mean walking distances for light rail transit (LRT), MTR, and KCR at three selected sites are given in Table 2 along with the relevant statistics. It was found that the KCR riders tend to walk farther than LRT and MTR passengers, as KCR mainly provides service for subregional travel between new towns and urban areas with larger station spacings. Although walking distances are a function of density and the spatial distribution of generators and attractors, the LRT and MTR walking distances in Hong Kong are not dissimilar to those observed in Canada. For example, in the Calgary central business district, the mean walking distance to and from LRT is 278 m, whereas access and egress to regular and express bus service before the introduction of LRT was 273 and 311 m, respectively (*3*).

Walking Speeds

Walking speeds were measured on six pedestrian facilities as given in Table 3. Walking speeds are considerably higher on outdoor

TABLE 2 Pedestrian Walking Distances by Mode

MODE	MEAN WALKING DISTANCE (m)	STD. DEVIATION (m)	RANGE		SAMPLE SIZE
			LOW (m)	HIGH (m)	
LRT	262	110	63	663	192
MTR	280	107	97	759	156
KCR	493	260	125	1025	260

walkways than on indoor walkways. The walking speed indoors is slower because there are more distractions and congestion than there are outdoors. Walking speeds were slightly higher for men than women, 75.0 versus 70.2 m/min, respectively. Walking speeds at signalized crosswalks are higher during the red phase than the green, because pedestrians are hurrying to finishing crossing to avoid conflicts with vehicular traffic. Walking speeds observed at the LRT crosswalk are higher than they are at the signalized crosswalk. Walking speeds on stairways are higher descending than ascending, as to be expected. The lower ascending walking speeds on the MTR stairway are due to the higher riser on the MTR stairway. A comparison of walking speeds for various cities is presented in Table 4. The mean walking speed of 72 m/min for Hong Kong is typical for other Asian cities such as Bangkok (*4*), Singapore (*5*), and Colombo (*6*). A comparison of walking speeds on stairways is also given in Table 4. For similar riser heights, ascending and descending walking speeds are higher for Hong Kong than Bangkok. Hong Kong ascending and descending walking speeds for the MTR are similar to those observed under free-flow conditions in passageways in the London Underground, as reported by Daly et al. (*7*). In addition, Table 4 provides a comparison of mean walking speeds at signalized crossings in Bangkok, Hong Kong, and Calgary.

Maximum Observed Flow Rates

Table 5 gives the maximum observed flow rates by facility type. The maximum flow rate reported for Singapore (*5*) is 89 pedestrians (ped)/m/min, which is comparable to 90 ped/m/min for Hong Kong at LRT crosswalks.

SPEED-DENSITY-FLOW MODELS

A range of speed-density-flow models were developed for each facility type. Table 6 summarizes the models developed for each pedestrian facility. Figure 2 displays the variations of walking speed and pedestrian flow data for indoor and outdoor walkways, and Figure 3 illustrates their fitted relationships by speed-density, flow-density, flow-speed, and flow-space. The models developed for each facility are discussed in turn.

Indoor Walkways

The Greenshields model was adopted for indoor walkways. As shown in Table 6 and Figure 3, the relationships are as follows:

- The speed-density relationship is linear.

$$\mu = 77.4 - 21.5\,k \qquad (1)$$

where μ equals walking speed, in meters per minute, and k is density, in pedestrians per square meter.

- The flow-density relationship is parabolic.

TABLE 3 Pedestrian Walking Speeds by Facility Type

FACILITY	MEAN WALKING SPEED (m/min)	STD. DEVIATION (m/min)	RANGE		SAMPLE SIZE
			LOW (m/min)	HIGH (m/min)	
INDOOR WALKWAY	49.8	22.2	10.2	75.2	908
OUTDOOR WALKWAY	71.6	15.6	9.0	88.8	395
SIGNALIZED CROSSWALK					
GREEN	76.2	17.0	21.6	216.0	916
RED	90.0	27.0	28.2	265.8	1147
LRT CROSSWALK					
SIGNALIZED CROSSWALK	98.4	10.2	19.8	210.0	91
RAMP (1:12)	39.6	18.6	15.6	70.8	26
MTR STAIRWAY					
ASCENDING	35.4	13.9	10.1	56.6	143
DESCENDING	40.8	16.3	10.5	79.8	124
KCR STAIRWAY					
ASCENDING	38.7	16.2	14.4	71.6	77
DESCENDING	48.2	19.6	15.6	82.8	80

TABLE 4 International Comparison of Walking Speeds on Various Pedestrian Facilities

Facility	CITY	MEAN WALKING SPEED (m/min)		REMARKS
Walkways	RIYADH (*6*)	65		
	HONG KONG	72		
	BANGKOK (*4*)	73		
	SINGAPORE (*5*)	74		
	COLOMBO (*6*)	75		
	CALGARY (*6*)	84		
	LONDON (*7*)	88		
Stairways		Ascending	Descending	Riser Height (mm)
	BANGKOK (*4*)	27.9	35.0	200
		29.8	35.9	150
		32.3	36.6	140
		33.8	37.2	130
	HONG KONG	35.4	40.8	158
		38.7	48.2	148
	LONDON (*7*)	35.4	40.2	FREE-FLOW
		21.6	33.6	CAPACITY
Signalized Crossings	BANGKOK (*4*)	76.5		
	HONG KONG	76.2		GREEN SIGNAL
		90.0		RED SIGNAL
		98.4		LRT CROSSWALK
		80.2		OBSERVED AVERAGE
	CALGARY	72.0		PLANNING STANDARD
		60.0		ELDERLY PEDESTRIANS

$$q = 77.4\,k - 21.5\,k^2 \quad (2)$$

where q is pedestrian flow, in pedestrians per meter per minute.

- The flow-speed relationship is also parabolic.

$$q = 3.6\,\mu - 0.0465\,\mu^2 \quad (3)$$

- The flow-space relationship is inverse parabolic.

$$q = 77.4/M - 21.5/M^2 \quad (4)$$

where M is the area module, in square meters per pedestrian.

The relationships for indoor walkways are compared with results obtained for Singapore in Table 7 (*5*). It is noted that the Greenshields model developed for Hong Kong indoor walkways compares favorably with speed-flow-density models developed for Singapore.

Outdoor Walkways

As shown in Table 6, the Underwood model fit the best for outdoor walkways resulting in an $R^2 = .91$. Figure 3 shows the relationships of speed-density, flow-density, flow-speed, and flow-space for outdoor walkways.

Crosswalks

For signalized crosswalks the Bell model was the best-fitting model, whereas the Underwood model was the best fit for the LRT crosswalk data.

Stairways

As indicated in Table 6, a range of models was developed for stairways for both ascending and descending flows. A comparison of

TABLE 5 Maximum Observed Flow Rates by Facility Type

FACILITY	MAX FLOW RATE (ped/m/min)
INDOOR WALKWAY	68
OUTDOOR WALKWAY	71
SIGNALIZED CROSSWALK	60
LRT CROSSWALK	90
MTR STAIRWAY	
ASCENDING	71
DESCENDING	77
KCR STAIRWAY	
ASCENDING	66
DESENDING	73

TABLE 6 Speed-Density-Flow Models for Pedestrian Facilities

FACILITY	MODEL ADOPTED	RELATIONSHIP	MODEL EQUATION
INDOOR WALKWAY	GREENSHIELDS $R^2 = 0.82^{(1)}$	SPEED-DENSITY FLOW-DENSITY FLOW-SPEED FLOW-SPACE	$\mu = 77.4 - 21.5\ k$ $q = 77.4\ k - 21.5\ k^2$ $q = 3.6\ \mu - 0.0465\ \mu^2$ $q = 77.4/M - 21.5/M^2$
OUTDOOR WALKWAY	UNDERWOOD $R^2 = 0.91$	SPEED-DENSITY FLOW-DENSITY FLOW-SPEED FLOW-SPACE	$\mu = e^{(4.47 - 0.572\ k)}$ $\ell nq = 4.47 + \ell nk - 0.57\ k$ $q = 7.8\ \mu - 1.75\ (\mu \ell n\mu)$ $\ell nq = 4.47 + \ell n(1/M) - 0.57/M$
SIGNALIZED CROSS WALK	BELL $R^2 = 0.81$	SPEED-DENSITY FLOW-DENSITY FLOW-SPEED FLOW-SPACE	$\mu = 85e^{-(0.347k^2)}$ $q = 85ke^{-(0.347k^2)}$ $q^2 = -2.9\mu^2 \ell n(\mu/85)$ $q = (85/M)e^{-(0.347/M^2)}$
LRT CROSS WALK	UNDERWOOD $R^2 = 0.75$	SPEED-DENSITY FLOW-DENSITY FLOW-SPEED FLOW-SPACE	$\mu = 100\ e^{-(0.5k)}$ $q = 100\ k\ e^{-(0.5k)}$ $q = -2\ \mu \ell n(\mu/100)$ $q = (100/M)\ e^{-(0.5/M)}$
MTR STAIRWAY (ASCENDING)	UNDERWOOD $R^2 = 0.67$	SPEED-DENSITY FLOW-DENSITY FLOW-SPEED FLOW-SPACE	$\mu = 53.3 - 9.9\ k$ $q = 53.3\ k - 9.9\ k^2$ $q = 5.4\ \mu - 0.1\ \mu^2$ $q = 53.3/M - 9.9/M^2$
MTR STAIRWAY (DESCENDING)	UNDERWOOD $R^2 = 0.46$	SPEED-DENSITY FLOW-DENSITY FLOW-SPEED FLOW-SPACE	$\mu = 65.4\ e^{-(0.41\ k)}$ $q = 65.4\ k\ e^{-(0.41\ k)}$ $q = -3.42\mu \ell n(\mu/65.4)$ $q = (65.4/M)\ e^{-(0.414\ M)}$
KCR STAIRWAY (ASCENDING)	BELL $R^2 = 0.84$	SPEED-DENSITY FLOW-DENSITY FLOW-SPEED FLOW-SPACE	$\mu = e^{(3.89 - 0.2k^2)}$ $\ell nq = 3.89 - \ell nk - k$ $q^2 = \mu^2/0.22(3.89 - \ell n\mu)$ $\ell nq = 3.89 + \ell(1/M) - 0.22/M^2$
KCR STAIRWAY (DESCENDING)	UNDERWOOD $R^2 = 0.86$	SPEED-DENSITY FLOW-DENSITY FLOW-SPEED FLOW-SPACE	$\mu = e^{(4.6 - k)}$ $\ell nq = 4.6 + \ell nk - k$ $q = -2\mu\ (\ell n\mu - 4.6)$ $\ell nq = 4.6 + \ell n(1/M) - 1/M$

Note: (1) R^2 is the coefficient of determination which is a measure to reflect the accuracy of the model equation adopted for the relationship between speed and density.

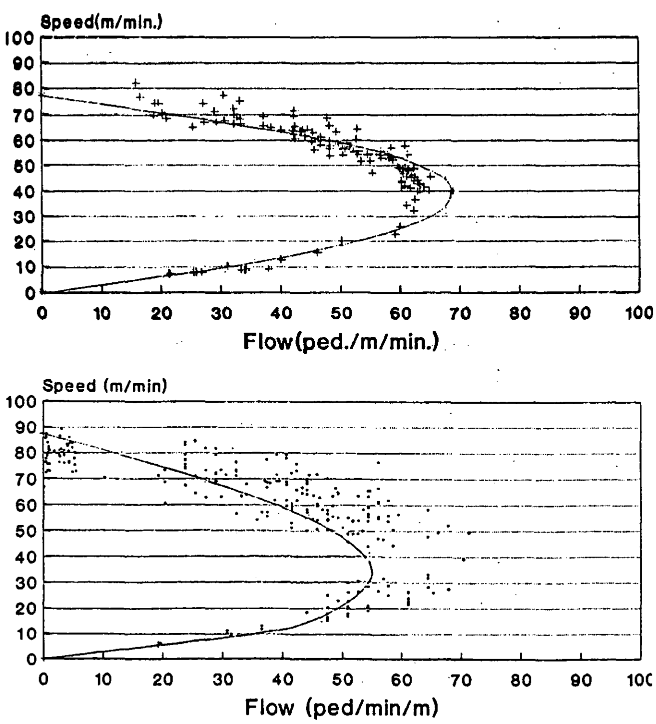

FIGURE 2 Pedestrian speed and flow data for indoor (*top*) and outdoor (*bottom*) walkways.

capacity and speed at capacity for stairways on the MTR, KCR, and London Underground is presented in Table 8. For both ascending and descending stairways, the MTR and the KCR data show slightly higher speeds but with comparatively much higher capacity than the London Underground (*7*). The higher capacities can be partially explained by the smaller physique of Oriental people. In addition, as observed by Tanaboriboon et al., Asians "tend to require less space and are more tolerant to invasion of this space" (*5*). Finally, the higher capacities observed on the MTR are also attributed to the predominant unidirectional flow on MTR stairways.

CONCLUSIONS

It was found that mean walking distances for LRT and MTR are smaller than the KCR, as the LRT and the MTR mainly serve urban areas with shorter station spacings. Pedestrian characteristics in Hong Kong show that the population tends to walk slower than pedestrians in North America, a finding that has been observed by other researchers who have compared walking speeds in Asian and North American cities. The speed-density-flow models developed for Hong Kong are similar to those developed for Singapore for similar facilities. The fact that no single model fits all pedestrian facilities indicates that more data collection is required for a larger range of flow conditions.

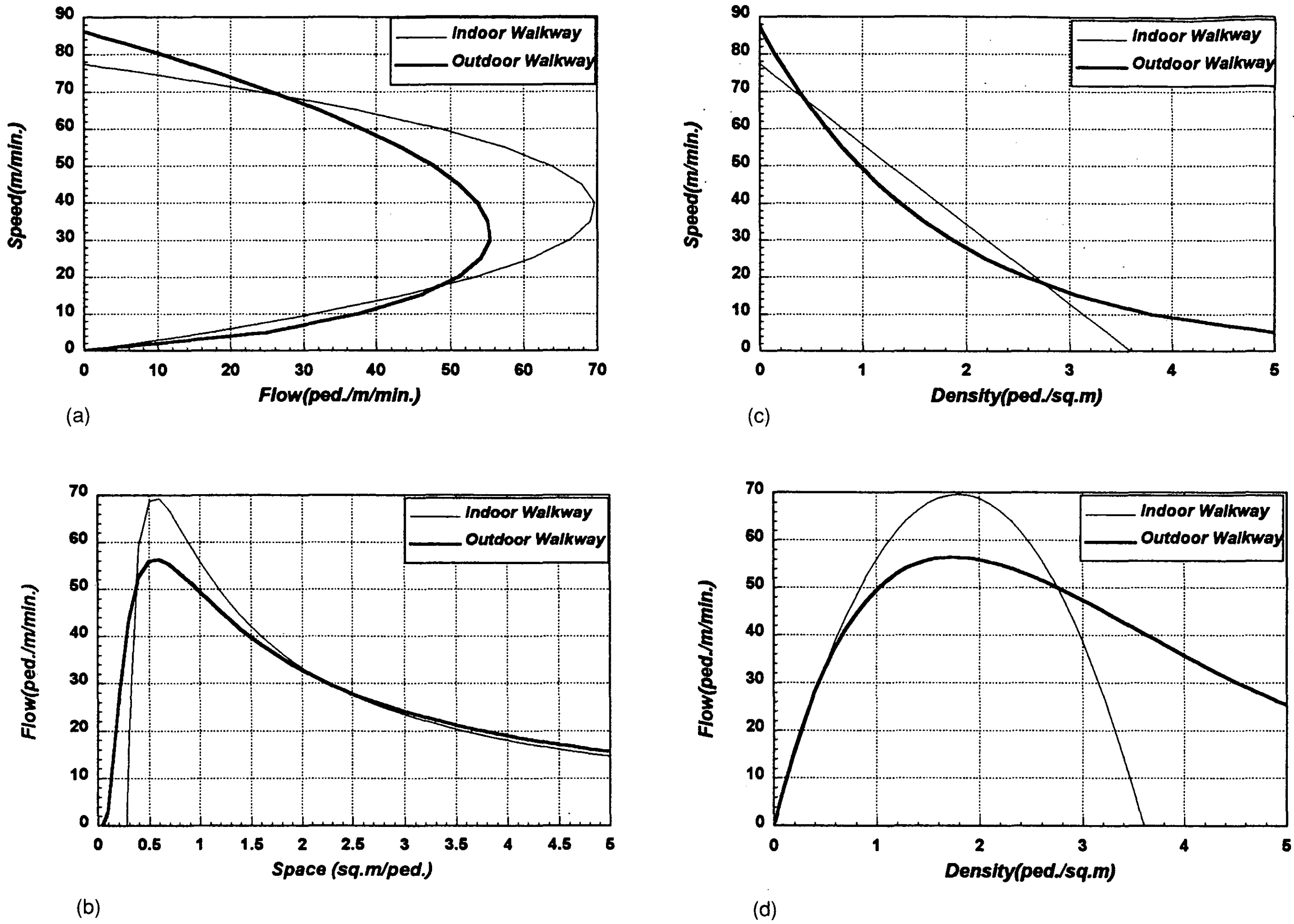

FIGURE 3 Speed versus flow (*a*), flow versus space (*b*), speed versus density (*c*), and flow versus density (*d*) for indoor and outdoor walkways.

TABLE 7 Comparison of Speed-Flow-Density Models for Singapore (*5*) and Hong Kong (Indoor Walkway)

RELATIONSHIP	HONG KONG	SINGAPORE
SPEED-DENSITY	$\mu = 77.4 - 21.5\ k$	$\mu = 73.9 - 15.3\ k$
FLOW-DENSITY	$q = 77.4\ k - 21.5\ k^2$	$q = 73.9k - 15.3\ k^2$
FLOW-SPEED	$q = 3.6\mu - 0.0465\mu^2$	$q = 4.8\mu - 0.065\mu^2$
FLOW-SPACE	$q = 77.4/M - 21.5/M^2$	$q = 73.9/M - 15.3/M^2$

TABLE 8 Comparison of Capacity and Speed at Capacity for London Underground (*7*), Hong Kong MTR, and KCR

FACILITY COMPARISON		CAPACITY (ped/m/min)	SPEED AT CAPACITY (m/min)
STAIRWAYS ASCENDING	LONDON UNDERGROUND (7)	62	21.6
	HONG KONG MTR	71	25.2
	HONG KONG KCR	66	26.0
STAIRWAYS DESCENDING	LONDON UNDERGROUND (7)	68	33.6
	HONG KONG MTR	77	34.8
	HONG KONG KCR	73	38.0

REFERENCES

1. *Transport Planning and Design Manual*, Vol. 6. Transport Department, Hong Kong Government, 1990, Chapter 10.
2. *Model for Pedestrian Movement Literature Review.* Data Record 393. Traffic and Transport Survey Division, Transport Department, Hong Kong Government, 1985.
3. Lam, W., and J. F. Morrall. Bus Passenger Walking Distances and Waiting Times: A Summer-Winter Comparison. *Transportation Quarterly,* Vol. 36, No. 3, July 1982, pp. 407–421.
4. Tanaboriboon, Y., and J. A. Guyano. Analysis of Pedestrian Movements in Bangkok. In *Transportation Research Record 1294,* TRB, National Research Council, Washington, D.C., 1991, pp. 52–56.
5. Tanaboriboon, Y., S. S. Hwa, and C. H. Chor. Pedestrian Characteristics Study in Singapore. *Journal of Transportation Engineering,* ASCE, Vol. 112, No. 3, May 1986, pp. 229–235.
6. Morrall, J. F., L. L. Ratnayake, and P. N. Senerviratne. Comparison of Central Business District Pedestrian Characteristics in Canada and Sri Lanka. In *Transportation Research Record 1294,* TRB, National Research Council, Washington, D.C., 1991, pp. 57–61.
7. Daly, P. N., F. McGrath, and T. J. Annesley. Pedestrian Speed/Flow Relationships for Underground Stations. *Traffic Engineering and Control,* Vol. 32, No. 2, Feb. 1991, pp. 75–77.

Walking Speeds of Elderly Pedestrians at Crosswalks

ANN COFFIN AND JOHN MORRALL

Elderly pedestrians are an increasing part of the North American population. Their growing numbers raise the question of the suitability of the assumed normal walking speed used to determine the pedestrian clearance interval. Findings of a study that measured the walking speed of elderly pedestrians at various types of crosswalks are reported. Walking speeds of pedestrians over the age of 60 were recorded at seven locations: six field locations and a seniors club. The field locations included pedestrian actuated midblock crosswalks, crosswalks at signalized intersections, and crosswalks at unsignalized intersections. The field studies included a short interview following the recording of curb-to-curb walking time. Study participants at the seniors club were asked to walk at their normal speed and then their fast speed down a corridor, then they completed a short questionnaire. One of the main findings was that people over age 60 are not a homogeneous group; they possess a range of walking speeds and mobility levels. Elderly pedestrians reported several problems associated with crosswalks, including difficulty in negotiating curbs and judging the speed of oncoming vehicles, discourteous drivers, turning vehicles and confusion with the Walk, flashing Don't Walk, and Don't Walk pedestrian signal indications. At signalized intersections near seniors and nursing homes, where most pedestrians are elderly, a design walking speed of 1.0 m/sec is satisfactory. Suggested design walking speeds of elderly pedestrians at midblock crosswalks and signalized intersections are 1.0 and 1.2 m/sec, respectively.

Walking speeds of pedestrians are used to determine the pedestrian clearance interval of pedestrian signals or, in locations where there are no pedestrian signals, to obtain the minimum green time for concurrent traffic.

In Canada and the United States, pedestrian signals consist of a Walk interval, then a flashing Don't Walk interval, followed by a solid Don't Walk interval. The *Manual on Uniform Traffic Control Devices* (MUTCD) recommends the following for pedestrian intervals and phases (*1*):

1. "The Walk interval should be at least 4 to 7 seconds in length," and
2. The flashing Don't Walk interval (or pedestrian clearance interval)" should be sufficient to allow a pedestrian crossing in the crosswalk to leave the curb and travel to the center of the farthest lane before opposing vehicles receive a green indication." The "normal walking speed is assumed to be 4 feet per second" (1.2 m/sec).

Elderly pedestrians are an increasing part of the North American population. Their growing numbers raise the question of the suitability of the assumed normal walking speed used to determine the pedestrian clearance interval. The purpose of this paper is to report the findings of a study that measured the walking speed of elderly pedestrians at various types of crosswalks (*2*).

A. Coffin, Reid Crowther and Partners, Suite 300, Atrium VII Midpark Way, S.E., Calgary, Alberta, T2X 1P1 Canada. J. Morrall, Department of Civil Engineering, University of Calgary, 2500 University Drive, N.W., Calgary, Alberta, T2N 1N4 Canada.

CURRENT PRACTICE

A letter survey was undertaken by the authors to determine the crossing speeds used by municipalities in North America. Twenty-six municipalities responded to the survey. Eighty-five percent of the respondents replied that they used a walking speed of 1.2 m/sec to calculate pedestrian crossing time at intersections. Almost all of the surveyed jurisdictions replied that they usually made some sort of adjustment to the pedestrian signal timings for the benefit of elderly pedestrians. The most popular walking speeds used for signal timing for the elderly were between 1.0 and 1.1 m/sec.

The lack of a uniformly accepted walking speed for elderly pedestrians is the result of ambiguity in the traffic control manuals. The MUTCD (*1*) states that 4.0 ft/sec (1.2 m/s) is the "assumed" normal walking speed. The *Uniform Traffic Control Devices for Canada* (UTCD) manual does not recommend a walking speed but reports that normal walking speeds vary from 1.1 to 1.4 m/s (*3*). The *ITE Manual of Traffic Signal Design* (*4*) mentions the "normal" speed of 4.0 ft/sec (1.2 m/s) but also says that research has shown the 85th-percentile walking speed to be 3.5 ft/s (1.1 m/s). None of the Canadian (*3*) or American (*1,4,5*) manuals recommends a walking speed for elderly pedestrians; instead, each suggests the use of engineering judgment.

In general, there appear to be two purposes for researching walking speeds: to augment physiological or medical discussions and to measure how people operate in the transportation system.

Most of the reviewed studies demonstrate some connection between age and walking speed. In their study, Imms and Edholm (*6*) suggested that age is a masking variable and that walking speed actually decreases with decreasing mobility level. In their laboratory study, Cunningham et al. (*7*) showed that fitness level is a better indicator of walking speed than age.

Actual walking speeds for Imms and Edholm's study ranged from 0.399 m/s for housebound subjects to 0.931 m/s for subjects with unlimited outdoor activity. Testing was conducted indoors and may have influenced walking speeds. The remaining studies were conducted outdoors and demonstrate higher walking speeds.

Using time-lapse photography and interviews, Wilson and Grayson (*8*) measured the walking speeds of more than 11,000 people over age 15 crossing at a midblock crosswalk. By counting the number of nearside and farside glances made by subjects as they crossed the street, the study indicated a link between increased level of caution and decreased walking speeds. Furthermore, subjects over age 55 appeared to be more cautious than their younger counterparts. The average walking speeds for male and female subjects over the age of 60 was 1.10 and 1.15 m/s, respectively. However, the researchers concluded that age-related differences in road crossing behavior are small and that the elderly should not be considered as a separate group within the population.

Molen et al. (*9*) suggest that trip purpose, location, and the presence of other people might influence the walking speed of pedestrians of all ages. Unfortunately, the researchers could not draw any conclusions regarding walking speed and age.

In an unpublished Japanese study, Shimizu et al. determined the differences between elderly and nonelderly users of a crosswalk, underpass, and an overpass. They reported that the difference between the crossing speeds of elderly and nonelderly users of the signalized crosswalk was smaller than at either of the other two facilities. The researchers concluded that the time limitation at a signalized crosswalk might have caused elderly users to walk faster than their normal speed. The crossing speeds of the elderly and nonelderly users were 1.23 and 1.41 m/s, respectively.

Dahlstedt (*10*) also found that time limitations influenced walking speed; his subjects (age 70 and over) appeared to increase their walking speeds by 0.1 m/s when crossing at a signalized crosswalk versus walking on a paved lot. Dahlstedt also found that walking speeds decreased with age but this relationship was not closely correlated. However, Dahlstedt's results indicate that variability in walking speed decreased with age. The average "fast" walking speeds of his female and male subjects on a paved lot were 1.14 and 1.33 m/s, respectively.

In summary, the literature indicates that age or age-related factors do influence walking speed. As well, factors such as location and crossing time limitations may also influence the walking speeds of elderly pedestrians.

STUDY METHOD

The walking speeds of pedestrians over 60 were recorded at seven locations: six were crosswalks located in Calgary and the seventh was a hallway in a seniors club in Calgary. In all six field locations, no selection procedure was used except that pedestrians had to be older than 60. Furthermore, the subjects were unaware that they were being timed. The purpose of the field study was to examine the influence of environmental factors such as location and crosswalk type on walking speed. The purpose of the indoor study was to understand the influence of gender and functional classification on walking speed.

All of the study participants were given a questionnaire to complete. The questionnaire enabled walking speeds to be matched with information such as age, gender, location, time, and a series of behavioral questions. A pilot study was conducted at the Golden Age Club in Calgary before walking speed measurements made at the Kerby Center, a Calgary seniors club.

INDOOR DATA COLLECTION

Walking speeds of 184 people over age 60 were measured under ideal conditions at the Kerby Center. These participants came from a variety of backgrounds; many were in good physical and mental condition. Some of the participants eagerly took part in the study; others were at first hesitant and uncertain but then participated after observing other participants. The short duration of the timings and the interview—less than 3 min—was also an important factor in their decision to participate.

Participants were asked to walk at their normal speed and then at their fast speed 13 m down a flat, well-lit corridor with a minimum of environmental influences. After the timings, each participant completed a short questionnaire. Their timings, as well as height (including footwear), gender, and age were recorded. Participants were then asked if they had any problems crossing streets in Calgary. After the participant departed, the researcher classified the participant as either "adult" or "senior." Classification was based on an intuitive reaction on the part of the researcher to the interviewee's attitude and alertness. The classification was not based on age, gender or walking speed. Instead, the researchers hoped that it would be a quick summary of a person's functional abilities.

The mean normal walking speed of all women was 1.24 m/s, and the mean fast walking speed was 1.55 m/s. As noted, participants were classified as adult or senior. The mean normal walking speed of senior women was 1.13 m/s, and the mean normal speed of adult women was 1.27 m/s. The mean normal speed of all men was 1.29 m/s. The mean normal speed of senior men was 1.13 m/s, and the mean normal speed of adult men was 1.34 m/s.

The main problems identified by participants concerning crosswalks included being extra cautious because of a mistrust of drivers, fear of turning vehicles, difficulty negotiating curbs, inability to judge vehicular speeds, problems during winter, and annoyance with quick-changing lights. It was also found that many elderly pedestrians do not understand the purpose of the Walk, flashing Don't Walk, and solid Don't Walk lights. This finding was confirmed in the intersection study of elderly pedestrians. This finding is not confined to elderly pedestrians in Calgary, and it is noted that the city of Buenaventura (*11*) has developed a sign to improve the understanding of pedestrian indications at signalized intersections.

FIELD DATA COLLECTION

The six field locations were chosen after a brief evaluation to ensure significant numbers of elderly pedestrians. Four of the six locations were near shopping centers. The field locations consisted of two pedestrian actuated midblock crosswalks, two crosswalks at signalized intersections, and two crosswalks at unsignalized intersections.

The objective was to interview at least 30 elderly pedestrians at each of the six intersections. Fifteen pedestrians were timed in each direction.

The procedure for gathering information consisted of two main steps: timings and interviews. Without their knowledge, pedestrians assumed to be over age 60 were timed starting from where they stepped off the curb until they stepped onto the sidewalk at the other side.

To calculate crossing speed, the measured curb-to-curb distance was divided by the time taken to walk from one curb to the other. The measured distance for each intersection was equivalent to the observed most traveled path of the pedestrians using the crosswalk. Admittedly, not all participants walked the same distance across the intersection. Thus, for the field conditions, the more accurate term of crossing speed was used instead of walking speed.

Once the pedestrians had finished crossing the road, they were intercepted and asked if they had time to answer questions about that particular intersection. If the pedestrians agreed to that interview, they were shown and asked between six and eight behavioral questions, depending on the location. For each question, the interviewee had a choice of five one-word answers ranging from "never" to "always." At the end of the interview, the participants were asked their age discreetly. The behaviorial questions were included in the questionnaire in the hopes that road crossing behavior might be correlated with crossing speed.

In general, most of the pedestrians consented to the short interview. Some who were in a particular hurry did not consent to the interview, and only those persons who consented were included in the study.

FINDINGS

Table 1 contains a brief description of the six crosswalks and the average walking speed of elderly women, men, and total surveyed. The highest crossing speeds were measured at the two signalized intersections. The crossing speeds at both midblock crosswalks were quite close. Surprisingly, the crossing speeds at the unsignalized intersections differed significantly with 90 percent confidence although the crosswalks were geographically only one block apart. In all cases the men had higher walking speeds than the women.

The Chinook and Safeway intersections had the same type of traffic control device: traffic lights with separate pedestrian lights. However, the intersection geometries were quite different: the Chinook pedestrians had to cross a distance of 40.03 m and six lanes of two-way traffic separated by a raised median. Meanwhile, the Safeway pedestrians only had to cross a distance of 16.09 m and four lanes of one-way traffic. There were differences in pedestrian herding, pedestrian signal phasing, and surrounding land use. Fifty percent of the Safeway pedestrians stated that they had walked fast when crossing the intersection but 85 percent of the Chinook pedestrians stated that they had walked fast when crossing. Using the results of the Kerby Center data analysis, which stated that the average fast speed of elderly pedestrians as a group is significantly greater than their average normal speed, the Chinook crossing speed should have been greater than the Safeway crossing speed. Yet, a hypothesis test stated with 80 percent confidence that the two crossing speeds were the same.

One explanation for this contradiction may be fatigue. The crosswalk at Chinook was more than twice the length of the crosswalk at Safeway. Furthermore, although it was not asked, overall trip length for pedestrians at Chinook may have been longer than for those at Safeway because of differences in land use between the two sites. In fact, hypothesis testing indicated that the mean crossing speed for pedestrians returning from Chinook Center was lower than the speed of pedestrians going to Chinook Center.

The difference may indicate that pedestrians are more tired when returning from a shopping center than when they are going to a shopping center. The trend was reversed at the other signalized intersection; the crossing speed of the pedestrians going toward Safeway was lower than the crossing speed of the pedestrians traveling away from Safeway. However, unlike most pedestrians at the Chinook Center, the pedestrians crossing the Safeway intersection appeared to have a variety of trip destinations.

The second pair of statistically similar intersection samples was the Lions Park and Market Mall samples. The samples were found to be statistically similar with an 85 percent confidence interval. There are several possible explanations for this similarity. The most obvious reason is that they shared the same type of traffic control device. Both crosswalks were midblock crosswalks with pedestrian-actuated overhead beacons. Once a pedestrian activated it, the beacon immediately began flashing as warning to drivers. Pedestrians very rarely waited for longer than a few seconds before crossing.

Second, vehicular traffic volumes were similar at both crosswalks. On average, two cars were delayed by each participant at the Lions Park crosswalk and three cars for each participant at the Market Mall crosswalk.

Third, as part of the study, participants at each intersection were asked whether they walked faster when they crossed the respective intersection. Just over 80 percent at the Lions Park crosswalk and 70 percent at the Market Mall crosswalk replied that they did walk faster than normal while crossing.

However, there were a number of differences between the two samples, the biggest being the respective pedestrian herding characteristics. Many more pedestrians were using the Lions Park crosswalk than the Market Mall crosswalk. Yet, because of the nature of the pedestrian-actuated beacons, no pedestrian at either crosswalk waited for very long; arrivals were quickly dispersed. So, although there were not pedestrian herds at either crosswalk, there was a sufficient volume of pedestrians at the Lions Park crosswalk to create a continuous string of pedestrians. Thus, while pedestrians using the Lions Park crosswalk could not take comfort among a pedestrian herd, they could derive a certain amount of security in the knowledge that other pedestrians were in the crosswalk. The frequency of pedestrian arrivals at the Market Mall crosswalk was so low that nearly all pedestrians crossed singly.

As an aside to the preceding discussion of pedestrian crossing strings, it is possible that a pedestrian's position in the string influences walking speed. For example, the flashing beacon lasted longer than 20 sec, and a pedestrian crossing immediately after the beacon

TABLE 1 Average Walking Speeds of Elderly Pedestrians

CROSSWALK			AVERAGE WALKING SPEED (m/s)		
TYPE	LOCATION	WIDTH (m)	WOMEN	MEN	TOTAL
Signalized	**Chinook Centre**	**40.03**	**1.33**	**1.41**	**1.36**
	Safeway	**16.09**	**1.37**	**1.45**	**1.40**
Ped-Actuated	**Market Mall**	**21.98**	**1.20**	**1.30**	**1.23**
	Lion's Park	**11.92**	**1.17**	**1.31**	**1.22**
Unsignalized	**Four-Way Stop**	**13.14**	**1.26**	**1.35**	**1.29**
	Two-Way Stop	**14.20**	**1.13**	**1.19**	**1.15**

had been activated might be confident in the knowledge that he or she had ample time to cross. However, a pedestrian arriving later would not be aware of how much longer the beacon would flash. This later pedestrian has two choices: (*a*) to hurry across or (*b*) to reactivate the beacon and then cross. Therefore, the pedestrian who arrived after the beacon had been activated and who did not reactivate the beacon most likely walked faster than the pedestrian who knew how much time he or she had to cross. Although no formal observations were made, many pedestrians were seen to reactivate the flashing light unless they arrived directly on the heels of the other pedestrians.

The other dissimilarities between these two crosswalks concerned traffic speed and level of aggressiveness. Since the Lions Park light rail transit (LRT) area was a hub of activity, with buses, an LRT station, and mall entrances and exits along with the midblock crosswalk, most drivers appeared to drive slowly and cautiously. Contrary to this scenario, drivers near Market Mall had a wide boulevard on which to travel and few obstructions in their path. Occasionally, pedestrians at the Market Mall crosswalk purposely waited for a gap in traffic before activating the flashing lights.

Despite the dissimilarities, the average crossing speeds were not statistically different. Since the crosswalks share many environmental factors, focusing on one environmental variable to explain the similar crossing speeds is difficult.

The two-way- and four-way-stop crosswalks, although only one block apart, were found to be statistically different with a 90 percent confidence interval. The reasons for the dissimilar mean crossing speeds are likely to be related to the different user characteristics.

First, these two crosswalks do share similar types of traffic control devices. The four-way-stop crosswalks is located at an intersection controlled on all four legs by stop signs. Meanwhile, the two-way-stop crosswalk is located at an intersection controlled on the east-west legs by stop signs. In this instance, the study crosswalk cuts across the north-south street, which is uncontrolled. Drivers were aware that there was a crosswalk at this junction since the crosswalk was signed as an elderly pedestrian crosswalk, as shown in Figure 1. The *City of Calgary Traffic Control Manual* (*12*) contains an elderly pedestrian crosswalk sign that is used at painted crosswalks in areas commonly used by elderly pedestrians such as areas near senior citizens' homes. The sign is used in conjunction with the elderly pedestrian advance warning sign (Figure 1). Both crosswalks are used as access conduits from the immediate residential area to a nearby shopping and service district. Many pedestrians use either crosswalk on their way to or from a shopping plaza located just west of the two intersections. The crosswalks were parallel to each other and had close but not equal crossing distances: 13.14 m for the four-way-stop crosswalk and 14.20 m for the two-way-stop crosswalk.

The reason that the two-way-stop crossing speeds were so much lower than the four-way-stop crossing speeds was probably due to a flaw in the data collection procedure. For instance, at the two-way-stop intersection, pedestrians who were in a hurry probably either crossed midblock or crossed the intersection on a diagonal. These pedestrians were not counted in the study. Thus, the two-way-stop study is biased toward unhurried pedestrians. This bias is illustrated in the answer to the question, "Do you walk faster than normal when crossing?" Sixty-five percent of pedestrians at the two-way-stop crosswalk answered no; 45 percent of pedestrians at the four-way-stop crosswalk answered no. Furthermore,

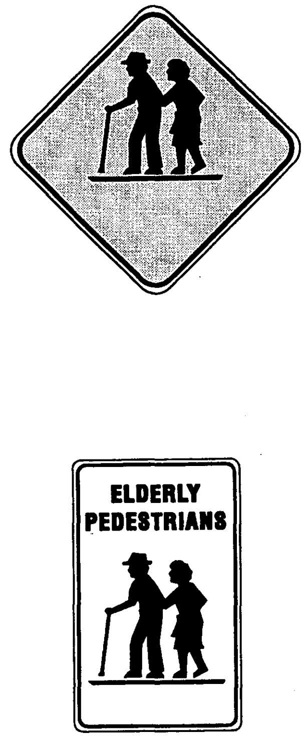

FIGURE 1 Elderly pedestrian crosswalk signs (*12*).

as at other study intersections where traffic volumes changed throughout the day, many participants added that their crossing speed depended primarily on prevailing traffic conditions. The four-way-stop intersection was busier than the two-way-stop intersection. The four-way-stop is more representative of crossing speeds of elderly pedestrians at uncontrolled intersections than the two-way stop.

Hypothesis testing indicated that the walking speeds at the signalized crosswalks could be combined as could the walking speed at the midblock pedestrian-actuated crosswalk. Figure 2 shows the cumulative frequency diagrams for both combined groups and the Kerby Center normal walking speed. Note that the cumulative walking speed diagram at the midblock crosswalk closely matches that of the Kerby Center normal speed. As shown in Figure 2, 15 percent of elderly pedestrians walked slower than 1.0 and 1.2 m/s at midblock and signalized crosswalks, respectively. The 85th percentile is commonly used in transportation engineering as a fair compromise between the needs of the majority and realistic design. Using this principle, the following design crossing speeds are suggested: for midblock crosswalks, 1.0 m/s; for signalized intersections, 1.2 m/s.

CONCLUSIONS

The following conclusions were drawn from this study:

1. It appears that the walking speed of elderly pedestrians varies according to functional classification, gender, and intersection type.
2. Elderly pedestrians reported a range of problems associated with crosswalks, including difficulty negotiating curbs, fear of turning vehicles, inability to judge the speed of incoming vehicles, discourteous drivers, and confusion with the WALK, flashing DON'T

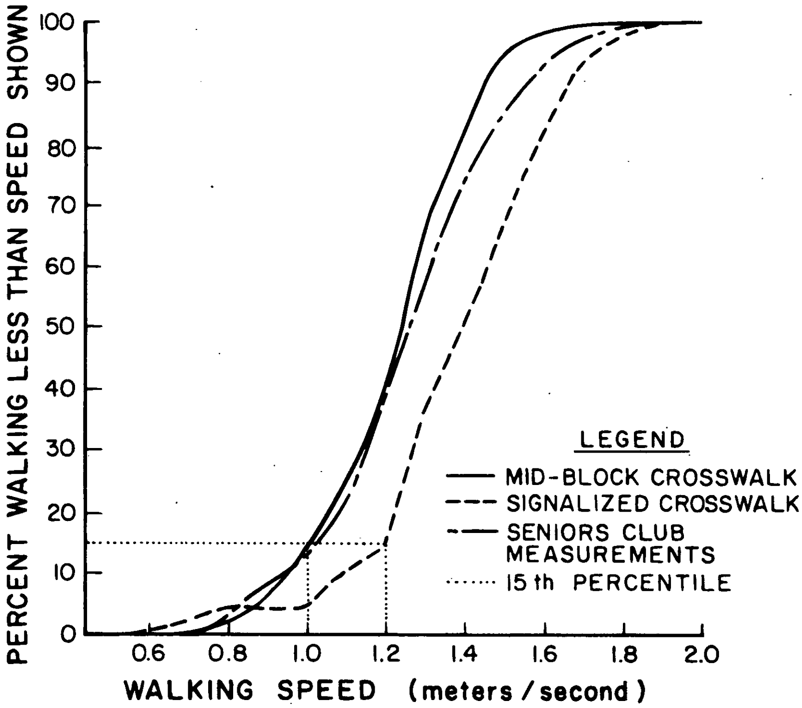

FIGURE 2 Cumulative distribution of walking speeds of elderly pedestrians.

WALK, and solid DON'T WALK pedestrian signal indications. At signalized intersections near seniors and nursing homes, where most pedestrians are elderly, a design walking speed of 1.0 m/s is satisfactory.

3. Suggested design walking speeds for elderly pedestrians at midblock crosswalks and signalized intersections are 1.0 and 1.2 m/s, respectively. At signalized intersections near seniors and nursing homes, a design walking speed of 1.0 m/s is suggested.

ACKNOWLEDGMENT

This study was funded by the Natural Sciences and Engineering Research Council of Canada.

REFERENCES

1. *Manual on Uniform Traffic Control Devices.* FHWA, U.S. Department of Transportation, 1988.
2. *The Walking Speeds of Elderly Pedestrians.* Department of Civil Engineering, University of Calgary, Alberta, Calgary, 1992.
3. *Uniform Traffic Control Devices for Canada.* Transportation Association of Canada, Ottawa, Ontario, 1976.
4. Kell, J. H., and I. J. Fullerton. *ITE Manual of Traffic Signal Design.* Prentice-Hall, Englewood Cliffs, N.J., 1982.
5. Traffic Control Devices Handbook. FHWA, U.S. Department of Transportation, 1983.
6. Imms, F. J., and O. G. Edholm. Studies of Gait and Mobility in the Elderly. *Age and Ageing,* Vol. 10, 1981, pp. 147–156.
7. Cunningham, D. A., P. A. Rechnitzer, and A. P. Donner. Exercise Training and the Speed of Self-Selected Walking Pace in Men at Retirement. *Canadian Journal on Ageing,* Vol. 5, No. 1, 1986, pp. 19–26.
8. Wilson, D. G., G. B. Grayson. *Age-Related Differences in the Road Crossing Behavior of Adult Pedestrians.* TRRL Laboratory Report 933. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, 1980.
9. Molen, N. H., R. H. Rozendal, and W. Boon. Fundamental Characteristics of Human Gait in Relation to Sex and Location. *Proc., Koninklijke Nederlands Akademie van Wetenschappen,* Series C, Vol. 75, 1972, pp. 215–223.
10. Dahlstedt, S. *Långsamma Fotgängare—Pensionärers Gånghastigheter och Promenadvanor* (in Swedish). Report R2. Swedish Council for Building Research, Stockholm, 1978.
11. Lanalni, N., and B. Baranowski. Reducing Public Confusion About the Use of Pedestrian Signals. *ITE Journal,* Vol. 63, No. 1, 1993, pp. 41–43.
12. *City of Calgary Traffic Control Manual.* Traffic Operations Division, Transportation Department, Calgary, Alberta, Canada 1990.

Nonmotorized-Motorized Traffic Accidents and Conflicts on Delhi Streets

JOSEPH FAZIO AND GEETAM TIWARI

The city of Delhi had more than 1,900 traffic fatalities in 1993. Delhi police firsthand information reports show that most of these fatalities involved heavy vehicles striking pedestrians and bicyclists at midblock locations. Results reveal that Delhi has many nonmotorized traffic entity fatalities given its degree of traffic homogeneity and total traffic fatalities as compared with other places in the world. To find heterogeneous traffic characteristics that may significantly enhance traffic safety and operations, a heterogeneous traffic conflict study for 14 Delhi midblock sites followed. The sites ranged from ones with many fatalities to one with none. To evaluate the association between heterogeneous conflict rates at each site and respective site fatalities, a Spearman rank correlation produced a measure. A positive correlation of 0.14 exists between conflict rates and fatalities for all traffic entities.

In 1993 the city of Delhi had approximately 1,900 reported traffic fatalities, more than twice that of all other major Indian cities combined (*1*). Most of these traffic fatalities involved collisions between motorized vehicles and nonmotorized traffic. A newspaper article reported that heavy vehicles caused approximately 70 percent of the 1993 Delhi fatalities (*1*). Another study showed that buses and trucks struck 58 percent of Delhi's 1985 traffic fatalities (*2*). For instance, buses struck and killed 41 percent of the 222 motorized two-wheeler fatalities; trucks, 28 percent; cars, 9 percent; and other vehicles, 21 percent (*2*).

The goal of this paper is to explore the reason that Delhi has so many nonmotorized victims in its total traffic fatalities. One objective is to see how nonmotorized fatality percentage varies by traffic homogeneity as a function of location. Doing so allows a comparison between Delhi and other places in the world. The second objective is to measure the impacts of microdesign elements. Measuring impacts occurs by conducting midblock heterogeneous conflict studies at 14 sites varying from 28 to 0 fatalities.

Automobiles, buses, trucks, tempos, autorickshaws, motorcycles, motorscooters, mopeds, and other vehicles propelled by internal combustion engines or motors compose one group: motor vehicles (MVs). Nonmotorized vehicles (NMVs) or entities primarily include pedestrians, bicycles, pedal/cycle rickshaws, animals, animal-drawn carts, and human-powered push/pull carts. Average peak-period traffic composition (excluding pedestrian traffic) on an urban arterial or major street defines heterogeneous traffic. This traffic composition has less than 85 percent automobiles or less than 90 percent automobiles, trucks, and buses. In 12 of the 14 sites in Delhi, motorized two-wheeled vehicles composed the greatest percentage of traffic. The Defense Colony site had the highest degree of motorization, with 95 percent MVs. However, cars accounted for only 47 percent of traffic entities at this site; buses and trucks, only 2 percent.

Victims of urban heterogeneous traffic crashes are usually pedestrians and bicyclists. Of 358 pedestrian fatalities, buses struck approximately 43 percent of them, trucks, 28 percent; cars, 8 percent, three-wheeled taxis, 6 percent; and some other vehicle, 14 percent (*2*). For 116 bicyclist fatalities, buses killed 36 percent of the bicyclists; trucks, 43 percent; cars 5 percent; and others, 15 percent (*2*). Concerning MVs and NMVs, MVs striking NMVs (MV-NMV) resulted in 43.4 percent of Delhi's 1,114 fatalities; of the total, 27.6 percent had fatalities related to MVs striking MVs (MV-MV) (*3*). The NMV-MV collisions accounted for 8.9 percent of Delhi's roadway fatalities, whereas NMV-NMV fatalities were 4.3 percent (*3*). The remaining 15.8 percent fatalities involved "unknown" striking "unknown" (*3*).

Figure 1 shows the distribution of the percentage of NMV fatalities versus the percentage of MV trips composing the location's modal split. Modal split information may include or exclude pedestrian trips; Figure 1 includes only information that includes such trips. Theoretically, no nonmotorized fatalities can result from a striking MV at the origin on the graph because no MVs exist in the traffic stream at this point. When MVs account for 100 percent of the trips, no NMV fatalities occur because of the absence of NMVs in the traffic. Data points below 50 percent MV trips are difficult to find, perhaps because prevailing socioeconomic conditions do not allow accurate fatal accident reporting systems. Surprising is the general symmetry of the predicted curve and its height. The curve shows that Delhi, with an MV trip split of 47 percent, is near the area of the highest percentage of NMV fatalities. This graph's curve does not imply that having homogeneous MV traffic is safer than having heterogeneous traffic. The curve shows the distribution of percentage NMV fatalities (most of these deaths result from being struck by MVs) with respect to the degree of MV homogeneity as a transportation mode.

Nonmotorized and motorized traffic mix on the streets of Delhi, forming heterogeneous traffic. Some interactions in heterogeneous traffic unfortunately involve traffic crashes between MVs and NMVs, and a few crashes result in death. Figure 1 plots Delhi and other non-Indian places where heterogeneous traffic prevails. The figure also shows places with a high degree of MV homogeneity. Delhi's plot occurs where the percentage of NMV fatalities is maximum on the predicted curve.

Many interactions in heterogeneous traffic result in motorized-nonmotorized traffic conflicts. These conflicts are partly due to the various design elements existing at midblock. Traffic conflicts involve driver or pedestrian responses such as decelerating or changing direction to avoid a collision. A traffic conflict is a poten-

J. Fazio, Department of Civil Engineering, Illinois Institute of Technology, 3201 South Dearborn Street, Chicago, Ill. 60616. G. Tiwari, Applied System Research Program, Indian Institute of Technology, Delhi, Hauz Khas, New Delhi 110016 India.

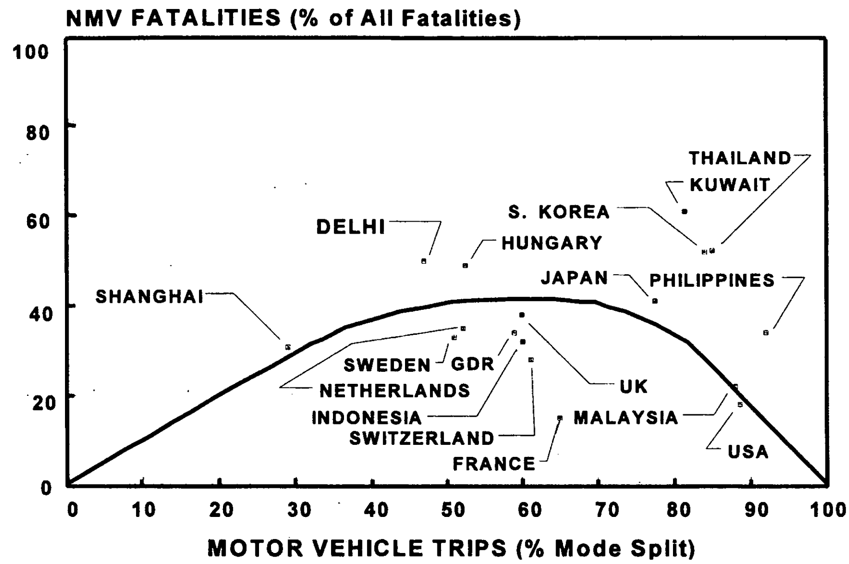

FIGURE 1 Degree of traffic homogeneity on percentage NMV fatalities (*8–27*).

tial traffic accident (*4*). For instance, when a bus is traveling behind a bicycle, a bus-bicycle, rear-end conflict occurs if the bus driver applies the brakes or steers to avoid colliding with the bicycle and successfully avoids a collision. If the bus driver is unsuccessful, a bus-bicycle, rear-end crash occurs. To change this example, reverse the position of the bus and bicycle. If the bicyclist must brake or steer to avoid colliding with the rear end of the bus, then a bicycle-bus, rear-end conflict happens. Obviously, conflicts may propagate into similar or other types of upstream conflicts. For example, one midblock conflict in heterogeneous traffic may create a bicycle-bicycle, rear-end conflict, and a truck-bicycle change direction conflict.

In denoting a midblock conflict in heterogeneous traffic, three items of information are essential:

1. The MV or NMV that is causing the conflict,
2. The MV or NMV reacting to avoid collision with the unit in item 1, and
3. The type of conflict.

Seven types of midblock conflicts manifested themselves for heterogeneous traffic: rear-end, change direction, sideswipe, fixed object, head-on, angle, and traverse angle. Each type of conflict has a corresponding collision type coded on Delhi accident report forms. For example, rear-end and change direction conflicts correspond to rear-end (back) and "hit bicyclist" collisions. Sideswipe conflicts correspond to angle (left or right side) collisions. Head-on conflicts form an association with head-on (front) collisions. Angle and traverse angle conflicts create an affiliation with "hit pedestrian" collisions. Fixed object conflicts relate to fixed object collisions.

Traffic engineers conduct conflict studies when conflicts occur at their greatest frequency, usually during peak periods before the onset of any forced-flow operations. Tallying conflicts at 15-min intervals is usually standard procedure. Midblock sections where one counts conflicts for the study of crash-conflict relationships are those segments where crashes cluster and where they do not cluster. One may also tally at those midblock sites that the public perceives as safe or hazardous. One finds out exact midblock locations where crashes cluster (or not) from computer data bases that have accident report form records of known crash sites, or from street maps that show crash locations.

In high-income countries (HICs), traffic engineers usually conduct traffic conflict studies at intersections (*5*). These studies quickly assess the safety of a newly designed intersection facility or evaluate the safety impact of design changes in existing facilities. Traffic engineers do these conflict studies without waiting years for a significant crash history to develop. Most crashes occur at intersections in HICs, which is primarily why engineers conduct conflict studies in HICs. In other words, traffic conflict studies are most effective when done at intersections in HICs.

In low-income countries (LICs) and middle-income countries (MICs), heterogeneous traffic dominates. The predominate MV-MV crashes in HICs are generally replaced by MV striking NMV (MV-NMV) crashes in LICs, as shown in Figure 1. Not shown in Figure 1 is the shift in crash locations. Although HIC traffic crashes happen mostly at intersections, LIC crashes generally occur at midblock locations (at straight sections). In Delhi 72 percent of traffic crashes happened on midblock locations (*2*). Since most traffic crashes occur midblock in Delhi, midblock traffic conflict studies were conducted. After that, the relationships between reported MV-NMV crashes and their corresponding MV-NMV conflict rate derived from field data were examined. This examination involved sites where fatalities clustered or not.

The analyses included four comparisons between combinations of collision types and conflict types for two groups of traffic entities (i.e., NMV and/or MV.) The NMV-MV crash comparison (e.g., bicycle striking a car, or bicycle-car), and the NMV-NMV crash comparison did not take place because of the small sample size and low kinetic energy in NMV-NMV collisions. Most NMV-NMV crashes go unreported.

DATA

The determination of which Delhi streets to select for traffic conflict studies followed a flexible procedure. A first step involved grouping the streets into three levels of reported fatalities—high, moderate, and low. Streets with an average of more than 80 fatalities a year had a high level; those with a fatality rate between 40 and 60 were moderate; and those between 0 and 20, fatalities low. By averaging fatality counts over the years 1989 through 1992, the level for each street was determined. Color coding the three levels on a street map of Delhi gave a good perspective. Additionally, exact traffic fatality locations were marked on this street map. These locations came from police first-hand information reports (FIRs) between June 1992 and July 1993. The Delhi police provided the fatality count by street and FIRs. When the color code of a particular site corresponded to the density of fatality points on the map, the site was designated as a "potential" site. Prescreening potential sites in each category reduced the sample size further. Sites were eliminated usually when the mounting angle of the video camera proved infeasible. Crash data from a FIR data base decided the exact directional locations on midblock sections for filming, a process that reduced the sample size to 14.

The location was videotaped in either the morning or evening peak period, depending on which side of the street the desired crash category occurred at the site. The fatality data base included only daylight fatalities because the conflicts were filmed in daylight. Videotaping at each site lasted for 1 to 2 hr so that the maximum 15-min conflict counts would be captured. NMV traffic usually peaks earlier than MVs in the weekday mornings and later in the evenings. Thus, 1 to 2 hr of videotaping ensured that the greatest interaction between NMV and MV traffic was captured. Length of the filmed midblock section is at least 25 m (*6*).

Data reduction involved the use of a video cassette player, a monitor, and trained observers. At 5-min intervals, the observers noted traffic composition at midblock, sampled space mean speeds of entities in the NMV and MV modes, and recorded conflicts by conflict type, reactor, and cause. Converting raw conflict counts into rates involved dividing the counts by the site's total observation time and midblock observation length.

The noted information was coded into a microcomputer file to carry out the analyses of the data using a statistical software application. Analyses reveal the strength of the association between specific collision types of midblock, daytime fatalities, and their corresponding conflict rates. Moreover, analyses reveal the association between midblock fatalities and midblock conflict rates.

RESULTS

Table 1 presents the results of the analyses for 14 Delhi sites. It contains correlations between crashes and conflicts by type of crash/conflict groups. A Spearman rank correlation of +0.14 exists between MV-NMV and NMV-MV conflicts and all fatalities. In the study of crash-conflict associations, +0.14 represents a weak correlation.

The ranking of site changes for different combinations of conflict types when one compares conflict data for various sites. Furthermore, the ranking also changes for the two groups of traffic entities. Of the two highly nonmotorized sites, Site 8 (Govindpuri) and Site 3 (Mahraul Badarpur Road) rank lowest and second lowest in the MV-MV sideswipe and traverse angle group. In the rear-end and change direction group, the two sites had moderate MV-MV conflict rates. Compared with the sites with a large MV share, the lack of MV-MV sideswipe, fixed object, angle, and traverse angle conflicts characterized these two sites.

Site 6 (Bhogal) ranks highest for MV-NMV and NMV-MV conflict rates for all conflict groups except the rear-end and change direction ones. A high share of MVs characterizes this site. Pedestrians crossing midblock significantly increase traverse angle conflicts. The high ranking reveals that the presence of a few NMVs is enough to cause an exponential increase in conflicts between MVs and NMVs.

CONCLUSIONS

The ranking of normalized conflict data and fatality data from police records for each site occurred from highest to lowest. Spearman correlations for various groups in Table 1 reveal weak and moderate associations between conflict rates and fatal crashes.

The analyses proved limiting in several aspects. One limitation is that the conflict-crash comparisons involved only traffic fatality counts, not all traffic crashes. Because of poor accident statistics in developing countries, traffic fatality reports are often more reliable and accurate than reports of minor traffic crashes (*7*). However, using total traffic crashes instead of fatalities probably would have resulted in more confidence in the correlation coefficients. Using a fatality or crash rate probably would have led to more confident correlations than raw counts.

Another limitation is the extent of the analyses. Aggregation of raw data fell into MV and NMV modes. Conducting detail analyses by vehicle/entity type would provide important insights. For example, comparing "bus striking bicyclist" fatalities with "bus driver avoiding collision with bicyclist" conflicts may produce higher correlations. In the midblock sites that had bus stops, the detailed conflict data base revealed that bicyclists reacted more with buses than with any other traffic entity in the heterogeneous traffic including other bicyclists, as presented in Table 2. Of the 14 sites, buses were the highest cause of conflicts for bicyclists in 7 sites, and pedestrians reacted more to motor vehicles in 9 of the sites. Bus operators interacted mostly with buses and trucks, and automobile drivers reacted more to other automobiles than any other traffic entity. As mentioned, most of the fatalities in Delhi involve a bus or truck striking a bicycle. Thus, further investigation into this association is desirable.

Figure 1 clearly shows that Delhi has a higher proportion of NMV traffic fatalities than most other international locations. Given that total trips include walking ones, Delhi's unique MV trip percentage maximizes the proportion of NMV traffic fatalities. Shanghai, with a lower percentage of MV trips than Delhi, has a lower percentage of NMV fatalities. The curve in Figure 1 suggests two options for the people of Delhi if they want to reduce their percentage of NMV fatalities. One option is to encourage MV users to substitute many of their short trips with NMVs. The other option is to encourage NMV users to make more trips using MVs. These two options are mutually exclusive. Delhi NMV users usually have limited access to at-capacity public transportation. This system is at

TABLE 1 Comparison of Crashes and Conflict Rates

a. All conflict types						
Duration (minute)	Length (hectometer)	Site ID	Conflicts/ 15 min.-hm		Fatalities	
			MV-NMV NMV-MV	MV-MV	MV-NMV	MV-MV
80	0.6475	1	5.8	18.2	9	4
75	0.4061	2	591.5	341.8	17	2
120	0.4760	3	100.8	157.3	0	0
75	0.2941	4	185.6	469.2	1	0
60	0.4258	5	29.9	200.8	20	8
70	0.4140	6	1040.9	153.7	7	0
75	0.6077	7	44.4	144.8	8	0
60	0.3495	8	17.9	101.6	8	4
80	0.4208	9	35.2	89.6	10	0
95	0.6891	10	50.4	78.1	5	0
80	0.2681	11	363.0	193.7	13	4
70	0.6374	12	7.7	43.0	4	2
85	0.6012	13	15.3	109.8	3	4
90	0.4382	14	27.0	219.8	0	0
	RCC (MV-NMV)	=	0.1417			
	RCC (MV-MV)	=	-0.0944			

b. Rear End + Change Direction Conflicts and Crashes						
Duration (minute)	Length (hectometer)	Site ID	Conflicts/15 min.-hm		Fatalities	
			NMV-MV MV-NMV	MV-MV	MV-NMV	MV-MV
80	0.6475	1	0.3	40.0	6	7
75	0.4061	2	28.1	327.0	12	7
120	0.4760	3	23.4	153.4	0	0
75	0.2941	4	380.8	412.1	0	1
60	0.4258	5	11.2	183.8	6	22
70	0.4140	6	29.5	135.1	2	5
75	0.6077	7	4.3	134.3	4	4
60	0.3495	8	14.3	98.7	2	10
80	0.4208	9	3.6	75.3	8	2
95	0.6891	10	36.4	59.8	0	5
80	0.2681	11	17.5	141.3	4	13
70	0.6374	12	6.7	36.0	1	5
85	0.6012	13	8.2	81.9	2	5
90	0.4382	14	29.7	155.6	0	0
	RCC (MV-NMV)	=	-0.5485			
	RCC (MV-MV)	=	-0.1252			

(continued on next page)

TABLE 1 *(continued)*

c. Side Swipe and Traverse Angle Conflicts and Crashes						
Duration (minute)	Length (hectometer)	Site ID	Conflicts/ 15 min.-hm		Fatalities	
			MV-NMV NMV-MV	MV-MV	MV-NMV	MV-MV
80	0.6475	1	5.5	7.2	0	13
75	0.4061	2	562.4	12.3	4	15
120	0.4760	3	73.3	4.7	0	0
75	0.2941	4	121.0	55.8	1	0
60	0.4258	5	14.7	17.0	15	13
70	0.4140	6	942.6	16.0	4	3
75	0.6077	7	38.8	10.2	2	6
60	0.3495	8	1.4	2.9	4	8
80	0.4208	9	26.7	14.3	1	9
95	0.6891	10	14.9	15.1	1	4
80	0.2681	11	344.1	51.8	8	9
70	0.6374	12	1.3	6.7	3	3
85	0.6012	13	2.6	27.9	1	6
90	0.4382	14	7.6	46.4	0	0
	RCC (MV-NMV)	=	0.2006			
	RCC (MV-MV)	=	-0.1231			

Site ID Legend:
1=Noida Link Marg
2=Aurobindo Marg
3=Mahrauli Badarpur Road
4=Vikas Marg
5=Nanakpura
6=Bhogal
7=Sundar Nagar
8=Govindpuri
9=Panchsheel Marg
10=Moolchand Hospital
11=A.I.I.M.S. Hospital
12=Mahrauli Road-Vasant Ku
13=Defence Colony
14=Sarojini Nagar

crush occupancy during peak periods; it cannot handle more users. Delhi NMV users usually cannot afford to make daily private MV trips. People in Delhi are increasingly exposed to poor air quality. Given these factors, the first option is more economically and socially feasible than the second option.

The data points of Kuwait, South Korea, Thailand, and the Philippines in Figure 1 do not concur with the predicted curve and appear to define a subtrend. This subtrend may result from something unique about Kuwait, South Korea, Thailand, and the Philippines or something inherent in their data collection procedures.

ACKNOWLEDGMENTS

The data collected and findings presented in this paper resulted from a jointly funded Indo-U.S. project. Funding sources were the Government of India's Department of Science and Technology and the U.S. Agency for International Development. The authors express their sincere thanks to the Central Road Research Institute and Delhi Police Department for their cooperation and assistance. In Delhi, the Indian Institute of Technology graciously provided facilities for completing the paper, especially the Center for Biomedical Engineering and the Applied System Research Program.

TABLE 2 Causes of Turbulence in Heterogeneous Traffic

			Top Three Causes of Conflicts (%)						Top Three Causes of Conflicts (%)		
Site	Reactor	n	1st	2nd	3rd	Site	Reactor	n	1st	2nd	3rd
SEB Noida	G1	47	G1 (75)	G2 (23)	G4 (2)	NWB	G1	88	G1 (64)	G2 (15)	G4 (8)
Link Marg,	G2	38	G1 (50)	G2 (26)	G4 (13)	Ashram	G2	55	G2 (45)	G1 (20)	G4 (13)
Mayur Vihar	G3	30	G1 (57)	G3 (23)	G2 (17)	Road,	G3	60	G3 (38)	G2 (30)	G1 (20)
	G4	49	G4 (45)	G1 (24)	G3 (18)	Bhogal	G4	130	G1 (34)	G2 (25)	G3 (18)
	G5	50	G5 (60)	G3 (22)	G4 (14)		G5	59	G2 (53)	G6 (17)	G1 (10)
	G6	0	---	---	---		G6	1995	MV (97)	G6 (2)	G5 (1)
NB	G1	302	G1 (72)	G4 (11)	G2 (10)	EB	G1	181	G1 (36)	G2 (34)	G4 (12)
Aurobindo	G2	71	G2 (39)	G1 (32)	G3 (15)	Mahrauli	G2	65	G2 (34)	G3 (22)	G1 (18)
Marg,	G3	85	G3 (33)	G2 (22)	G1 (20)	Badarpur	G3	105	G1 (31)*	G2 (31)*	G4 (14)
Hauz Khas	G4	129	G1 (43)	G2 (20)	G4 (17)	Road,	G4	286	G2 (44)	G1 (36)	G3 (13)
Enclave	G5	107	G2 (37)	G5 (36)	G6 (17)	Khanpur	G5	221	G6 (35)	G5 (32)	G2 (11)*
	G6	1142	MV (100)	---	---		G6	320	MV (86)	G6 (14)	---
NWB Ring	G1	130	G2 (44)	G1 (43)	G4 (8)	WB	G1	127	G1 (71)	G2 (12)	G4 (9)
Road,	G2	75	G2 (48)	G1 (25)	G3 (16)	Panchsheel	G2	10	G1 (60)	G3 (20)	G4 (10)*
Nanakpura	G3	50	G2 (50)	G4 (20)	G3 (16)	Marg,	G3	37	G3 (59)	G1 (19)	G2 (8)*
	G4	90	G2 (36)	G1 (31)	G4 (17)	Malviya	G4	36	G2 (39)	G1 (28)	G3 (19)
	G5	22	G2 (36)	G5 (32)	G1 (14)	Nagar	G5	46	G5 (70)	G6 (20)	G2 (11)
	G6	67	G5 (27)	G6 (21)	G3 (16)		G6	64	MV (86)	G6 (8)	G5 (6)
SWB Vikas	G1	194	G1 (43)	G2 (30)	G3 (9)	NWB	G1	62	G2 (35)	G1 (32)	G4 (24)
Marg,	G2	102	G2 (41)	G1 (20)	G4 (18)	Mahrauli	G2	17	G2 (41)	G1 (29)	G3 (18)
Shakarpur	G3	139	G2 (31)	G3 (26)	G4 (20)	Road,	G3	9	G5 (44)	G3 (22)	G1 (11)+
	G4	290	G4 (27)	G2 (26)	G1 (25)	Vasant	G4	58	G1 (34)	G4 (21)	G5 (17)
	G5	100	G2 (55)	G5 (19)	G6 (15)	Kunj	G5	26	G5 (69)	G6 (19)	G1 (12)
	G6	251	MV (69)	G6 (31)	---		G6	4	G1 (50)*	G6 (50)*	---
NB road,	G1	42	G3 (31)	G4 (29)	G1 (21)	NB	G1	270	G1 (76)	G2 (12)	G4 (7)
Govindpuri	G2	10	G3 (40)	G2 (30)*	G4 (30)*	Mathura	G2	60	G1 (42)	G2 (23)	G4 (20)
	G3	25	G3 (36)	G4 (24)	G2 (20)	Road,	G3	50	G4 (32)	G3 (26)	G2 (20)
	G4	79	G4 (24)	G3 (23)	G2 (22)	Sundar	G4	63	G2 (33)	G1 (32)	G3 (21)
	G5	113	G5 (96)	G3 (2)*	G6 (2)*	Nagar	G5	48	G5 (46)	G6 (23)	G1 (17)
	G6	19	G6 (47)	G3 (42)	G5 (5)		G6	125	MV (94)	G5 (6)	---
EB Ring Rd,	G1	101	G1 (67)	G3 (15)	G2 (11)	NB Lal	G1	125	G1 (63)	G4 (19)	G3 (10)
Moolchand	G2	35	G2 (83)	G1 (11)	G3 (6)	Lajpat	G2	19	G2 (47)	G1 (42)	G3 (11)
Khairati	G3	74	G3 (39)	G1 (32)	G2 (24)	Raj Path,	G3	104	G3 (44)	G2 (30)	G1 (21)
Ram Hosp.,	G4	153	G1 (33)	G2 (27)	G3 (16)	Defence	G4	126	G1 (47)	G3 (25)	G2 (17)
Lajpat	G5	206	G2 (63)	G6 (14)	G3 (12)	Colony	G5	23	G2 (83)	G3 (9)	G1 (4)*
Nagar	G6	44	G1 (32)*	G4 (32)*	G5 (20)		G6	69	G6 (58)	MV (42)	---
SB	G1	63	G1 (56)	G2 (24)	G3 (11)	EB	G1	193	G4 (33)	G2 (27)	G1 (23)
Aurobindo	G2	23	G2 (35)	G3 (30)	G1 (26)	Ring Road,	G2	148	G2 (39)	G4 (24)	G1 (23)
Marg,	G3	45	G2 (49)	G3 (47)	G5 (2)	Sarojini	G3	112	G3 (32)*	G4 (32)*	G2 (21)
AIIMS,	G4	156	G1 (39)	G2 (21)	G4 (17)*	Nagar	G4	129	G1 (36)	G4 (22)*	G2 (22)*
Yusuf	G5	105	G5 (73)	G2 (16)	G5 (6)		G5	75	G2 (41)	G5 (37)	G3 (16)
Sarai	G6	490	MV (100)	---	---		G6	22	MV (95)	G6 (5)	---

Legend: G1=cars/vans/minivans/jeeps G2=trucks/buses/minibuses/minitrucks G3=motorized three wheelers G4=motorized two wheelers G5=nonmotorized two and three wheelers G6=other nonmotorized traffic entities MV=G1+G2+G3+G4+unknown motor vehicles.

* = two-way tie + = three-way tie

Lastly, the authors express deep appreciation to the many individuals who rendered advice and indirect assistance in completing the paper.

REFERENCES

1. "Better Traffic Policing Urged." *Indian Express*, February 26, New Delhi, 1994.
2. Mohan, D., and M. Kumar. Road Traffic Fatalities In Delhi, India: Lessons For Low Income Countries. Prepared for First World Conference on Accident and Injury Prevention.
3. Mohan, D. Safety of Vehicles, Pedestrians, Passengers and Drivers. Presented at National Transport Day, Sri Lanka, Feb. 1994.
4. Perkins, S., and J. I. Harris. Traffic Conflict Characteristics—Accident Potential At Intersections. In *Highway Research Record HRB*, National Research Council, Washington, D.C. 225, 1968, pp. 35–43.
5. *The Malmo Study: A Calibration of Traffic Conflict Techniques*. Report R–84–12. Institute for Road Safety Research SWOV, Leidschendam, The Netherlands, 1984.
6. Box, P. C., and J. C. Oppenlander. *Manual of Transportation Studies*, 4th ed. Institute of Transportation Engineers, Washington, D.C., 1976, pp. 82–83.
7. Kumala, R. Traffic Conflict Technique as a Measure for Safety Evaluation. *Proc., 6th ICTCT Workshop: Safety Evaluation of Traffic Systems: Traffic Conflicts and Other Measures,* Salzburg, Austria, Oct. 1993, pp. 269–271.
8. *Mobility Levels and Transport Problems of Various Population Groups.* Planning Commission, Government of India, CRRI, New Delhi, June 1988, p. 27.
9. Hutchinson, T. P. *Road Accident Statistics*. Rumsby Scientific Publishing, Adelaide, South Australia, 1987, p. 7.
10. Mohan, D., and M. Kumar. Road Traffic Fatalities in Delhi, India: Lessons for Low Income Countries. *Proc., 1st World Conference on Accident and Injury Prevention,* Stockholm, Sweden, Sept. 1989, p. 4, Figure 2.
11. Rigby, J. P. *An Analysis of Travel Patterns Using the 1972/73 National Travel Survey*. Report 790. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, 1977.
12. Bonoan, M. M. Road Safety in the Philippines Review Report. *Proc., Conference on Asian Road Safety*, Kuala Lumpur, Oct. 1993, pp. 3–16, Table 6-A.
13. Pucher. Urban Travel Behavior as the Outcome of Public Policy: The Example of Modal-Split in Western Europe and North America. *APA Journal*, Autumn 1988, p. 510.
14. Klofac, J. Transportation Engineering and Urban Transport in Czechoslovakia. *IATSS Research,* Vol. 13, No. 2, 1989, p. 47.
15. Monigl, J., L. Kutas, and P. Hinel. State of Art of Urban Transport in Hungary. *IATSS Research,* Vol. 13, No. 2, 1989, p. 34.
16. Jadaan, K. S. An Investigation into Fatal Accidents and Their Prediction. *IATSS Research,* Vol. 14, No. 2, 1990, p. 27.
17. Fontaine H., and Y. Gourlet. Road Accidents in France. *IATSS Research,* Vol. 14, No. 2, 1990, p. 69.
18. Knoflacher, H. Road Accidents in Austria. *IATSS Research,* Vol. 17, No. 2, 1993, p. 87.
19. Craddock, B. Road Accidents in Hong Kong. *IATSS Research,* Vol. 17, No. 2, 1993.
20. Replogle, M. Non-Motorized Vehicles in Asian Cities. Technical Paper 162. Asia Technical Department Series, World Bank, Washington, D.C., Jan. 1992, p. 56, Table A. 2.
21. *Urban Transport in Asia.* World Bank, 1991, p. 119, Annex 1, Table 11.
22. Tiwari, G. Nonmotorized Transport in Urban Areas: On the Verge of Extinction or Hope for the Future? *Indian Highways,* Indian Roads Congress, New Delhi (in press), Table 2.
23. Ryan, G. A., and J. R. Freund. Road Traffic Crashes in the Western Pacific Region. *Proc., International Conference on Traffic Safety,* Jan. 1991, New Delhi, India, p. 311.
24. Mohan, D. Traffic Safety Priorities in Asian Countries. *Proc., Conference on Asian Road Safety*, Kuala Lumpur, Oct. 1993, pp. 1–24.
25. Lim, P. N. Present Status and Prospect of the Strategy of the Road Traffic Safety in Korea. *Proc., Conference on Asian Road Safety,* Kuala Lumpur, Oct. 1993, pp. 2–19.
26. Hills, B. L. and C. J. Baguley. Accident Data Collection and Analysis: The Use of the Microcomputer Package MAAP in Five Asian Countries. *Proc., Conference on Asian Road Safety*, Kuala Lumpur, Oct. 1993, pp. 4–24.
27. Lianrong, G., and S. Ze. The Use of the Bicycle in the People's Republic of China. *Proc., International Conference on Traffic Safety*, New Delhi, India, Jan. 1991, p. 125.

Analysis of Bicycle Accidents and Recommended Countermeasures in Beijing, China

XIAOMING LIU, L. DAVID SHEN, AND JIAN HUANG

In Beijing, China, bicycle traffic constitutes more than 50 percent of passenger transportation and more than 30 percent of traffic accident fatalities. Nearly 70 percent of the traffic accidents were related to bicycles. The rate of fatalities for bicyclists 60 and older is five times greater than the average. Farmers have the greatest number of bicycle incidents. The peak hour for bicycle accidents is usually 7:00 to 8:00 a.m., depending on the bicycle and motorized vehicle traffic flows. Monday is the peak day for bicycle accidents. It was also found that more bicycle accidents happened in July, which is Beijing's tourism season. Generally speaking, roads and streets with higher speed limits, such as arterials and rural highways, have higher rates of bicycle accident fatalities. Bicycle accidents can be attributed to many causes, including road and environmental conditions, traffic safety measures, operations of motorized vehicles, and bicyclists' habits and skills. The most pressing factor contributing to bicycle accidents is the inadequate and insufficient facilities provided for bicyclists. To reduce the annual toll of bicyclist injuries and fatalities, a number of countermeasures, such as improvement of road and environmental conditions, education in traffic laws, training in cycling, and use of helmet, are recommended.

Beijing, the capital of China, has been the locality of many dynasties. It is famous not only for being the political and cultural center of China, but also for having many historic sites. Every year, many tourists from other parts of China and abroad visit Beijing. Statistical data show that there are more than 1.2 million daily visitors and temporary workers in Beijing. The city of Beijing has an area of 16 800 km^2 with more than 10 million residents. Its nearly 8 million registered bicycles make it the city with highest bicycle ownership in China (*1*). There are also more than 700,000 motor vehicles registered, and at the end of 1992, the length of highways and streets in Beijing totaled 11 400 km.

Because of reform policy, the economy of China has been rapidly growing at a two-digit annual rate during the last decade and a half. Great changes have taken place in Beijing. From 1980 to 1992, the ownership of bicycles and automobiles in Beijing increased two and three times, respectively (Figure 1) (*2*). According to a 1986 origin-destination survey, bicycles constitute 54 percent of urban passenger transportation, a trend that has grown in recent years (*3*). In 1992 about 60 percent of all passenger trips were made by bicycle. Bicycles will continue to be one of the major modes of private transportation in Beijing in the coming decades (*4*).

With the growth in bicycle traffic, conflicts between bicycle and automobile traffic also increase. As shown in Figure 2, traffic accidents, fatalities, and injuries in Beijing have increased between 1980 and 1992. The highest annual toll for road fatalities was 756, in 1985. But even though the number of motorized vehicles has doubled and the number of bicycles has increased by 1.3 times, the death toll has decreased steadily during the past half decade. Nevertheless, traffic accidents are still a serious problem. The death rates per 10,000 vehicles for China and Beijing are 56 and 9.7, respectively, compared with less than 3.0 for most motorized countries. The big discrepancy is due to the mixed traffic in Beijing, in which about 60 percent of passenger trips are made by bicycle (*1*). Bicyclists are major participators in traffic accidents. An analysis of accident data recorded from 1981 to 1990 reveals that accidents related to bicycles account for more than 70 percent of the total (*5*). Table 1 reveals the principal parties in road accident rates. Bicycles are responsible for 38.7 percent of the traffic fatalities. Obviously, bicycle traffic is a significant contributor to road accidents. Therefore, an analysis of bicycle accidents to determine countermeasures against accidents is warranted.

This paper attempts to characterize bicycle accidents in Beijing and study their trends on the basis of Beijing road accident records between 1980 and 1992; analyze the causes of bicycle accidents in terms of human factors, road and environmental conditions, urban transportation operations, and traffic characteristics; and propose effective countermeasures for reducing bicycle accidents.

DATA COLLECTION

Questionnaire surveys were conducted to collect data. Detailed statistical data for bicycle accidents in Beijing are not available on a routine basis because there is no well-developed accident reporting system. In this study, data on bicycle accidents from 1980 to 1992 were obtained from the traffic management police department. Other data were obtained from the Beijing Statistics Report.

The traffic management police department in Beijing is the unit authorized to enforce traffic laws, manage traffic flow, and respond to traffic accidents. It is also responsible for having traffic accidents recorded and input into a data base. The research conducted in this paper is based on the traffic accident statistic data recorded during recent years. The authors realize that more data are needed for performing a comprehensive analysis of bicycle accidents. Therefore, the conclusions derived hereafter are considered preliminary. Further data analysis will be needed for verification.

X. Liu, Department of Civil Engineering, Beijing Polytechnic University, Beijing 100022, China. L. D. Shen and J. Huang, Department of Civil and Environmental Engineering, Lehman Center for Transportation Research, Florida International University, State University of Florida at Miami, Miami, Fla. 33199.

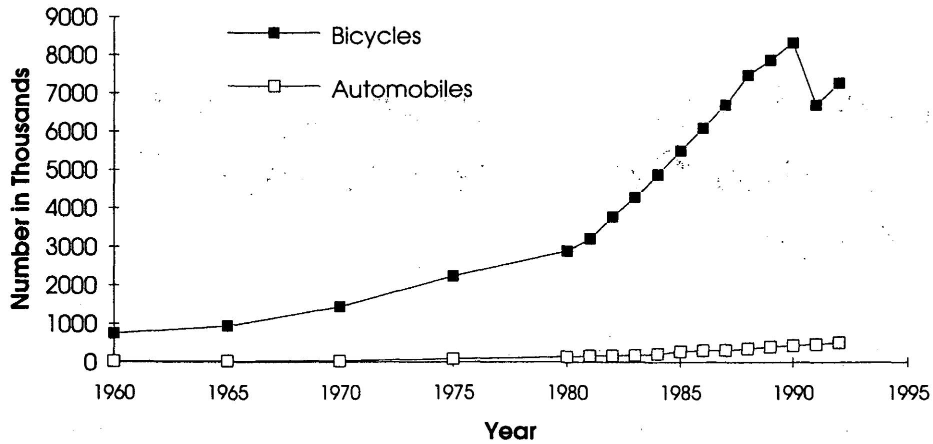

FIGURE 1 Ownership of bicycles and automobiles in Beijing.

ANALYSIS OF BICYCLE ACCIDENT CHARACTERISTICS

Many factors, such as bicycle usage, automobile operations, bicycle safety facilities, road environments, bicyclist skill, traffic management, and weather, contribute to the number of bicycle accidents. Other major factors closely related to bicycle accidents are considered in the following analysis.

Rate of Bicyclists in Accident Fatalities

Figure 3 shows the rates of bicyclists in accident fatalities in a yearly time series. The highest rate is 43.3 percent, in 1981; the lowest is 25.5 percent, in 1989; and the average is 31.4 percent. It was also found that the accident rate is related closely to automobile operating speed. In 1989 automobile operating speeds were about 25 km/hr lower than those in 1992 or 1982. Therefore, more attention should be given to managing the high-speed roads.

In recent years, the rate of traffic accidents displayed an increasing trend. One reason for this may be the traffic "chaos" during the construction of transportation facilities. Obviously, it is beneficial and life-saving to find and implement effective countermeasures.

Time Distribution

Hourly Distribution

The hourly distribution of bicycle accidents is shown in Figure 4. It is easy to see that a distinguishable peak is located between 7:00 and 8:00 a.m., when bicycle flows are the heaviest. In other words, the peak period for accidents coincides with the peak period for traffic. It may be concluded that roads with insufficient capacities cannot adequately accommodate both bicycles and motor vehicles during rush hours and the mix of different modes with different operating speeds leads to more automobile-bicycle accidents.

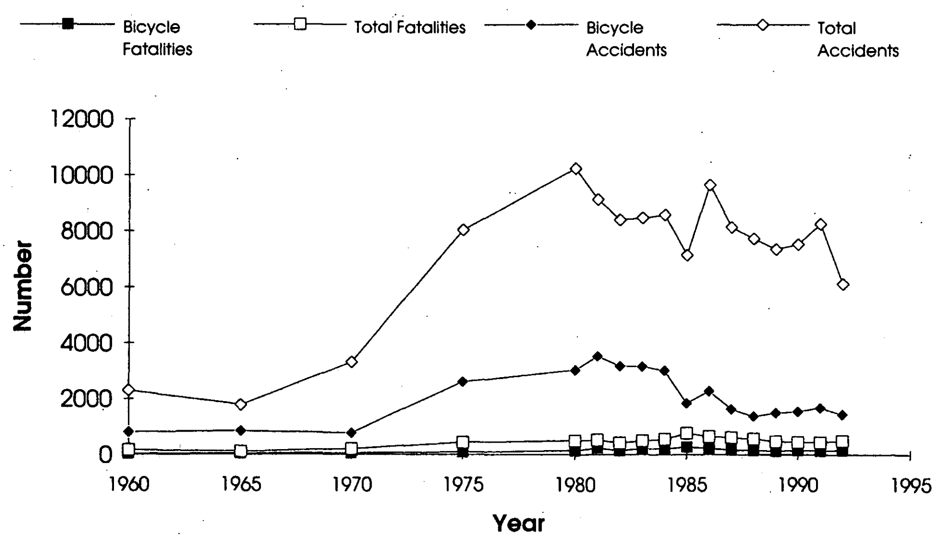

FIGURE 2 Statistics of traffic accidents in Beijing.

TABLE 1 Percentages of Traffic Accidents by First Participator, 1981–1990

	First Participator		
Type	Automobile	Bicycle	Pedestrian
Number of Accidents (%)	63.5	27.9	8.6
Number of Injuries (%)	41.6	45.7	12.7
Number of Fatalities (%)	45.7	38.7	15.6

Day and Night Distribution

Day and night distributions of bicycle accidents, injuries, and fatalities are presented in Table 2. Most accidents in Beijing occur during the day, but those that happen at night are more severe. Statistics reveal that each daytime accident results in 0.93 injury and 0.15 death, whereas each nightime accident results in 0.97 injury and 0.24 death. In explanation, most roads in Beijing are poorly illuminated at night, contributing to poor visibility, and automobiles can operate at a faster speed during the night because there is less road congestion. Furthermore, a significant portion of commuters in Beijing work in the suburbs of the city and return in the late afternoon. Considering that approximately 85 percent of the average daily traffic occurs in the daytime (*6*), the rate of nightime bicycle accidents is high.

Daily Distribution

The daily distribution of bicycle accidents in Beijing is shown in Figure 5. It should be noted that the normal working days in Beijing before May 1, 1995, were Monday through Saturday. It can be seen that Monday has the highest percentage of fatalities, whereas Sunday has the lowest percentage of accidents. It is obvious that bicy-

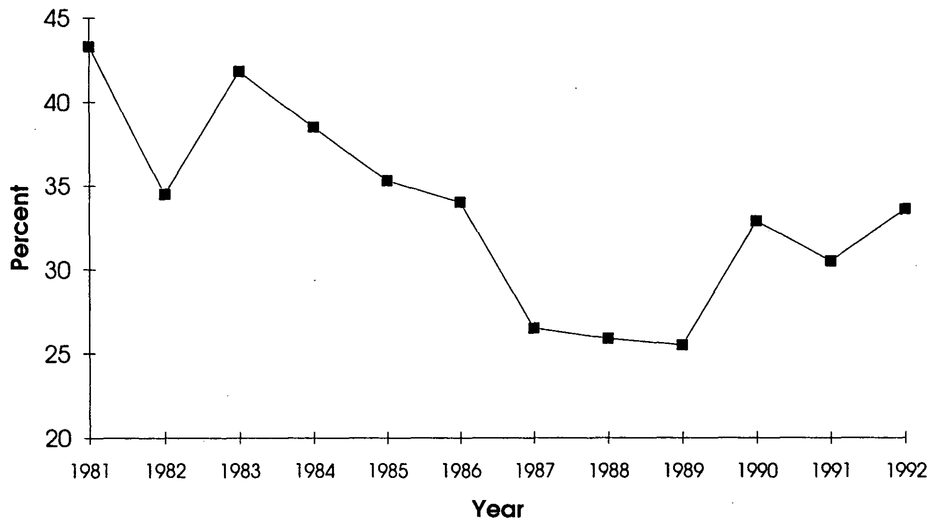

FIGURE 3 Percentage of bicyclists in accident fatalities in Beijing.

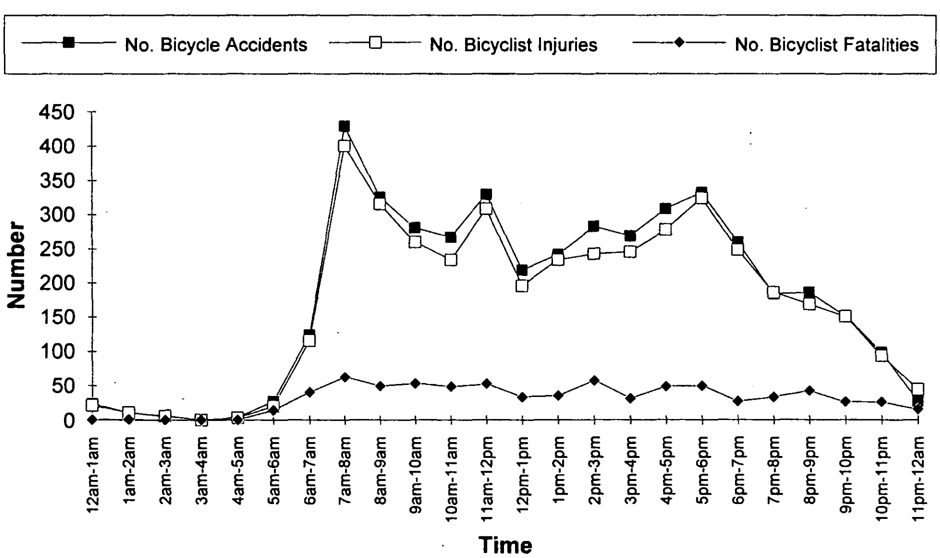

FIGURE 4 Hourly distribution of bicycle accidents in Beijing.

TABLE 2 Day and Night Distribution of Bicycle Accidents, Injuries, and Fatalities in Beijing

Type	Day	Night
Accidents (%)	80.8	19.2
Injuries (%)	79.2	20.8
Fatalities (%)	73.3	26.7
Ratio of Injuries to Accidents	0.93	0.97
Ratio of Fatalities to Accidents	0.15	0.24

cle accidents are closely related to the volume of bicycles on the road.

Monthly Distribution

Figure 6 shows the monthly distributions of bicycle accidents, injuries, and fatalities in Beijing. The highest rate of accidents and injuries occurred in July. Since it is very hot in July in Beijing, drivers are easily exhausted and bicyclists ride faster. In addition, more trips are made this month because July is the tourism season for Beijing.

Rider Characteristics by Age

Table 3 gives the frequency distributions of bicycle accidents by age group. The most critical age group is those persons 60 years and older. The percentage of fatalities for this group is higher than that for the general population. The age group between 17 and 59 as a whole has a lower bicycle accident rate than that of the general population. It is clear that more attention should be paid to elderly bicyclists in traffic safety.

Rider Characteristics by Gender

In Beijing the ratio of men to women is approximately 1 to 1 (*7*). However, men have about twice as many bicycle traffic accidents as women (66.2 versus 33.8 percent). This discrepancy may be explained by the riding characteristics of women, who generally ride more carefully and at lower speeds than men. Another factor may be that many men over 60 still ride bicycles, but few women of that age do. The rate of bicycle accidents involving men over 60 is about 25.7 percent (*8*).

Occupation Characteristics

Figure 7 shows the distribution of bicycle accidents among different occupations. The data in this figure are obtained by averaging the data from 1989 to 1991. Farmers have the highest rate, 38.2 percent, of bicyclist fatalities; they are followed by blue-collar workers. The leading causes for farmer bicyclist fatalities are as follows:

- Farmers have the poorest knowledge of traffic laws and little concept of obeying the laws.
- Many farmers ride bicycles that are in poor repair, such as those having unstable braking systems.
- Medical help is often delayed because of a lack of communication equipment and the longer distance necessary for transportation.
- Automobiles operate at higher speeds in rural areas, increasing the chances for serious damage.

Location Distribution

Table 4 reveals the numbers of bicycle accidents, injuries, and fatalities by urban and rural areas. Although bicycle accidents occurring in urban areas are as much as 2.34 times of those in rural areas, the fatality share in the rural areas is larger than that of the urban areas. However, the ratio of injury to bicycle ownership is comparable. Therefore, it can be safely assumed that accidents in rural areas are more severe than those in urban areas. A logical explanation for this may be that automobiles operate at higher speeds in rural areas. Another reason may be that a rural bicyclist has a poorer knowledge of

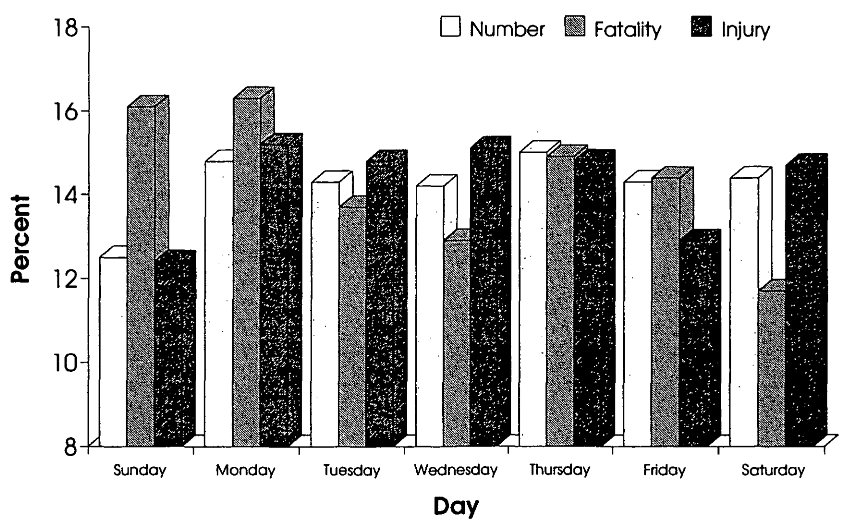

FIGURE 5 Daily distribution of bicycle accidents in Beijing.

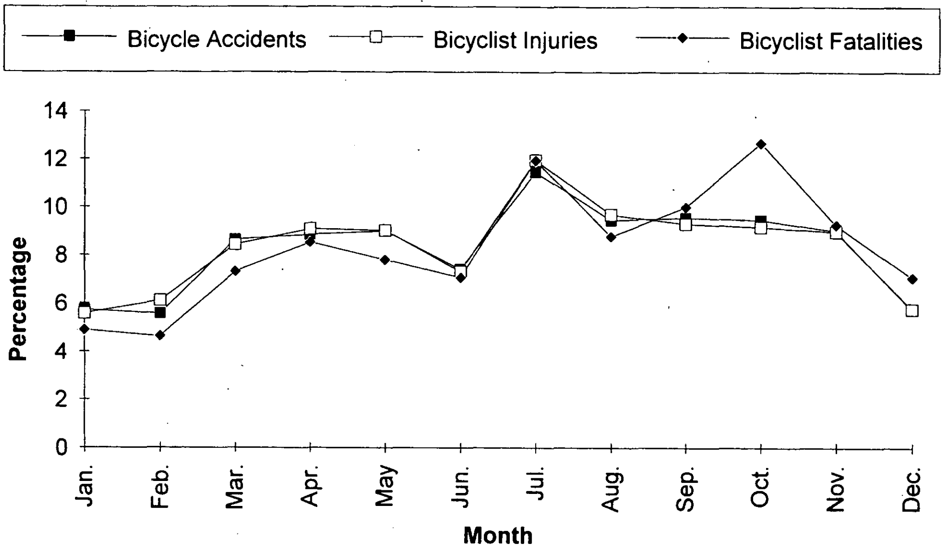

FIGURE 6 Monthly distribution of bicycle accidents in Beijing.

TABLE 3 Age Distribution in Cyclist Fatalities in Beijing, 1981–1992 (*8*)

	Age				
	<7	7-16	17-35	36-59	60 & over
Population (%)	8.47	10.54	35.01	34.68	11.30
Trips (%)	N/A	9.25	47.96	34.70	5.13
Fatalities (%)	N/A	8.82	34.08	31.40	25.70

traffic laws and a lesser sense of traffic danger than an urban bicyclist.

Road and Site Distribution

Studies of the sites where bicycle accidents occur are important for identifying specific roadway characteristics that cause problems for bicyclists and the situations in which the roadway could avert future accidents. Figure 8 reveals that 80 percent of all bicycle accidents in Beijing occur on arterials and subarterials. These accidents may be attributed to the higher operating speeds on these roadways than on other roadways. Moreover, there are many more entrances and exits along these roadways, which increases the likelihood for collision. According to statistics, 54 percent of the accidents occurred at intersections. Only about a quarter of intersections in Beijing are

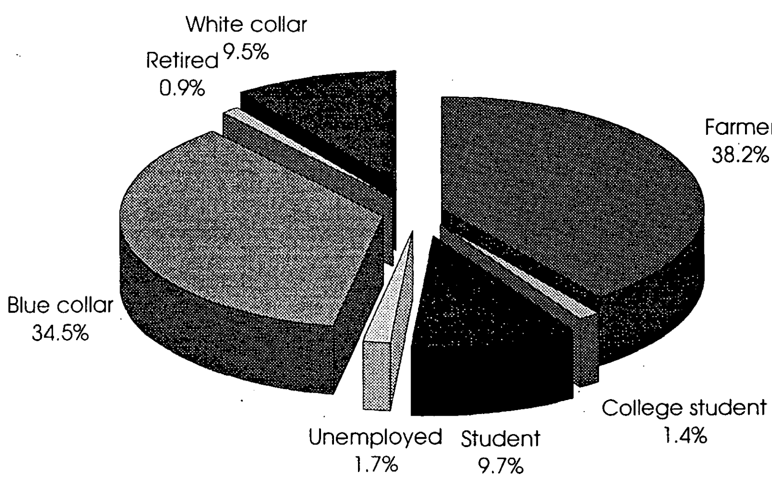

FIGURE 7 Occupation distribution in bicyclist fatalities in Beijing.

TABLE 4 Bicycle Ownership and Accidents in Urban and Rural Areas

	Area	
	Urban	Rural
Population (%)	58.0 (61.4)[a]	42.0 (38.6)[a]
Bicycle Ownership (%)	67.6	32.3
Accidents (%)	70.1	29.9
Injuries (%)	68.2	31.8
Fatalities (%)	48.0	52.0

[a]Including temporary residents

signalized, and many of the roads with signalized intersections are inadequate to meet traffic demand during the peak hours.

FACTORS RESULTING IN BICYCLE ACCIDENTS

Many factors may contribute to the high rate of bicycle incidents. These include motorcycles, other bicycles, environmental and road conditions, and inadequate traffic management. Often, an accident is the result of a combination of these factors. To accurately identify the causes of accidents in Beijing from 1981 to 1990, factors directly responsible for traffic accidents are categorized in Figure 9 (*9*). It was found that bicycles are responsible for 37.3 percent of traffic accidents.

Bicyclists

The leading cause of bicycle accidents is bicyclists themselves. It is not unusual to see bicyclists displaying unlawful riding characteristics. Riders commonly pay no attention to the traffic regulations at intersections. This is a serious problem in that bicyclists ignore not only traffic lights but also the directions made by police officers. It is thought that only automobile drivers need to follow traffic regulations.

Studies show that more than 80 percent of bicycle accidents are caused by bicyclists. The most dangerous behavior is that bicyclists do not yield to motorized vehicles, as indicated in Table 5. The second cause is sudden turning (mainly, turning left), which accounts for 26.3 percent of bicycle accidents. The accidents resulting from not yielding to other traffic, suddenly turning, and riding on a highway make up 69.4 percent of the bicycle accidents.

Mixed Traffic

One of the major characteristics of urban traffic in Beijing is the mix of bicycles and motor vehicles. Mixed traffic exists on about 70 percent of the roads and at more than 85 percent of intersections. According to the survey (*10*), the average volume of bicycle traffic at intersections within the second-beltway expressway is 16,000 bicycles per hour. The volume between the second- and third-beltway expressways is 12,000 bicycles per hour. Inside the first beltway, more than 90 percent of intersections formed by primary and secondary streets have a flow of over 10,000 bicycles in the peak hour. Moreover, 14 percent of the intersections have a flow of more than 20,000 bicycles per hour. The mixing of these two transportation modes with totally different operating speeds results in a low traffic capacity and a high accident rate.

Additionally, the ratio of bicycle flows during the peak hour to lowest flows in the daytime decreased from 3.0 in 1986 to 1.7 in 1991. In other words, as daily bicycle trips increase, so does the chance for collisions between bicycles and automobiles. From the survey, 45 percent of the collisions between bicycles and motorized vehicles lead to fatalities. Separating bicycles from motorized vehicles may be a key to reducing bicycle accidents and improving bicycle safety.

Bicycle Lanes

The growth in bicycle ownership outpaces that in bicycle lanes. In Beijing, many roads do not have sufficient capacities for bicycle traffic. That forces bicycles to ride in vehicle lanes and cause bicycle-automobile traffic accidents easily. Table 6 gives the required widths for bicycle traffic on some roads inside the third beltway (*10*). Along arterial roads, there are many exits and entrances with insufficient sight distances. These locations are the places where collisions easily happen between bicycles and automobile vehicles.

Three typical bicycle lanes are used on the roads and streets of Beijing:

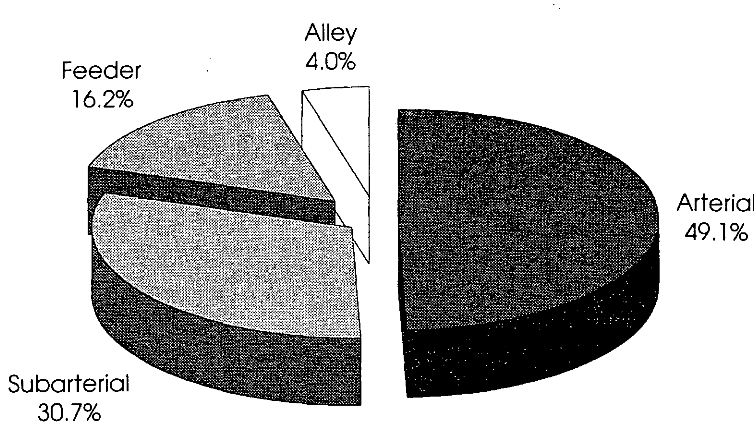

FIGURE 8 Road distribution in bicyclist fatalities in Beijing.

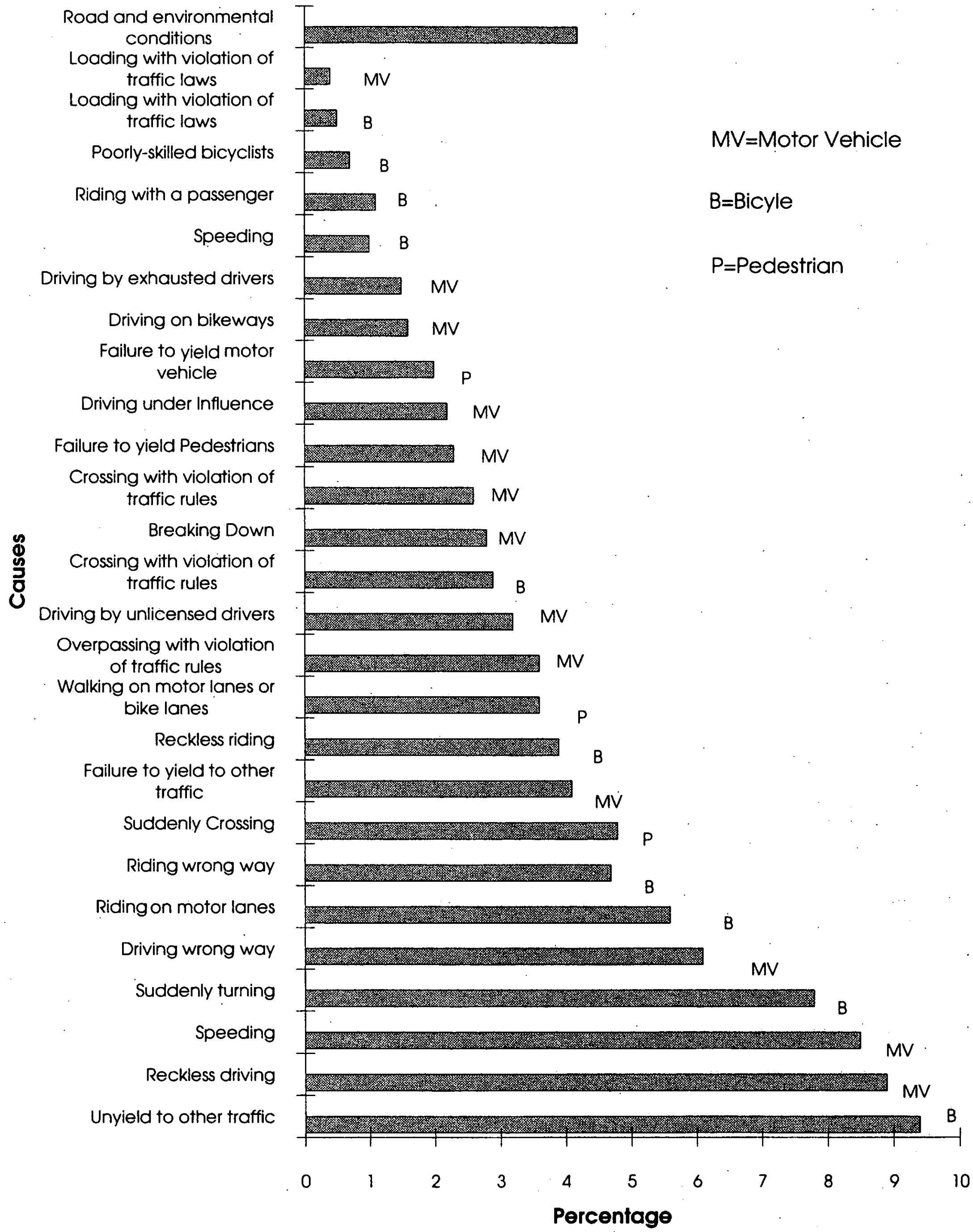

FIGURE 9 **Percentages of traffic accidents in Beijing by cause.**

- Type A: *exclusive bicycle lanes* are mostly located on one or both sides of automobile lanes with grass median or Jersey separators. These roads are called "three-slab roads" by Chinese transportation engineers.
- Type B: *independent bicycle lanes* are located on one or both sides of automobile lanes with traffic barriers or a grass median.
- Type C: *dependent bicycle lanes* are located on both sides of automobile lanes without physical or marking separation, but some may be separated by pavement markings.

Although the Type A and B lanes are considered safer for bicyclists, only 28.7 percent of the roads have these lanes. It is noteworthy to mention that such roads carry more than 60 percent of passenger transportation.

Management

Increased education and enforcement would contribute to safety improvement in many dangerous situations.

TABLE 5 Causes of Bicyclist Fatalities in Beijing

Causes	Percentage
Unyielding to other traffic	27.0
Suddenly turning	26.3
Riding on motorway	16.1
Crossing more than four lanes	8.5
Riding on the wrong way	7.7
Reckless riding	5.3
Riding with a passenger	1.9
Poor riding skills	1.2
Riding under influence	0.9
Others	2.3

- It is very common in Beijing to see automobiles parked on bicycle lanes, severely blocking the bicyclists' sight distances and forcing them to ride on the roadway.
- A number of bicyclists ignore or disobey the traffic regulations because of poor knowledge of traffic laws.
- No inspections of bicycles are mandated to guarantee that bicycles are operated in a good state of repair.
- No bicyclists wear helmets. When an accident happens, the heads of cyclists will be easily injured.

COUNTERMEASURES

Policy

The bicycle plays a key role in passenger transportation in Beijing, accounting for more than 54 percent of passenger trips. Because of the ideal geographic and weather conditions in Beijing, the bicycle is the favorite mode of residents. Moreover, bicycle transportation will continue to be one of the major modes for private passenger transportation in Beijing in the coming decade (*11*).

Increasing numbers of bicycles and motor vehicles will add to the problems of effectively managing urban transportation in Beijing. To improve passenger transportation and reduce bicycle accidents, public transportation systems, which would reduce the need for private bicycles, should be incorporated in the transportation plans for the city. Bicycles can then be used only for short-distance trips, (within 30 min or 6 km) or as a substitute for walking. The general objective is to establish an efficient, comfortable, and safe urban transportation system.

Bicycle Road Systems

In an effort to reduce vehicular collisions and decrease bicycle accidents, it is strongly recommended that bicycle traffic be segregated from motorized vehicle traffic by raising rails, Jersey barriers, and separating strips. In other words, to ensure that bicycles have their own rights of way, the following countermeasures are recommended for road environments:

- Reshape the roads of Type C cross sections into roads of Types A or B,
- Use physical barriers to separate bicycles from automobiles,
- Widen bicycle lanes to increase their capacity,
- Build a three-level cloverleaf interchange for bicycles,
- Carefully design entrances and exits,
- Warrant enough sight distances in design,
- Set up obstacles at bicycle entrances to prevent automobiles from entering,
- Set up obstacles at motor vehicle entrances to prevent bicycles from entering,
- Add bicycle lanes in some business areas, and
- Manage well the bicycle and motor vehicle flows at intersections (*12*).

Education

Educational programs about traffic laws should be offered at the preschool and elementary school levels. The education can be conducted with the help of pictorial books and videotapes, with emphasis on traffic regulations. Education is very important in improving bicycle safety. Drivers, elementary students, and senior citizens should be given special attention. In addition to general knowledge of bicycle safety, bicyclists should be familiar with traffic psychology and accident characteristics. The psychological and physical characteristics of aged people should be stressed for senior citizens.

TABLE 6 Existing and Required Bicycle Lanes on Roads and Streets in Beijing

Roads/Streets	Bicycle Flow (bicycles/hr)	Required Lanes[a] (meters)	Existing lanes (meters)	Short (meters)
North Dongshi	10,813	11.4	6.5	-4.9
North Xishi	5,596	6.1	4.5	-1.6
Xuanwumennei	11,797	12.3	9.5	-2.8
East Dianmen	6,903	7.5	5.5	-2.0
South Lishilu	4,627	5.2	5.0	-0.2
Congwenmenwai	14,437	15.0	8.5	-7.0
South Xinhua	10,430	11.0	8.0	-3.0
West Zhusiko	9,552	10.1	7.5	-2.6
Xuanwumenwai	10,634	11.2	8.5	-2.7
Guanganmennei	14,825	15.4	7.0	-8.4

[a]Required lanes (meter) = (Flow+500)/1,000

Training of Cycling and Wearing Helmets

The primary cause of bicycle accidents in Beijing is lack of safety training in riding. For example, bicyclists who are new to riding should be required to attend a bicycle safety training program. In addition, according to the research reports from other cities, about 90 percent of bicyclist fatalities are caused by head injuries (*13*). Therefore, it should be recommended that bicyclists wear helmets when riding.

Special Countermeasures for Elderly Cyclists

The following countermeasures against bicycle accidents are recommended for elderly cyclists:

- Reeducate elderly bicyclists about traffic regulations,
- Organize elderly bicyclists to watch videotapes with special emphasis on their needs for bicycle safety, and
- Require a regular physical examination, with recommendations to discontinue bicycling if one's health is found to be poor.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the study, conclusions and recommendations follow:

1. Bicycle transportation plays an important role in the passenger transportation system in Beijing. Bicycle fatalities accounted for 38.7 percent of Beijing's road fatalities. Therefore, more attention should be paid to improving the safety of bicycle transportation.
2. Bicycle accidents are related closely to the volume of bicycles and motor vehicles on the roadway. The peak hour for bicycle accidents is from 7:00 to 8:00 a.m.
3. Bicycle accidents occurring at night usually result in injuries more severe than do those in the daytime.
4. There is a correlation between the number of bicycle accidents and the operating speeds of motor vehicles higher rates of accidents happen on arterial and subarterial roads.
5. Elderly cyclists have a fatality rate 4.76 times higher than average. Students have a fatality rate 1.3 times the average level.
6. In an occupational distribution, farmers have the highest rate of bicycle accidents.
7. The most pressing causes of bicycle accidents are inadequate bicycle facilities and large numbers of bicyclists who ignore the traffic law, especially when no police are on duty.
8. The best way to improve the safety of bicycle transportation is to separate bicycles from automobiles with strips or barriers and allow bicycles to have their exclusive rights of way.
9. Wearing a helmet when cycling is strongly recommended.
10. Certificates of recognition should be awarded to elementary and high school students who have completed bicycle safety training.

ACKNOWLEDGMENTS

The authors wish to thank Caijun Luo for helping to compile the data and Allison C. Smith for editing this paper.

REFERENCES

1. Liu, X., L. D. Shen, and F. Ren. Operational Analysis of Bicycle Interchanges in Beijing, China. In *Transportation Research Record 1396*, TRB, National Research Council, Washington, D.C., 1993.
2. Duan, L. General Evaluation of Road Traffic Safety. Presented at the 3rd Multinational Urban Traffic Conference, Beijing, China, Nov. 1993.
3. *The Report of Trips Original-Destination Survey in Beijing.* Beijing Municipality, Beijing, China, 1988.
4. Liu, X., and F. Ren. Cycling in China. *Proc., International Symposium on Non-Motorized Transportation,* Beijing, China, May 1994.
5. Liu, X., and F. Ren. Analysis of Urban Accident Characteristics. *Road Traffic Management,* Vol. 12, No. 7, 1992.
6. *Comprehensive Evaluation of Urban Transportation in Beijing.* Research Report. Beijing Polytechnic University, China, 1990.
7. *1990 Census of Beijing.* Department of Statistics of Beijing, China, 1990.
8. Kong, T. *Analysis of Cyclist Characteristics.* Research Report. Beijing, China, 1993.
9. Liu, X., and J. Zhang. Road Traffic Safety in China. Presented at the 3rd Multinational Urban Traffic Conference, Beijing, China, Nov. 1993.
10. Li, G. *Study of the Evaluation of Bicycle Traffic Management.* Research Report. Beijing, China, 1993.
11. Shen, L. D., X. Liu, and C. Luo. A Study of Non-Motorized Passenger Transport in China. *Proc., International Symposium on Nonmotorized Transportation,* Beijing, China, May 1994.
12. Liu, X., and X. Chai. Operational Analysis and Safety Measures of Bicycles at Intersections. Presented at the Beijing-UN Bicycle Transportation Seminar, Beijing, China, April 1994.
13. Xu, P., and B. Li. The Study of Strategy for Bicycle Safety in Shanghai. *Proc., International Symposium on Non-Motorized Transportation,* Beijing, China, May 1994.

Experiences in Developing Countries with Impact of Exclusive Lanes for Nonmotorized Transportation: Case Studies of China and Indonesia

Y. TANABORIBOON, TUTI AGUSTIN, AND YU MINFANG

The effect of exclusive lanes for nonmotorized transportation (NMT) in Shanghai, China, and Surakarta, Indonesia, is investigated. NMT speeds in exclusive lanes and ordinary (mixed traffic) lanes were compared to examine the impact of the exclusive paths, as it is not possible to conduct before and after studies. Contradicting results were obtained between Shanghai and Surakarta. Exclusive bike lanes were found to have a positive impact in Shanghai: mean riding speeds on the exclusive lanes were significantly faster than those on the ordinary paths. But no significant difference was found between the mean speeds of exclusive and ordinary lanes in Surakarta. The NMT exclusive paths have no effect on the speeds of their NMT modes.

Western countries are now shifting their focus to the greater use of nonmotorized transportation (NMT) modes—in particular, the bicycle. Some believe this is the sustainable transportation mode, which is environmentally conscious. Developing countries, on the other hand, are still trying to follow the Westerners' previous traditional focus: fast growth in the number of automobiles. Their tactics in solving urban transportation problems still concentrate on motorized transportation without much consideration of the role of NMT in their planning, even though many still rely on NMT modes. Much less attention has been given to providing adequate and suitable NMT facilities. Perhaps only a few countries (such as China and Indonesia) provide the exclusive NMT lanes to facilitate their NMT modes. Nevertheless, the impact of these exclusive facilities is worth examining even then.

This paper investigates the effect of the NMT exclusive lanes in two developing countries, China and Indonesia. Two cities—namely, Shanghai, China, and Surakarta, Indonesia—were chosen as the study areas because of the availability of the NMT exclusive facilities in these two cities.

DATA COLLECTION

Because it is impossible to conduct before and after studies on the impact of NMT exclusive lanes in the two cities as generally practiced, comparative speeds on the two NMT facilities were analyzed to examine the effect of NMT exclusive lanes. Speeds were collected on the ordinary lanes (mixed traffic lanes) and the lanes exclusive to NMT modes. In Shanghai, only bicycle speeds were collected, but in Surakarta, bicycle and becak speeds were included in the analyses. (A becak, or pedicab, is a three-wheeled, pedal-powered nonmotorized taxi that carries one or two passengers. Currently about 8,100 becaks operate in Surakarta.)

Various techniques have been mentioned in traffic engineering textbooks for collecting vehicular traffic speeds, but unfortunately none of these textbooks describe any method for collecting bicycle or other NMT mode speeds. As such, conventional speed collection techniques were not used in this study. Instead, all data were collected with video cameras. Because it is not possible to employ the license plate technique as normally practiced to conduct the vehicular travel time survey, this study used two video cameras installed at the entrance and exit of the test sections to record the travel time of the NMT modes. The times at which each sample passed the reference lines of both ends of the test sections were recorded. The data were then processed on each cassette tape and all times were counted using the timer installed on the screen of the monitor. Two sets of videocassette players and monitors were used to identify each sample and its travel time. With the known distances of each test section, NMT speeds could then be determined.

In Shanghai, three bicycle paths were chosen as study sites: a bike path (Jiangwan Road), a bike lane (Dalian Road), and a bike route (Chifeng Road). Bike paths are streets used for bicycles only. Bike lanes are exclusive lanes along streets with barriers to segregate other traffic from disrupting bicyclists. Bike routes are ordinary streets with mixed traffic and no barriers to segregate bicycles and vehicular traffic. In Surakarta, the exclusive paths for NMT modes (Slamet Riyadi and Adi Sucipto streets) were selected along with other ordinary streets with mixed traffic (Piere Tendean and Yos Sudarso streets) as study sites. Table 1 gives a detailed description of these sites.

IMPACT OF NMT EXCLUSIVE LANES

Shanghai, China

Before the effect of exclusive bike lanes was investigated in Shanghai, an attempt had been made to verify the results of the analyses to avoid any bias. Riding speeds of Shanghai residents were classified by gender and age and then compared with the findings of a previous study. As indicated by another study in Shanghai (*1*), male cyclists ride faster than their female counterparts, regardless of age (Table 2). Moreover, among different age groups, young cyclists

Y. Tanaboriboon, Department of Civil Engineering, Tohoku University, Aoba, Aoba-ku, Sendai 980, Japan. T. Agustin, Sebelas Maret University, Surakarta, Indonesia. Y. Minfang, Asian Consultant Co., Bangkok, Thailand.

TABLE 1 Description of Observation Sites

Site No.	Name of Site	Type of Bicycle Facility	Exclusive Lane Width, m.	Total Road Width, m.	Observation Length, m.
Shanghai, China					
1	Jiangwan Road	Bike Path	8	8	197
2	Dalian Road	Bike Lane	10	24	457
3	Chifeng Road	Bike Route	-	14	268
Surakarta, Indonesia					
1	Slamet Riyadi	Bike Path	4	4	650
2	Adi Sucipto	Bike Path	4	4	400
3	Piere Tendean	Mixed Traffic Lane	-	9	300
4	Yos Sudarso	Mixed Traffic Lane	-	9	253

ride faster than adults and the elderly, with average riding speeds of 15.62, 14.8 and 11.87 km/hr, respectively. These results are also similar to previous findings (Table 2). However, it must be noted that average speeds obtained in this study were slightly different from the previous findings. This may be due to different selected survey sites, data collection periods, and techniques for collecting the speed data. The modified moving bicycle test—in which observers with stopwatches rode along with other bicyclists and recorded their travel time—was used to collect speed data in that study (*1*). Nevertheless, it is not the intention of this paper to debate the best technique for collecting bicycle speed data except to inquire whether is it time to consider seriously the publication of bicycle manual and data collection methods.

Bicycle speeds were influenced by the exclusive paths in Shanghai. While enjoying the privileged use of the entire right of way without being disrupted by other vehicular traffic, riders on the bike path obtained the highest speed—15.51 kph—compared with other bikeways (14.76 kph on the bike lane and 13.45 kph on the bike route). Undoubtedly, riders on the bike route were not provided any preferential treatment and, easily subjected to traffic interference, were the slowest. Cyclists may have more confidence in speeding when an exclusive right of way

TABLE 2 Comparison of Bicycle Speeds by Age and Gender with Previous Study, Shanghai

Characteristics	Young			Adult			Elderly		
	Men	Women	Both	Men	Women	Both	Men	Women	Both
Present Study, Shanghai 1994 (Photographic Technique)									
Mean Riding Speeds (kph)	16.37	14.56	15.62	15.29	14.2	14.8	12.3	11.05	11.87
Standard Deviation (kph)	2.3	1.98	2.35	2.46	2.52	2.55	2.08	1.61	2.02
Range									
High (kph)	24.97	22.68	24.97	23.8	22.47	23.8	18.5	16.47	18.5
Low (kph)	11.24	10.45	10.45	9.34	8.35	8.35	8.25	6.22	6.22
Sample Size	509	361	870	1002	750	1752	315	183	498
Significant at 5% level between sexes among age group	Significant			Significant			Significant		
Previous Study, Shanghai 992 (Modified Moving Bicycle Test)(1)									
Mean Riding Speeds (kph)	16.17	15.03	15.66	14.76	14.32	14.57	13.72	13.02	13.66
Standard Deviation (kph)	2.62	2.01	2.44	2.04	2.05	2.06	1.85	0.82	1.79
Sample Size	389	313	702	497	352	849	102	16	118
Significant at 5% level between sexes among age group	Significant			Significant			Significant		

is provided. Their mean speeds are significantly different at the 5 percent level.

Comparing the results of this study with the previous findings, despite two distinct techniques for collecting the speed data, the same trends were also observed on the effect of the bikeway facilities (Table 3): riders on the bike path were the fastest, and those on the bike route were the slowest. Furthermore, as indicated in a study in Beijing (*2*), mean riding speed along a street with a raised island to separate motorized and nonmotorized traffic was higher than on streets that have no separation. The observed mean speeds on these streets were 16.28 and 14.23 kph, respectively. Hence, it can be concluded that NMT exclusive lanes have a positive effect on bicycle speeds in China.

Surakarta, Indonesia

Unlike many cities in developing countries, Surakarta has paid more attention to its NMT modes. In the city planning for 1993–2013, the planning for the development and construction of the city road network also considered the expansion of NMT facilities. NMT exclusive paths will be constructed along arterial streets with minimum widths of 4.5 m in both directions or 6 m on only one side of the street (*3*). Nonetheless, the effectiveness of these NMT exclusive lanes is still subject to examination.

As mentioned earlier, NMT exclusive paths in Surakarta were used by bicycles and becaks; therefore, both NMT modes are presented separately. To verify the nonbiased selection of samples and study sites, riding speeds by gender and age were identified first. Since all becak drivers are men, no attempts were made to investigate their individual riding speeds.

BICYCLE SPEEDS

As is typical with other cyclists, male riders in Surakarta generally ride faster than their female counterparts (12.1 versus 11.08 kph), and young cyclists are the fastest group (Table 4). However, typical results were obtained for riding speeds along exclusive paths and ordinary routes. The mean speeds observed along the exclusive bike paths and the mixed traffic lanes were nearly the same (11.87 versus 11.80 kph) and were found to have no significant difference at the 5 percent level (Table 5). Moreover, the maximum riding speed observed along the exclusive paths (25.26 kph) was even slower than that of the mixed traffic lanes (26.16 kph).

The main reason for these unusual trends—especially compared with the findings in Shanghai—was that the exclusive paths are not truly exclusive to NMT modes. Many intruders abuse the function of these lanes. The exclusive paths are also used for street vendors, parking lots for motorized vehicles, and even the installation of construction materials, especially if maintenance for utilities (electricity lines, telephone cables, drainage pipes, etc.) is taking place along the route. Such abusive practices interfere greatly with cyclists and hurt the condition of these exclusive bike lanes, as clearly indicated by the results of Table 5.

BECAK SPEEDS

The same technique used for capturing bicycle speeds was applied to collect the becak speeds. Becak speeds were also further classified into two distinct groups: becaks with passengers and becaks without passengers. It is not possible to identify an obvious result for becak speeds, so, to verify the nonbiased sample selections, becak speeds were first compared with bicycle speeds. Since bicycle and becak speed measurements were conducted at the same time, in the same place, and under the same conditions, their mean speeds could be compared. Undoubtedly, the average and maximum bicycle riding speeds were higher than the becak speeds (Table 6). These results are supported by another study in Indonesia (*4*), in which bicycle speeds were found to be greater than becak speeds. Nonetheless, typical results were again obtained for the NMT mode in Surakarta.

Considering the speeds of becaks with and without passengers, one may easily presume that having higher loads, becaks with passengers would travel more slowly. However, of the average speed of becaks with passengers (11.05 kph) was higher than that of becaks without passengers (9.94 kph) (Table 7). Moreover, even when further analyses were made to classify these speeds along the different paths, the same findings were obtained. No matter whether they were on the exclusive paths or the mixed traffic lanes, becaks without any passengers traveled still slower than when they were

TABLE 3 Comparison of Bicycle Riding Speeds on Each Bikeway Facility with Previous Study, Shanghai

Characteristic	Present Study, Shanghai 1994 (Photographic Technique)			Previous Study, Shanghai 1992 (Modified Moving Bicycles Test) (1)		
	Bike Path (Jiangwan Road)	Bike Lane (Dalian Road)	Bike Route (Chifeng Road)	Bike Path (Fengyang Road)	Bike Lane (Nanjing Road)	Bike Route (Rujing Road)
Mean Speed (kph)	15.51	14.76	13.45	15.26	14.83	14.29
Standard Deviation (kph)	2.46	2.31	2.82	2.06	2.37	1.71
Sample Size	1007	993	1116	430	424	408
Significance of difference between mean speed at 5% significant level	Significant	Significant	Significant	Significant	Significant	Significant

TABLE 4 Comparison of Bicycle Speeds by Age and Gender, Surakarta

Item	Sex			Age		
	Men	Women	Combined	Young	Adult	Elderly
Mean Speed (kph)	12.1	11.08	11.83	12.24	11.78	11.27
Standard Deviation (kph)	2.2	1.49	2.08	2.31	2.06	1.54
Range						
High (kph)	26.16	18.29	26.16	24.59	26.16	17.35
Low (kph)	6.85	6.78	6.78	7.03	6.78	7.82
Sample size	1486	547	2033	504	1274	255
Significance of difference between means at 5% level	Significant			Significant	Significant	Significant

TABLE 5 Comparison of Bicycle Speeds on Different Paths, Surakarta

Item	Exclusive Bike Path	Mixed Traffic Lane
Mean Speed (kph)	11.87	11.80
Standard Deviation (kph)	1.84	2.24
Range		
High (kph)	25.26	26.16
Low (kph)	7.03	6.78
Sample Size	837	1196
Significance of difference between means at 5% level	Not Significant	

carrying passengers. This phenomenon occurs because drivers without passengers tend to ride slowly while searching for potential passengers, whereas drivers with passengers rush to their customers' destinations so as to be able to search for their next passengers.

Similar findings were obtained for exclusive becak paths. Table 7 presents the results of mean becak speeds observed along the exclusive and nonexclusive paths. Regardless of the lane traveled, becak speeds were nearly the same (10.49 versus 10.45 kph). Even becaks with and without passengers did not have a difference in mean speeds that was significant at the 5 percent level (Table 8). In other words, exclusive facilities in Surakarta have no effect on becak speeds.

The maximum riding speed observed on the nonpreferential treatment routes (23.91 kph) was much higher than that on exclusive paths (13.71 kph), for the same reason given for the bicycles: obstructions along the exclusive paths prevented becak drivers from speeding up. It must be noted that those speeding on the mixed traffic lanes were subject to higher accident risk; even so, drivers still rode faster on the nonexclusive path.

CONCLUSION AND RECOMMENDATIONS

The benefits of the NMT exclusive facilities rely heavily on the ways in which the provided facilities are used. This paper has shown that not all existing NMT paths have positive effect on the NMT modes, especially if others cannot be prevented from occupying the paths. Shanghai cyclists could enjoy the faster riding speeds on the exclusive bike lanes, but Surakarta residents found no difference in

TABLE 6 Comparison of Bicycle and Becak Speeds, Surakarta

Item	Bicycle	Becak
Mean Speed (kph)	11.83	10.46
Standard Deviation (kph)	2.09	2.01
Range		
High (kph)	26.16	23.91
Low (kph)	6.78	5.25
Sample Size	2033	954
Significance of difference between means at 5% level	Significant	

TABLE 7 Comparison of Becak Speeds With and Without Passengers on Different Facilities, Surakarta

Item	Becak Path		Mixed Traffic Lane		Combined	
	with	without	with	without	with	without
Mean Speed (kph)	10.93	9.99	11.09	9.92	11.05	9.94
Standard Deviation (kph)	1.26	1.34	2.00	2.16	1.83	2.02
Range High (kph)	13.71	12.77	23.91	19.95	23.91	19.95
Range Low (kph)	7.48	7.30	6.14	5.25	6.14	5.25
Sample Size	116	104	331	403	447	507
Significance of difference between means speed at 5% level	Significant		Significant		Significant	

Note: With - with passengers
Without - without passengers

travel speeds along the exclusive paths whether on their own bicycles or in becaks. The main reason is that the exclusive paths were not truly exclusive.

Nevertheless, this phenomenon in Surakarta came as no surprise—in many instances in developing countries, exclusive lanes are abused by unauthorized vehicles. The best example is the provision of bus priority lanes. Although bus lanes have been proven many times to have a positive impact, inconsistent and inefficient enforcement have caused special privileges for bus-only lanes to fade, and eventually they become ordinary lanes, just as is happening in Bangkok (*5*).

Such failures do not mean that NMT exclusive lanes play an insignificant role. Instead, more tactics should be considered to promote and expand exclusive paths. Provision of these lanes may help minimize conflicts with other vehicular traffic, resulting in a smoother flow as observed in Shanghai. Besides, these lanes can become attractive especially to ensure safety, which is of concern particularly to nonusers.

The provision of NMT exclusive lanes by itself will not promote further uses of NMT. Other facilities to ensure more convenience and comfort as well as safety must also be considered. Incentives to use NMT modes must also be clearly defined, but perhaps the most important of all is each government's policy of promoting NMT. In reality, this task becomes extremely difficult. Not only do the concerned authorities have no interest in promoting NMT modes, but commuters are trying in vain to shift to motorized vehicles. In most developing countries, those who cannot afford automobiles first try to obtain motorcycles. Owning motorized vehicles is no longer only a means of transportation; to some it is a social or status symbol. Attaining a sustainable society will be a difficult task, another challenging issue for believers in NMT.

TABLE 8 Comparison of Becak Speeds on Different Paths, Surakarta

Item	Becaks with Passengers		Becaks without Passengers		Combined	
	Becak Path	Mixed Traffic Lane	Becak Path	Mixed Traffic Lane	Becak Path	Mixed Traffic Lane
Mean Speed (kph)	10.93	11.09	9.99	9.92	10.49	10.45
Standard Deviation (kph)	1.26	2.00	1.34	2.16	1.38	2.17
Range High (kph)	13.71	23.91	12.77	19.95	13.71	23.91
Range Low (kph)	7.48	6.14	7.30	5.25	7.30	5.25
Sample Size	116	331	104	403	220	734
Significance of difference between means speed at 5% level	Not Significant		Not Significant		Not Significant	

REFERENCES

1. Tanaboriboon, Y., K. Hokao, Y. Guan, and J. Qian. Speed Study on the Non-Motorized Transport in China. *Proc., International Symposium on Non-Motorized Transportation,* Beijing, China, 1994, pp. 145–150.
2. Liu, X., L. D. Chen, and F. Ren. Operational Analysis of Bicycle Interchanges in Beijing, China. In *Transportation Research Record 1396,* TRB, National Research Council, Washington, D.C., 1993, pp. 18–21.
3. *The Outline of General City Planning for Surakarta Municipality Years 1993–2013* (in Indonesian). Government of Surakarta Municipality, Indonesia, 1993.
4. Soegijoko, B. T. S., and S. I. Horthy. Role of Non-Motorized Transport Modes in Indonesian Cities. In *Transportation Research Record 1294,* TRB, National Research Council, Washington, D.C. 1991, pp. 16–25.
5. Tanaboriboon, Y. An Overview and Future Direction of Transportation Demand Management in Asian Metropolises. *Regional Development Dialogue,* Vol. 13, No. 3, 1992, pp. 46–73.

Nonmotorized Vehicles in Metropolitan Manila: Return of the Pedicabs

DEREK DYLAN BELL AND CHIAKI KURANAMI

Metropolitan Manila, the capital city of the Philippines, is located on Luzon Island and consists of four cities and 13 municipalities. In the 1960s and 1970s incomes were on the increase and the popular pedicabs (the local term for bicycles with sidecars that serve as nonmotorized taxis) of the 1950s were increasingly motorized (this motorized version of the pedicab is called a tricycle). However, the almost extinct pedicabs reappeared during the early 1980s at the time of the Ferdinand Marcos economic downturn and quickly regained popularity. Though not favored by government officials, pedicabs are popular with some residents and account for about 20 percent of all vehicle traffic in areas of nonmotorized vehicle (NMV) use. The pedicabs are joined by other NMVs such as handcarts, bicycles, and calesas (two-wheeled horse-drawn carriages). All of these NMVs have been on the increase recently, in part because of the structurally weak Philippine economy. As long as the unemployment situation does not improve and urban migration is not controlled, NMVs will provide a source of employment and means of livelihood. The number of poor people in metro Manila has been increasing in the past few years with little sign of abatement, and this has coincided with an increase in the number of pedicabs. Consequently, the national and local governments need to address this issue through balanced transport planning and the provision of a low-cost NMV transportation infrastructure.

The Philippines has a current population of 64.3 million. Metropolitan Manila, the largest and most densely populated region in the nation, has a population of 8.4 million and a population density of 13,160 residents per square kilometer. The average annual growth rate of this region's population from 1980 to 1985 was 3.1 percent, which decreased to 2.8 percent from 1985 to 1990. This trend is expected to continue in the future as the growth rate from 1990 to 1995 is forecast to be 2.4 percent. Rural migration is high: 45 percent of the nation's work force is in agriculture. The poorest of these migrants live in slums and squatter areas with no electricity or running water. The average household size in metro Manila is 5.4 persons (*1*, p.60).

The country's gross domestic product (GDP) per capita was $730 (U.S.) in 1991 (*2*, p.238). The country experienced a negative GDP growth rate of −1.0 percent and an inflation rate of 17.7 percent in the same year (*3*, p.134). These economic woes were combined with political uncertainties until early June 1992, when voters picked Fidel Ramos to succeed Corazon Aquino as President of the Philippines. The stagnating economy is partly a result of chronic electric power failures, which affect the operations of traffic signals and gasoline stations.

Padeco Co., Ltd., Yamaji Sanbancho Building, 5–24, Sanbancho, Chiyoda-ku, Tokyo 102, Japan.

TRANSPORTATION INFRASTRUCTURE

In metro Manila, there are 2980 km of roads, about 85 percent of which are paved. The main thoroughfares are in relatively good physical shape, but many of the side streets are in poor condition with broken pavement and numerous potholes. A lack of adequate pedestrian facilities has made travel by foot very dangerous, and pedestrians make up the majority of traffic accident fatalities. Along side streets, many of which are narrow with parked vehicles lining both sides, large motorized vehicles (MVs) have difficulty maneuvering. As a result, many nonmotorized vehicles (NMVs) can be found here. In general, there is a lack of well-developed secondary roads to support the reasonably good thoroughfares in metro Manila.

Drainage along side streets is insufficient, and flooding is a problem. In some roadways water is knee-deep during rainstorms. When this flooding occurs, pedicabs are the most reliable form of transportation for short distances, distances that people normally walk but do not because of the flooding.

VEHICLE OWNERSHIP

Handcarts

With the 1992 water shortage in metro Manila, handcarts increasingly were used to haul water in containers sold to residents in subdivisions or low-cost housing communities. Handcarts are also used for solid waste collection and waste paper recycling (Figure 1). For example, the Kaunlaran Multi-Purpose Cooperative, organized in 1991, with financing from the Development Bank of the Philippines (DBP), owns about 30 handcarts for collecting waste paper from households based in Barangay Kaunlaran of Quezon city. Each handcart has a capacity of about 100 kg. The kariton (cart) boys are given some initial business capital by the cooperative in the amount of 200 pesos ($8) a day. This money enables them to buy waste paper and old magazines and newspapers, which they sell to the cooperative. The cooperative, in turn, sells these items to paper mills for recycling.

The cooperative's undertaking is basically a buy-and-sell business that aims to provide unemployed and out-of-school youths with a source of income and to combat growing poverty. Members pay a one-time 20-peso ($0.80) membership fee and are required to take paper management seminars or training programs sponsored by PULPAPEL, an association of private pulp and paper companies. These seminars and programs teach paper sorting, grading (for price estimation), and basic accounting. Other regularly held seminars are sponsored by the Board of Investments and the DBP. Many of the members have been able to succeed, and additional handcarts have been purchased at 600 to 900 pesos ($24 to 36) each.

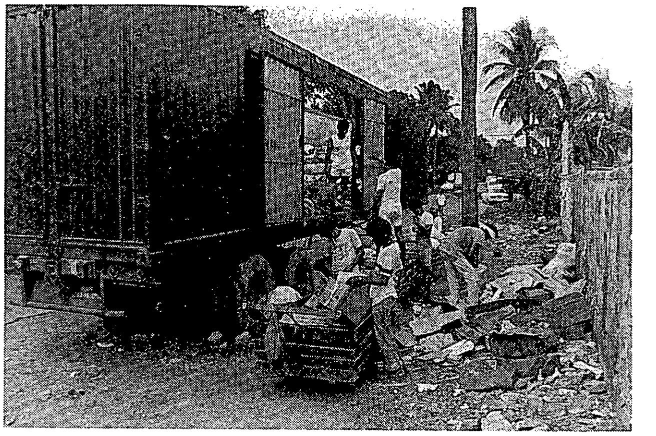

FIGURE 1 Kariton (cart) boys involved in wastepaper recycling.

The cooperative, which is supported by paper mills in terms of technical management, is assured a market for the waste paper it collects. The NMVs (handcarts) are a cheap form of transport for the buy-and-sell business of the cooperative, enabling it to undertake the dual function of being a private enterprise and a civic-oriented organization for assisting out-of-school youths and the unemployed. About 10 kariton boys deliver waste paper daily. Expansion plans are being pursued by the cooperative's management to reach out to other barangays (organized residential communities forming the smallest political subdivisions in the Philippines). The cooperative has acquired a six-wheeled truck to complement its handcarts in delivering 3 or 4 tons of waste paper two to three times a week to the paper mills.

Calesas

Calesas (Figure 2) are very limited in number primarily because they are relatively expensive to maintain and cater mainly to tourists. About 20 years ago calesas were very popular, but now they have been all but replaced by motorized jeepneys. Some local residents, especially store owners in Chinatown, still prefer calesas, which has helped ensure their limited survival.

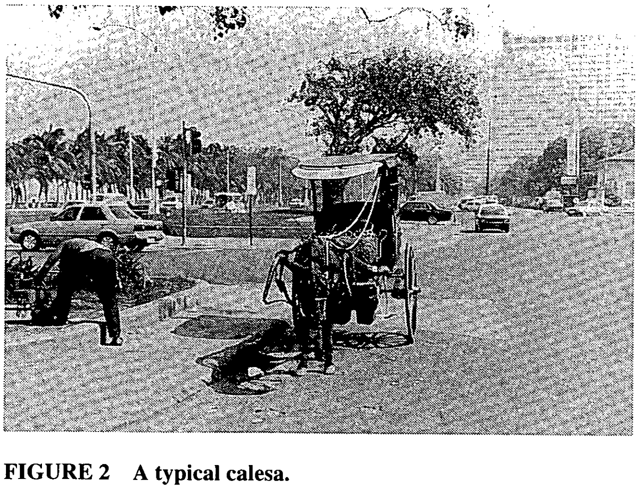

FIGURE 2 A typical calesa.

Bicycles

Bicycles are not registered in metro Manila, and there are no good records of their numbers. The figure in Table 1 is a best guess based on the estimates of government officials and the results of field surveys.

An increasing number of private messenger services use bicycles. In the early 1980s the government bought thousands of bicycles and distributed them to postal employees in metro Manila and the surrounding provinces on an installment basis, but this program was halted quickly without review.

Pedicabs

Determined by local government staff, the allotted numbers of pedicabs (Figure 3) per district in metro Manila are based on the "measured capacity" or the estimated number of people requiring service. Because the number of pedicabs in operation is two to three times higher than the number registered, the figure in Table 1 was estimated on the basis of registered and estimated unregistered numbers for Manila, Quezon city, and Makati expanded to metro Manila.

Most of the bicycles used for pedicabs come from Taiwan. The size and quality of the pedicab sidecars depend on the type of bicycle used. Pedicabs are basically bicycles (similar to mountain bikes) with a sidecar (sometimes covered, with or without seats).

Motorized Vehicles

Tricycles are powered mostly by Japanese motorcycles with engine displacements of 80 to 125 cc. Sidecars are produced locally by a variety of manufacturers, usually separate from motorcycle manufacturers. The sidecar can be mounted to the motorcycle by numerous mechanical shops throughout metro Manila. Tricycles and motorcycles combined represent only 9.7 percent of all registered MVs in metro Manila.

Jeepneys, which account for 37 percent of all registered MVs, are produced entirely in the Philippines. They are built primarily by hand in small auto body shops throughout metro Manila and neighboring areas. Many of these jeepneys are decorated lavishly with various accessories such as antennas, lights, curtains, and mirrors. Officials at the Department of Transportation and Communications (DOTC) estimate that there are far more jeepneys operating as "public utilities" than the 27,659 units registered as such.

Although metro Manila contains only 7.7 percent of the nation's population, it accounts for 68 percent of all automobiles, 52 percent of all trailers, 41 percent of all jeepneys, 34 percent of all trucks, 29 percent of all buses, and 17 percent of all motorcycles and tricycles. Automobile and jeepney ownership levels in 1990 were 39 and 32 per 1,000 population, respectively, whereas the level for motorcycles and tricycles combined was only 8.3 per 1,000 population.

NMV USE

Modal Split

According to surveys performed in 1984, metro Manila was an MV-dependent city—less than 1 percent of all person trips were made

TABLE 1 Vehicles by Type in Metro Manila, 1990

Classification	Vehicle Type	Number	Per Cent of Motorized Vehicles	Per Cent of Non-Motorized Vehicles
Private	Bicycle[a]	100,000	-	100.0%
	M/C & Tricycle[b]	48,413	8.1%	-
	Automobile	288,736	48.4%	-
	Jeepney	212,017	35.5%	-
	Bus	746	0.1%	-
	Truck	40,225	6.7%	-
	Trailer	6,632	1.1%	-
	Subtotal	696,769	100.0%	100.0%
For Hire	Pedicab[c]	5,500	-	95.7%
	Calesa[d]	250	-	4.3%
	M/C & Tricycle	16,418	26.8%	-
	Automobile	8,150	13.3%	-
	Taxi	1,715	2.8%	-
	Jeepney	27,659	45.1%	-
	Bus	4,329	7.1%	-
	Truck	2,532	4.1%	-
	Trailer	477	0.8%	-
	Subtotal	67,030	100.0%	100.0%
Total[e]	Bicycle	100,000	-	94.6%
	Pedicab	5,500	-	5.2%
	Calesa	250	-	0.2%
	M/C & Tricycle	66,577	9.7%	-
	Automobile	306,959	44.8%	-
	Jeepney	251,635	36.7%	-
	Bus	5,247	0.8%	-
	Truck	44,892	6.6%	-
	Trailer	9,468	1.4%	-
	Total	790,528	100.0%	100.0%

[a]Estimate based on discussions with local and national government officials.
[b]Motorcycles and tricycles are not categorized separately by the DOTC.
[c]Estimate based on registered numbers.
[d]Estimate based on field surveys and discussions with government officials.
[e]Totals may be greater than the sum of private and for-hire vehicles because of other categories, such as government-owned and diplomatic vehicles, not detailed above.

FIGURE 3 Pedicabs outside a light-rail station.

by NMVs (excluding walking). Mass public transit accounted for 15 percent, and most trips were made by automobile, jeepney, taxi, and other forms of low-capacity motorized transit (*4*, p.55).

Recent traffic counts in 12 locations in metro Manila, however, indicate that the share of NMVs is much higher, up to 34 percent in areas with frequent NMV use, with handcarts, bicycles, and calesas each accounting for a 4 to 5 percent mode share (*5*). The figure for calesas is slightly high since three of the locations in metro Manila were in Chinatown, which still has many calesas in operation. At these three locations calesas made up 16 percent of all vehicles (Table 2).

Metro Manila is unusual for a major city in Southeast Asia in that it has a relatively low number of motorcycles, and very few bicycles are used. In addition, it is clear from Table 2 that pedestrian activity is relatively high. This finding is supported by several surveys performed in the 1980s (*6*, p.4). In terms of vehicle use, automobiles/jeeps/taxis are most common with pedicabs and jeepneys

TABLE 2 Traffic Composition on 12 Typical NMV-Use Roads in Metro Manila

Mode	Total (Per Cent)	Per Cent of Vehicular Traffic	Per Cent of Motorized Vehicles	Per Cent of Non-Motorized Vehicles
Pedestrian	1,419 (33.4%)	-	-	-
Handcart	133 (3.1%)	4.7%	-	13.9%
Bicycle	147 (3.5%)	5.2%	-	15.4%
Pedicab	564 (13.3%)	19.9%	-	59.1%
Calesa	110 (2.6%)	3.9%	-	11.5%
Motorcycle	150 (3.5%)	5.3%	8.0%	-
Tricycle	17 (0.4%)	0.6%	0.9%	-
Auto/Jeep/Taxi	1,006 (23.7%)	35.5%	53.9%	-
Jeepney	447 (10.5%)	15.8%	23.8%	-
Truck	213 (5.0%)	7.5%	11.3%	-
Bus	45 (1.1%)	1.6%	2.4%	-
Total	4,251 (100.0%)	100.0%	100.0%	100.0%

placing second and third, respectively. The number of tricycles is quite low, largely because of the selection of survey locations and local government requirements that pedicabs operate in non–tricycle use areas (discussed later).

Reasons Pedicabs Are Preferred

Results from a recent pedicab user survey (*5*), summarized in Table 3, indicate a substantial reliance on pedicabs for a majority of users. The typical pedicab user is in an area not served by bus, does not own an automobile, is either commuting or shopping, and is traveling a distance of 1 km.

As for the reasons users gave for patronizing pedicabs, 72 percent of all users' responses were that pedicabs are less time-consuming and that the users do not want to walk. Both of these answers are similar in meaning since "do not want to walk" can be understood as implying that users would prefer a quicker means of transport. Only 17 percent of those responding that they did not want to walk cited the hot weather as a major factor.

The lack of bus or jeepney service reportedly caused 22 percent of the users to choose the pedicab. Clearly, a lack of bus service is not the main reason for patronizing pedicabs. For users who could have chosen to ride a bus rather than a pedicab, the two responses were "destination is near" and "bus is too crowded." These two answers likely reflect the main reasons that bus service is inferior for short-distance trips.

About a quarter of the respondents answered that they have an automobile in the household but prefer not to drive because "the destination is near," "the roads are too crowded," or "there is no parking available." Here again it is apparent that pedicabs are considered superior for short trips and in congested areas where maneuvering and parking conventional MVs is difficult.

Characteristics of Travel by Pedicab

An overwhelming number of pedicab users make shopping trips or commute between their homes and work places. Also common were trips between shopping areas and work places. No one was using a pedicab for school trips or for sightseeing. Pedicabs in metro Manila, unlike calesas, are rarely patronized by tourists.

The next item concerns the frequency of pedicab use. To better understand how often these NMVs are used and thus their relative importance in meeting daily travel needs, users were asked how many times each week they hire a pedicab. More than 29 percent of all users patronize pedicabs daily, and only 1.4 percent use a pedicab less than once a week. The average number of pedicab trips per user is four per week.

Patrons were then asked to provide the travel times for their pedicab trips. This information allows one to determine the average travel time and trip length of pedicabs for comparison with other forms of public transportation. As shown, the majority travel for 5 min or less in a pedicab. Considering that the average speed of pedicabs in traffic is 10 km/hr, this corresponds to a distance of less than 1 km.

An occupancy count survey was also performed to determine the average number of passengers per pedicab. Most carry two passengers. Although it is illegal, 19 percent of all pedicabs were observed carrying three passengers, often one adult with two children. Basically, no pedicabs were observed empty because they wait at designated terminal points to pick up passengers rather than cruising for patrons.

Safety and Accidents

Traffic is very congested and chaotic in metro Manila. People are constantly using their horns, and one observes MVs advancing in stop-and-go jerking movements, weaving in and out of lanes, and even straddling two lanes. Jeepneys often delay traffic by stopping in the middle of the road to let passengers board or alight. Conditions are exceptionally bad during brownouts, when many traffic signals stop working.

As one might expect, the number of people killed in traffic accidents is very high in metro Manila and corresponds to a fatality rate of 17.9 per 100,000 population. Many of these fatalities are the result of MVs striking pedestrians. The specific type of vehicles involved in traffic accidents is detailed in Table 4 for the area that encompasses the city of Manila, Quezon city, and Makati municipality, accounting for 49 percent of metro Manila's population.

TABLE 3 Pedicab User Survey Results in Metro Manila, 1992

Why People Use a Pedicab	Per Cent	
Less Time-Consuming	37.9%	
Do Not Want to Walk	33.6%	
No Bus or Jeepney Service	22.1%	
More Convenient	6.4%	
Total	100.0%	
Why Pedicab Users Do Not Ride a Bus	Per Cent	
No Service	95.7%	
Destination is Near	2.9%	
Bus is Too Crowded	1.4%	
Total	100.0%	
Why Pedicab Users Do Not Drive an Auto	Per Cent	Per Cent of Auto Owners
No Auto in the Household	75.7%	-
Destination is Near	10.7%	44.1%
Roads are Too Crowded	7.1%	29.4%
No Parking Available	6.4%	26.5%
Total	100.0%	100.0%
Trip Purpose of Pedicab Users	Per Cent	
Home to Shop/Shop to Home	51.4%	
Home to Work/Work to Home	42.9%	
Work to Shop/Shop to Work	5.7%	
Total	100.0%	
Trip Frequency of Pedicab Use	Per Cent	
Daily	29.3%	
5-6 Times a Week	11.4%	
3-4 Times a Week	21.4%	
1-2 Times a Week	36.4%	
Infrequently	1.4%	
Total	100.0%	
Pedicab Travel Time per Trip	Per Cent	
1-2 Minutes	2.1%	
2-5 Minutes	52.1%	
5-10 Minutes	39.3%	
10-15 Minutes	6.4%	
Total	100.0%	
Number of Passengers per Pedicab	Per Cent	
One Passenger	28.6%	
Two Passengers	52.9%	
Three Passengers	18.6%	
Total	100.0%	

Although the number of pedestrians involved in the total number of accidents is low, pedestrians' share of fatalities and injuries is quite high. This is also true of bicycles and pedicabs, though to a much lesser degree. Automobiles and jeeps for private use are most often involved in all types of traffic accidents. Vehicles involved in fatal traffic accidents at rates significantly below their observed traffic shares are calesas, bicycles, pedicabs, and jeepneys. Those with fatality rates exceeding their traffic shares are buses and a combination of automobiles, jeeps, and taxis.

The argument that NMVs are unsafe and pose a threat to motorized traffic appears baseless according to data on reported traffic accidents. From these data, it is clear that the biggest issue should be the safety of pedestrians from accidents caused by MVs since this accident type accounts for most traffic accident fatalities. Automobiles, jeeps, and buses are the vehicles with the highest accident rates, and they should be the targets of traffic safety campaigns.

COSTS AND FARES

Acquisition Prices

Second-hand bicycles and pedicabs cost about 1,000 and 2,800 pesos ($40 and $112), respectively (Table 5). Foreign-made bicycles and bicycle parts are subject to import duties of 50 and 20 percent, respectively. Tricycles are considerably more expensive, with an average second-hand price of 20,000 pesos ($800) and an average new price of 48,000 pesos ($1,920). This involves the cost of the motorcycle unit and a sidecar, which must be capable of traveling at speeds greater than those of pedicab sidecars. For people with little savings, the pedicab is clearly the most affordable capital investment available. Jeepneys, by contrast, are the most expensive at about 400,000 pesos ($16,000) for a second-hand vehicle and 1,600,000 pesos ($64,000) for a new one. As a result, most jeepney drivers do not own but instead rent the vehicles they operate for hire.

TABLE 4 Vehicles Involved in Traffic Accidents in the City of Manila, Quezon City, and Municipality of Makati, 1991

	Type of Accident[a]			
Vehicle Involved	Fatal (Per Cent)	Injury (Per Cent)	Property Damage (Per Cent)	Total (Per Cent)
Pedestrian	116 (40.3%)	1,252 (35.9%)	86 (0.4%)	1,454 (5.8%)
Handcart	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Bicycle or Pedicab	14 (4.9%)	45 (1.3%)	110 (0.5%)	169 (0.7%)
Calesa	0 (0.0%)	0 (0.0%)	2 (0.0%)	2 (0.0%)
Motorcycle	7 (2.4%)	141 (4.0%)	1,247 (5.8%)	1,395 (5.5%)
Tricycle	2 (0.7%)	77 (2.2%)	253 (1.2%)	332 (1.3%)
Private Auto	32 (11.1%)	526 (15.1%)	9,645 (45.1%)	10,203 (40.6%)
Private Jeep	44 (15.3%)	508 (14.6%)	3,363 (15.7%)	3,915 (15.6%)
Private Trailer	1 (0.3%)	114 (3.3%)	279 (1.3%)	394 (1.6%)
Taxi	9 (3.1%)	4 (0.1%)	4 (0.0%)	17 (0.1%)
Jeepney	18 (6.3%)	259 (7.4%)	2,514 (11.8%)	2,791 (11.1%)
Truck	13 (4.5%)	204 (5.9%)	1,094 (5.1%)	1,311 (5.2%)
Bus	29 (10.1%)	258 (7.4%)	2,265 (10.6%)	2,552 (10.1%)
Mil/Gov't Vehicle	3 (1.0%)	98 (2.8%)	509 (2.4%)	610 (2.4%)
Total	288 (100.0%)	3,486 (100.0%)	21,371 (100.0%)	25,145 (100.0%)

[a]Data was obtained from the Traffic Engineering Center, Quezon City Traffic Police Station, and Makati Traffic Police Station.

Fares in Public and Freight Transportation

Most pedicabs and tricycles in metro Manila are for public transit use, but some are equipped with a simply constructed sidecar used for transporting goods. Passenger fares are fixed by each local government for the registered pedicabs in its domain. Tricycle, taxi, and jeepney fares are under the control of the national government. Rates for goods movement are not controlled and are therefore subject to negotiation.

In the city of Manila, pedicabs are authorized to follow the fares prescribed by the Land Transportation Franchising and Regulatory Board for tricycles. This fare is 2.00 pesos ($0.08) for the first kilometer of travel and 0.50 pesos ($0.02) for every kilometer thereafter. In Quezon city, the rates are specified according to local ordinance at 1.00 pesos for the initial kilometer and 0.20 pesos for each additional kilometer.

However, from the field surveys, it is apparent that pedicabs rarely charge such low fares. In one area of the city of Manila, pedicab drivers charge local users a minimum of 5.00 pesos ($0.20) for 0.5 km, and beyond that they charge 10 to 20 pesos depending on the distance. In Chinatown, where most pedicabs and calesas are hired for short-distance travel and often for moving cargo, fares range from 25 to 100 pesos per trip depending primarily on the weight of the cargo. Fares are more tightly controlled in Quezon city and Makati, where the costs per trip per passenger are 1.50 to 7.00 and 3.00 pesos, respectively. After paying for their daily boundary costs (discussed later), pedicab operators in metro Manila net at least 85 to 165 pesos ($3.40 to $6.60) a day.

During flooding, pedicab drivers charge up to 10 times their normal rates because of significantly increased demand. Clearly, fare regulations have had little influence on the actual fares being charged. Pedicab operators can take advantage of the situation because people in some areas have no alternative mode available, not even walking. Tricycles stall out in flooded areas, and other public transit vehicles simply avoid traveling on routes affected. One could conclude that the inadequate drainage infrastructure in metro Manila helps support the survival of pedicabs.

TABLE 5 Prices of Different Vehicles in Metro Manila, 1992 (Pesos)[a]

	New Vehicles		Second-Hand Vehicles	
Vehicle Type	Price Range	Average Price	Price Range	Average Price
Bicycle	2,500 - 10,000	4,500	1,000 - 2,000	1,300
Pedicab	4,500 - 8,000	6,500	2,800 - 4,000	3,500
Motorcycle	30,000 - 100,000	45,000	no data	18,000
Tricycle	40,000 - 55,000	48,000	no data	20,000
Automobile	375,000 - 1,500,000	800,000	no data	200,000
Jeepney	700,000 - 2,000,000	1,600,000	no data	400,000

[a]Estimated by DOTC officials; US$ 1 = 25 pesos.

Annual Registration Fees

Although bicycles for personal use are not registered, pedicab operators and drivers are required to register their units with the local government office. The procedures of pedicab registration vary by local government, as do registration fees. In the city of Manila, the annual pedicab registration fee is 170 pesos ($6.80), of which 10 pesos is actually for vehicle registration, 10 pesos pays for a license enabling the pedicab to operate as a public utility and carry passengers for a fee, and 150 pesos is for the driver's license. In Quezon city, the annual registration fee is 250 pesos ($10), which is the same rate applied to tricycles at the local government level. The rate in Makati is 285 pesos ($11.40).

Tricycles are required to register with both the national and local governments. Local government procedures vary as the Land Transportation Office (LTO) of the DOTC requires a permission note from the respective local government before tricycle registration. This permission note costs about 40 pesos ($1.60) per year, but some local governments require local registration, which costs about 250 pesos per year and then serves as a permission note for the LTO. The national government fees for tricycles total an additional 450 pesos ($18). As a result, pedicabs are much cheaper to register than tricycles.

Operating and Maintenance Costs

Average annual operating and maintenance costs for all vehicles except trucks were calculated on the basis of data provided by LTO and previous transportation studies in metro Manila (*7*). As shown in Table 6, NMVs except for calesas are very cheap to operate and maintain compared with MVs. A pedicab costs less than 6 percent as much as a tricycle at only 800 pesos ($32) a year in contrast to 15,000 pesos ($600) a year, respectively. Calesas are relatively expensive since the cost of feeding and caring for a horse is involved. This high cost also explains why their numbers have dwindled.

One reason that pedicabs have become more popular, according to government officials, was the sudden increase in gasoline prices after the Gulf War. Gasoline prices soared from 8.00 pesos/liter to 12.75 pesos/liter, an increase of 59 percent. As of June 1992, gasoline prices leveled off at about 11 pesos/liter ($1.67/gal). Government officials have indicated that this increase in gasoline prices was followed by an increase in the number of pedicabs operating in metro Manila. Many people previously operating tricycles switched back to pedicabs. These people were joined by a larger number of new entrants into the pedicab service market.

Rental Charges

Most pedicab drivers rent vehicles from their owners, who pay for all maintenance costs. Drivers are charged a daily rent called a "boundary fee," which ranges from 30 to 65 pesos ($1.20 to 2.60). In some cases, the pedicab driver enters a verbal rental agreement for a longer period of time lasting several months.

NMV REGULATIONS AND ENFORCEMENT

Vehicle Registration

A pedicab owner must be a member of a pedicab operator association to qualify for registration with the city of Manila. These operator associations must, in turn, be registered with the Securities and Exchange Commission. Operators are further required to obtain insurance for third-party liability of at least 10,000 pesos ($400), which requires an affidavit of ownership. The pedicab driver is required to pass a medical health examination, and both the owner and driver must each provide a certificate of police clearance.

Third-party liability insurance is required for all motorized public utility vehicles throughout the country so that passengers have some form of protection. However, only the city of Manila and Makati municipality impose this rule on pedicabs. Even so, the insurance requirement for pedicab owners is not strictly enforced because insurance coverage tends to be expensive. Along similar lines, the health certificate requirement for pedicab drivers was instituted in 1992 in both the city of Manila and Makati municipality, and the two local governments received numerous complaints about how the required x-rays are too expensive. As a result, this requirement is not enforced either. Police clearance is required by all local governments to ensure that the applicant does not have any outstanding fines or warrants for his/her arrest.

The main reason that local governments decided to register pedicabs was to try to gain greater control over their numbers and operation. The local governments also required pedicabs to register because they wanted passengers to be insured by pedicab owners. During registration procedures in the city of Manila, potential pedicab drivers are even given a seminar on courtesy and safety. Interestingly, the local government of the city of Manila believes that the

TABLE 6 Average Annual Vehicle Operating and Maintenance Costs in Metro Manila, 1992 (Pesos)[a]

Vehicle Type	Tires	Lubrication	Fuel	Maintenance	Total
Bicycle	100	-	-	300	400
Pedicab	150	-	-	650	800
Calesa	250	-	-	15,000	15,250
Motorcycle	300	100	5,200	1,150	6,750
Tricycle	850	200	11,550	2,400	15,000
Automobile	1,100	400	22,000	5,300	28,800
Jeepney	3,750	1,750	79,100	14,100	98,700
Bus	36,500	7,100	298,950	38,000	380,550

[a]Based on estimates provided by representatives of the DOTC, City of Manila, Quezon City, and Makati Municipality; US$ 1 = 25 pesos.

creation of these pedicab ordinances in itself caused a boom in the numbers of pedicabs, possibly due to their sudden "official" legitimacy.

Restrictions on NMV Operations

When Ferdinand Marcos was president, he signed a presidential decree prohibiting tricycles and pedicabs from operating on major thoroughfares without placing any restrictions on handcarts, bicycles, or calesas. This holds true today, and one can observe handcarts, bicycles, and calesas on major thoroughfares, with only a few pedicabs and tricycles operating in violation of the law. Calesas are exempt for reasons of tourism promotion.

Pedicabs are also banned on any street allowing maximum speeds greater than 40 km/hr. In the city of Manila, pedicabs are prohibited to operate in areas already served by jeepneys or buses. Quezon city prohibits pedicabs from operating in areas already served by tricycles, jeepneys, or buses. Interestingly, Makati prohibits the operation of calesas. Throughout metro Manila, local ordinances limit the number of pedicab passengers to two.

Enforcement

Enforcement efforts and penalties vary by local government. In the city of Manila, the local ordinance states that violators will be punished by a fine of not more than 200 pesos ($8), by imprisonment of not more than 6 months, or by both a fine and imprisonment. Pedicabs are not impounded in the city of Manila as ticket issuance and payment are performed on the spot by local traffic police. In Quezon city, one must pay 350 pesos to retrieve an impounded pedicab. However, Quezon city commonly charges a 50-peso fee at the time of incident rather than impounding a vehicle. The municipality of Makati sometimes impounds pedicabs operating in violation of local law but normally charges a penalty of 50 pesos per infraction. Even though the daily net income of pedicab drivers is only 85 to 150 pesos, these fines are considered by government officials to be too low to discourage illegal pedicab operations.

The Makati municipality is unusual in that it employs 30 "traffic enforcers" who patrol the entire municipality and mainly look for illegal pedicabs or tricycles operating on main streets where they are prohibited. This may have helped to keep fares low, but it has not limited the number of unregistered pedicabs operating illegally in the area. According to a recent field survey in Makati, only 32 percent of the more than 500 pedicabs operating in Barangay Bangkal, one section of Makati, were registered.

NMV FACILITIES

The city of Manila has some yellow-striped lanes for bicycles on a few city streets, but these lines are very faded and the lanes are usually filled with MVs because traffic is severely congested. Other than this striping, there are no special facilities provided for NMVs in metro Manila. Specific pedicab terminal (curbside parking areas) are designated by the local governments and are always located in residential areas or along side streets. Pedicabs can also be found parked near light rail transit stations to take passengers to their final destinations.

Although the DOTC encourages schools and offices to provide bicycle parking facilities for students and employees, this is rarely done. There are essentially no bicycle parking facilities in metro Manila. This is also true for pedicabs, which queue along side streets at designated terminal points. Calesas park along curbsides during operating hours, but each requires a stable in the evening for storing the horse. These stables are usually the property of the calesa owner, so there is no direct cost to the driver.

Because transportation plans are normally prepared by the national department of public works, which excludes NMVs from consideration, all roadway designs and plans (including sidewalks) are conceived for motorized transportation. The local governments also ignore NMVs in transportation planning.

GOVERNMENT ATTITUDES

National and local government officials have many negative impressions about pedicab operations in metro Manila. The city of Manila does not want to encourage NMVs and believes that such vehicles can be effective only in residential areas. Otherwise, pedicabs are perceived as traffic hazards, serving to worsen already severe traffic congestion. Many local government officials would like to see pedicabs replaced by pedestrians. Some other opinions are that pedicabs should be standardized, strict enforcement is needed, operating a pedicab is "degrading" work, and all pedicabs should be outlawed.

CONCLUDING REMARKS AND RECOMMENDATIONS

The characteristic of metro Manila residents not wanting to walk short distances will enable pedicab business to continue, especially in locations near public markets, shopping malls, offices, and schools. Even if NMV use on major thoroughfares is effectively controlled, the presence of NMVs will still be felt in areas often visited and in smaller municipalities and *barangays* where they can be used to collect and haul water, solid waste, and other cargoes, either for public service or private enterprise. Handcarts and calesas will continue to be used for hauling cargo since they are the cheapest alternative to taxis or trucks.

Furthermore, as long as the unemployment situation does not improve and urban migration is not controlled, NMVs will provide a source of employment and a livelihood. Driving a pedicab is a relatively cheap and easy way for those with little money to make a living. The number of poor people in metro Manila has been increasing in the last few years, and—surely not by coincidence—so has the number of pedicabs.

Consequently, government officials should consider a plan that would both improve overall transport service and better meet the needs of NMV users. As the authors outlined in previous publications (*8–10*), this could be accomplished by incorporating NMV facility planning into the conventional urban transportation planning process, thereby providing a framework to supply basic NMV facilities. The simultaneous planning of both MV and NMV facilities enables close integration between transport services, such as bicycle- or pedicab-to-rail as well as an understanding of the patronage that each mode receives and the dynamics of competition and interaction among modes. A good example of this is the current practice of designating pedicab terminals; however, this is only an initial step toward the MV/NMV integrated planning required in metro Manila.

Measures that should be implemented include (*a*) an NMV network and routing plan, and (*b*) spatial separation measures, which can be divided into NMV lanes delineated by pavement markings and NMV lanes designated by barriers. Because motorists in metro Manila are not well disciplined, it is probably necessary to implement the latter by installing a physical barrier. MVs would then be physically prevented from encroaching on the NMV facility. The emphasis should be on low-cost improvements in transportation infrastructure. Temporal separation measures, such as access restrictions during certain hours of the day, should also be considered.

Last, funding constraints in metro Manila have severely limited road transportation improvements. This could be remedied with appropriate transportation infrastructure planning and development projects funded by international aid organizations. When providing funds for such projects, these organizations should take appropriate measures to remedy anti-NMV biases and thereby promote balanced transportation planning.

ACKNOWLEDGMENTS

Most of the information in the paper was gathered as part of the authors' work on the Study of Non-Motorized Vehicles in Asian Cities managed by the World Bank. Consequently, the authors would like to recognize the following World Bank staff for their valuable assistance and involvement with the study: John Flora, Slobodan Mitric, Paul Guitink, Richard Scurfield, Hubert Nove-Josserand, Peter Midgley, and Peter Ludwig. The authors would also like to extend their gratitude to Theresa Villareal, a local consultant who conducted the many surveys cited in this paper.

REFERENCES

1. Japan International Cooperation Agency. *The Metro Manila Transportation Planning Study Phase II.* Final Report, Technical Report, Supplemental Surveys and Analysis. Republic of the Philippines, Sept. 1985.
2. *World Development Report 1993, Investing in Health.* World Bank, Washington, D.C., June 1993.
3. *Asian Development Outlook 1992.* Asian Development Bank, 1992.
4. Replogle, M. *Non-Motorized Transport in Asian Cities.* Technical Paper 162. Asia Technical Department Series, World Bank, Washington, D.C., 1992.
5. Padeco. *Non-Motorized Vehicles in Asian Cities: Part I, Inventory of Needs and Opportunities (Appendix: Case Studies).* Draft Final Report. World Bank, Washington, D.C., June 1993, pp. 7-7–7-13.
6. *Philippines Urban Transport Sector Review,* Vol. 1. Main Report. World Bank, Washington, D.C., Oct. 1983.
7. P. G. Pak-Poy & Associates. *Motorized Tricycle Policy Study.* Philippine Ministry of Transportation and Communications, Feb. 1980, pp. 33–38.
8. Padeco. *Non-Motorized Vehicles in Asian Cities: Part II, Technical Guidelines.* Draft Final Report. World Bank, Washington, D.C., June 1993, pp. 2-9–2-18.
9. Bell, D. D., and C. Kuranami. Incorporating NMV Facility Planning into the Urban Transport Planning Process. *Proc., International Symposium on Non-Motorized Transportation,* Beijing, China, May 1994.
10. Bell, D. D., and C. Kuranami. Nonmotorized Vehicles in Hanoi and Phnom Penh: Existing Situation and Options for Improvement. In *Transportation Research Record 1441,* TRB, National Research Council, Washington, D.C., 1994, pp. 93–100.

Any errors in fact or judgment are the responsibility of the authors.

Transportation of Agricultural Commodities by Bicycle: Survey on Bombo Road in Uganda

W. GRISLEY

The transportation of agricultural commodities on the Bombo Road leading into Kampala, Uganda, is studied with special reference to the role played by bicycle transporters. In total, an estimated 43,127 tons of agricultural commodities was transported down the Bombo Road during 1992. Bicycles transported 7,620 tons, or 18 percent, but were responsible for almost all transportation within a 1-day (bicycle) distance to the market. Within this range, motorized vehicles could not compete with bicycles. The key to the success of the bicycle along the Bombo Road is the ease of road access to local markets. Other roads leading into Kampala are narrow and congested and bicycles cannot compete with the heavy motorized vehicle traffic. When used in transportation, bicycles create more employment, demand less foreign exchange, use less land, require a less costly road network system, cause less pollution, and can be less environmentally damaging than motorized transport. Bicyclists also provide vital market information to farmers, and they are able to service small-scale farmers. Motorized transportation cannot fulfill these roles as efficiently.

This paper reports on the results of a survey of vehicle types used in the transportation of agricultural commodities on the Bombo Road in Uganda. The Bombo Road is the only road leading into the capital city of Kampala from adjacent areas to the northwest of the city and from more distant areas in the northwestern part of the country. In particular, the role of bicycles in this transportation system is investigated.

The use of bicycles in transporting agricultural commodities in Uganda is growing in areas next to larger towns and urban centers (*1*). Bicycles, however, have not been uniformly successful. Their use as transporters is limited to areas in which motorized vehicle traffic is at a minimum and where there is an easily accessible retail food market. Bicycles are not successful in highly congested areas with narrow roads because of the difficulty of balancing large and bulky loads in heavy traffic. Much of Kampala is congested with narrow streets, and bicycle transporters travel only on the periphery of the city.

The success of bicycles in Uganda can be attributed to the low opportunity cost of labor, the limited capital requirements for business entry, and a growing demand for transportation by small-scale farmers. The bicycle industry is highly competitive with many participants. Drivers either own bicycles or rent them for a daily fee. In some cases, one person may own many bicycles and rent them out to drivers. These drivers are small businessmen who earn their livelihoods by purchasing small quantities of agricultural products and transporting them to local markets for wholesaling.

Because of their scale of operation, bicycles are unique in the transportation of agricultural commodities. The small load requirement allows them to seek out small-scale farmers with limited quantities to sell. Motorized vehicles cannot perform a similar function because it is uneconomical. In addition, bicycles can travel to areas impassable to motorized vehicles.

Bicyclists make it possible for small-scale farmers to engage in commercial production, especially for products that are highly perishable. Small-scale farmers would not be able to be involved commercially in the production of perishable commodities if they had to depend on motorized vehicles that make infrequent purchasing trips, but then only to readily accessible areas.

Besides their transportation role, bicycle drivers also perform several other critical functions, some of which are not easily or effectively handled by motorized vehicle drivers. Bicyclists provide most of the financing at the farm level for buying agricultural commodities. They also perform a vital role in spreading market information. Their frequent contact with markets makes them ideal for spreading market information at the farm level. Because of their large numbers and active involvement in buying and selling, bicyclists in many cases are the most important and reliable source of market information for farmers. Motorized vehicle drivers cannot serve the information function as well because they are fewer in number and they rarely reach the small-scale farmer.

AREA OF STUDY AND SURVEY METHOD

Besides serving the area immediately to the north and west of the city, the Bombo Road is the only transportation route for all areas of Uganda to the north of the Nile River from the west end of Lake Kyoga to the eastern edge of Lake Albert. Areas north of the Nile River specialize in sorghum, millet, beans, groundnuts, cassava, sunflower, sesame, and cotton. In addition, the northern districts and those immediately south of the Nile River produce significant quantities of live cattle, fresh milk, chickens, and eggs. Large quantities of fish are also harvested along the western edge of Lake Kyoga for export to Kampala, both fresh and dried. All shipments of these commodities going to Kampala-area domestic and export markets must be transported on the Bombo Road.

Vehicles carrying products on the Bombo Road were surveyed during the last week of April, May, and June 1992. The survey site was the Mpigi district commodity revenue collection station, which is 14 km from Kampala and 4 km from the large suburban market at Kwempe. Vehicles carrying commodities are required by law to pay a commodity transportation tax at the station. The only exception is for government-owned vehicles. In addition to agricultural cooperatives, most ministries have a limited number of vehicles that transport food products and other agricultural commodities. In

P. O. Box 278, Pittsburg, Ill. 62974.

general, these vehicles transport the grain products noted earlier in addition to cassava flower, cotton, and live cattle. Little horticultural produce, chickens, eggs, fish, or milk are transported on government-owned vehicles as the primary transport item.

Revenue collection stations are open daily between 6 a.m. and 8 p.m. Outside these hours trucks are not permitted to be traveling because of security reasons. However, a few are expected to violate the law in order to avoid the tax. The volume of illegal traffic is unknown, but it is expected to be limited relative to total traffic. In addition, the products carried are expected to be bulky items from areas north of the Nile River. Horticultural products, milk, and fish are not believed to be carried by illegal vehicles.

Most of the commodities were transported in uniform-size containers. Irrespective of vehicle type, most items are hauled in grain bags, boxes, baskets (fresh and dried fish), or 20-L containers (milk and banana beer). Green vegetables, sugar cane, banana leaves, and firewood are transported in bunches. For each commodity transported, the bunch is generally uniform in size. When hauled by motorized vehicles, firewood is transported in loads of uniform size.

The weight of commodity containers when full was determined using the expert opinion of transporters, market wholesalers and retailers, and market administrators. To validate these estimates, a nonrandom sample of containers for most of the commodities transported was weighed in local markets.

RESULTS AND DISCUSSION OF RESULTS

Number of Vehicles

During the three periods surveyed, an average of 275 bicycles transporting agricultural products passed the revenue collection point each day (Table 1). Pickups of 1-ton capacity were the most frequent motorized vehicle type averaging 36 trips per day, followed by lorries (trucks greater than 10 tons) at 13.6 trips, buses at 11, trucks (3 to 5 tons) at 4.2, and farm tractors at 1.5. In general, the daily average number of vehicles was similar across the three weekly periods, indicating a smooth flow of products going to markets.

The weekly averages were 1,923 bicycles, 252 pick-ups, 95 lorries, 78 buses, 30 trucks, and 10 tractors. Extrapolating these figures on an annual basis gives slightly over 100,000 bicycle trips and 13,140 pick-up, 4,964 lorry, 4,015 bus, 1,533 truck, and 548 tractor trips (Table 1). The extrapolated figures are expected to closely approximate the actual number of trips because the three periods studied are representative of periods before, during, and toward the end of the rainy season. However, the rainy season before the period studied was drier than usual, and thus the quantity and mix of products harvested could be different from that which occurs under normal rainfall conditions.

Differences in the number of vehicle trips per day were found across the three periods. In April, Sunday and Wednesday had the fewest number of bicycle trips, whereas Tuesday, Wednesday, Friday, and Saturday had the most. The results for May were similar to those for April. However, differences were found for June. The number of daily bicycle trips was lowest on Sunday, Monday, and Tuesday and highest during the period Wednesday through Saturday.

Reasons for these differences could not be determined, but they are probably related to the availability of and demand for commodities across seasons. Some products such as fresh vegetables, fruit, and fish are highly perishable and are supplied when demand is highest, usually just before the weekend. Other commodities, such as firewood and charcoal, are easily stored and can be offered at any time.

With the exception of Sunday, variability in the frequency of motorized vehicles within the week was not necessarily similar to that of bicycles. In most cases, Sunday had the fewest number of motorized vehicle trips, but no other daily trends emerged across the three periods studied.

Like bicycles, pick-ups are a flexible form of transportation, and the day of the week in which transportation occurs is a reflection of the availability of commodities and market demand. Monday was an important day during April and May, whereas Wednesday, Thursday, and Friday were the most important days in June. Evidently, the type and availability of commodities differed in June as compared with April and May. It is unlikely that demand for specific products changed significantly during a period as short as 3 months.

Kilometers Traveled

Bicycles accounted for 54 percent of the estimated 4 429 200 km traveled annually by all vehicle types. On average, bicycles traveled 24 km; buses averaged 158 km; tractors, 31 km; pick-ups, 65 km; lorries, 90 km; and trucks, 50 km (Table 2). Sixty-one percent of bicycles traveled fewer than 25 km, and only 3 percent traveled more than 50 km. Fifty-three percent of agricultural commodities transported by bus traveled fewer than 100 km. The percentage of pick-ups, lorries, and trucks traveling fewer than 100 km was 66, 90, and 50 percent, respectively. Ninety-seven percent of tractors traveled 25 km or fewer. Differences in the average distance traveled suggest that specific vehicle types either serve selected geographical areas or specialize in the transportation of selected commodities.

Type and Volume of Agricultural Commodities

The most widely transported commodities in April were charcoal (323 tons), firewood (118 tons), sesame (113 tons), cassava (74 tons), timber (68 tons), and fresh fish (63 tons). Other high-volume products were fresh milk, at 49 400 L, and banana beer (Tonto), at 8220 L. Bicycles carried a significant percentage of these commodities with the exception of timber, sesame, and fresh milk. These products were not carried by bicycle primarily because they are not produced within bicycle range of the market.

In weight terms, the commodities most frequently transported by bicycle during April were cassava (53 tons) and charcoal (45 tons). Other commodities of high volume transported by bicycles were firewood (17 tons), sweet potatoes (8.8 tons), cabbage (2.9 tons), tomatoes (2.5 tons), and banana beer (5440 L). For the 37 commodities found, bicycles delivered 50 percent or more of the total transported in 16 cases. In 10 cases, bicycles transported 75 percent or more of the total.

In May, bicycles carried 50 percent or more of 16 of the 39 commodities found to be transported. In addition, they transported 40 percent (5.7 tons) of banana leaves, 19 percent (27 tons) of firewood, 10 percent (48 tons) of charcoal, 47 percent (36 tons) of cassava, and 45 percent (9.8 tons) of sweet potatoes.

Bicycles carried 50 percent or more than 27 of the 50 commodities transported in June. A greater variety of commodities was mar-

TABLE 1 Frequency of Vehicle Type by Day and Week on Bombo Road, 1992

Month[a] Day of week	Frequency of vehicle type[b] Bicycle	Pickup	Truck	Lorry	Bus	Tractor	Total
April							
Sunday	186	13	2	11	9	0	221
Monday	283	38	6	17	13	1	324
Tuesday	311	29	9	11	9	0	369
Wednesday	248	28	3	14	14	3	310
Thursday	268	30	1	23	17	0	339
Friday	309	31	0	23	12	1	376
Saturday	314	34	5	17	16	0	386
Daily mean	274	29	4	17	13	1	332
Weekly total	1889	203	22	116	90	5	2,326
May							
Sunday	168	22	5	5	1	1	202
Monday	376	84	7	13	23	2	505
Tuesday	296	56	10	19	15	3	399
Wednesday	252	33	6	19	5	1	316
Thursday	249	44	11	12	10	0	326
Friday	286	47	6	18	10	6	377
Saturday	239	47	9	7	21	2	322
Daily mean	267	47	8	13	3	2	349
Weekly total	1866	330	54	93	85	15	2,443
June							
Sunday	193	14	2	5	1	0	215
Monday	187	21	0	4	3	0	215
Tuesday	192	28	2	12	7	6	247
Wednesday	326	46	1	25	8	0	406
Thursday	393	50	3	20	11	1	478
Friday	299	18	2	4	12	2	337
Saturday	343	46	3	9	6	2	409
Daily mean	276	32	2	11	7	2	330
Weekly total	1933	223	13	79	48	11	2,307
For three weeks							
Daily mean	275	36	4	14	11	1	341
Weekly mean	1923	252	30	95	78	10	2,388
Annual	100,375	13,140	1,533	4,964	4,015	548	

[a] Surveys took place during last week of the month.
[b] Pickup = 1 ton, trucks = 3-5 ton, and lorry = 10 ton.

keted during this period because it is the latter part of the harvest season and more commodities are available. For 20 commodities, bicycles delivered more than 80 percent of the total quantity transported.

Survey information on 31 of the most important commodities was extrapolated over 52 weeks to arrive at an annual estimate of the quantity transported (Table 3). Charcoal was the most important at 17,304 tons, followed by firewood, at 6,213 tons; fresh fish, at 3,642 tons; cassava at 3,349 tons; and mangoes, at 2,042 tons. In addition, 2 196 480 L of fresh milk, 409 413 L of banana beer, 67,895 live chickens, 5,668 trays of eggs (30 per tray), 2,791 live pigs, and 4,541 live cattle were transported. Bicycles were important in the transportation of all commodities except for fresh fish and milk and live chickens, pigs, and cattle.

Commodities for which bicycles hauled over 50 percent of the total quantity transported were white potatoes (93 percent), jack fruit (76 percent), avocado (69 percent), onions (69 percent), eggplant (67 percent), banana beer (64 percent), fresh beans (61 percent), sweet banana juice (59 percent), tomatoes (57 percent), cassava (53 percent), and green vegetables (52 percent). Other commodities for which bicycle transport was important were banana leaves (48 percent of total quantity), matoke or cooking bananas (46 percent), sweet potatoes (45 percent), cabbage (39 per-

TABLE 2 Distances from Commodity Source to Kwempe Market by Vehicle Type on Bombo Road, 1992

	Vehicle type[a]					
Kilometers	Bicycle	Bus	Tractor	Pickup	Lorry	Truck
Less-than or equal-to	... cumulative percent going down the column ...					
10	8	0	36	2	1	9
15	16	2	42	13	3	54
20	41	5	84	18	11	55
25	61	11	97	21	18	61
35	87	14	100	36	31	67
50	97	31	-	58	52	82
100	100	53	-	66	72	91
150	-	66	-	99	88	96
Mean kilometers	24	158	15	65	90	50

[a] Vehicle size: Pickup = one ton, lorry = ten tons, and truck = 3-5 tons.

TABLE 3 Estimated Quantity and Volume of Commodities Carried by Bicycle and All Vehicles on Bombo Road

Commodity	Bicycle[a]		All vehicles
Banana leaves	300	(48)	621
Firewood	1,043	(17)	6,213
Charcoal	2,134	(12)	17,304
Tomatoes	303	(57)	531
Cabbage	167	(39)	429
Cassava	1,778	(53)	3,349
Banana beer (liters)	262,756	(64)	409,413
Palm leaves	20	(16)	122
Poultry (birds)	2,288	(3)	67,895
Sweet bananas	126	(15)	821
Fresh fish	4	(*)	3,462
Dried fish	11	(3)	309
Jack Fruit (No.)	988	(76)	1,300
Sweet potatoes	365	(45)	816
Timber	-		313
Sweet banana juice (liters)	25	(59)	42
Live pigs (No.)	52	(2)	2,791
Sugar cane	67	(17)	396
Egg trays (30 eggs)	1,855	(33)	5,668
Fresh milk (liter)	403	(*)	2,196,480
Hides and skins	589	(4)	16,640
Avocado	18	(69)	26
Cattle (No.)	0	(0)	4,541
Matoke (bananas)	168	(46)	368
White potatoes	43	(93)	47
Green vegetables	76	(52)	146
Goats (No.)	104	(11)	971
Egg plant	65	(67)	97
Mango	254	(12)	2,042
Onions	36	(69)	52
Fresh beans	255	(61)	416

[a] Quantities are in tons unless indicated otherwise. Annual estimates were calculated using quantities transported during the last week of the months of April, May, and June 1992. Percent of total transported by bicycle enclosed in brackets. An asterisk indicates an insignificant quantity was transported.

cent), and eggs (33 percent). While not a major transporter in percentage terms, bicycles transported 2,134 tons of charcoal (12 percent of total), 1,043 tons of firewood (17 percent), 254 tons of mangoes (12 percent), 126 tons of sweet bananas (15 percent), and 67 tons of sugarcane (17 percent).

An estimated total of 43,127 tons of agricultural commodities were transported annually on the Bombo Road by private-sector vehicles (Table 4). Bicycles carried a total of 7,620 tons, or 18 percent of the total. Lorries were responsible for the largest quantity transported, at 19,090 tons (44 percent), followed by pickups, at 13,413 tons (31 percent); buses, at 2,077 tons (5 percent); and trucks, at 927 tons (2 percent).

Even though the percentage of the total transported by bicycles was relatively small, at 18 percent, its importance was significant. Bicycles were important transporters of a number of horticultural and food crops, and for the area within a 1 day's bicycle trip of Kwempe Market they were the dominant transportation mode. The only exception was the large quantities of firewood transported by tractors within 25 km of Kwempe Market. Evidently, motorized vehicles cannot compete with bicycles in areas that are within 1 day's cycling distance of the Kwempe Market.

The quantity carried per bicycle across all commodities averaged 76 kg. This is believed to be a maximum given the poor quality of the bicycles, uneven terrain, and general absence of paved or even improved roads over most of the area that bicycles cover. Loaded bicycles are ridden only under the best of road conditions and then only when the terrain is favorable. Drivers often push their bicycles for much of the distance.

The average load size across motorized vehicle types varied considerably. Lorries, which are 10 tons or more, average 3850 kg per load. Pick-ups averaged 1020 kg, followed by trucks, at 600 kg; and buses, at 520 kg. The reason for the small load size for lorries and trucks is that many of these vehicles were not specifically transporting agricultural products but passed the revenue checkpoint with a limited quantity of a commodity.

The average load for buses was low, at 520 kg. It was expected to be higher given that passengers often return from their home villages with bags of grain and other foodstuffs. In most cases, commodities on intercity buses are not taxed unless the commodity is readily visible to the revenue collector. Smaller quantities of commodities are also believed to be transported by taxis (up to 14 people) coming from short distances up the Bombo Road. However, taxis do not normally stop at revenue collection checkpoints unless they are carrying large quantities of agricultural commodities.

Bicycle Transportation of Selected Commodities

The distance that agricultural commodities are transported by bicycles is, in part, a function of the commodity's weight-to-value ratio. All else being equal, higher-value products can be transported economically a greater distance than can those of lower value. However, the distance that products are transported is also a function of their production location. The area immediately to the north and west of the Kwempe Market and within bicycle transporting distance is productive and agroecologically diverse. Most commodities can be produced almost anywhere within the region. However, there appear to be specialty areas for certain crops such as sweet bananas, banana beer, cabbage, fresh maize, mangoes, and eggs. Commodity specialization is expected to be more a function of tradition and farmer skills than of agroecological conditions.

The average distances that selected commodities were transported and the distribution of production sources in kilometers from the Kwempe Market are given in Table 5. As indicated, the average distance traveled by bicycles was 24 km. Deviations from this average were found for a number of commodities. Firewood and charcoal, two close production and consumption substitutes, had a dissimilar production distribution pattern. This difference is largely due to the difference in their weight-to-value ratios. Charcoal has a much lower weight-to-value ratio and can be economically transported much greater distances. Sixty-five percent of firewood came from within 20 km of the market, but only 26 percent of charcoal came from within the same distance.

TABLE 4 Number of Trips, Distance Traveled, and Amount Transported by Vehicle Type on Bombo Road to Kwempe Market, 1992

	Vehicle type					
Variable	Bicycle	Bus	Tractor	Pickup	Lorry	Truck
Trips ('000)	100.4	4.0	0.5	13.1	5.0	1.5
Kilometer ('000)	2,409	634.4	8.2	854.1	446.8	76.7
Percent of total	54	14	1	19	10	2
Tons[a]	7,620	2,077	na	13,413	19,090	927
Percent of total	18	5	na	31	44	2
Kilogram/trip	76	520	na	1,020	3,850	600

[a] An estimated total of 43,127 tons was transported down the Bombo Road to Kwempe Market. Information on the limited quantity transported by tractors and the large quantities transported by government tagged vehicles was not available (na) and is not included in the figures.

TABLE 5 Distances from Production Source to Kwempe Market for Commodities Transported by Bicycle on Bombo Road

Commodity	Kilometers					
	<10	<15	<20	<25	<35	Mean
	.. cumulative percent going across ..					
Firewood	19	25	65	85	95	19
Charcoal	1	3	26	53	87	26
Cassava	4	11	28	53	82	27
Sweet potatoes	7	16	32	59	81	26
Banana beer (Tonto)	3	7	28	67	85	25
Sweet banana juice	37	50	77	93	100	15
Sweet bananas	1	7	9	21	53	36
Matoke (bananas)	1	15	24	46	69	30
Eggs	63	88	100			11
Avocado	12	31	62	73	85	22
Mango	4	14	24	28	63	32
Green vegetables	9	34	55	71	91	21
Egg plant	4	29	74	81	88	20
Tomatoes	3	7	22	38	88	28
Cabbage	6	13	32	51	79	27
Onions	10	10	30	50	60	29
Fresh beans	4	27	53	67	88	23
Fresh maize	5	15	36	49	69	29

These results can have important environmental implications. Firewood cannot be economically converted to charcoal on a small scale, forcing it to be sold in its natural form. Without bicycles, firewood production would not be economical and farmers would be less inclined to engage in tree production. Thus the existence of a bicycle transportation industry allows farmers to diversify into tree production, a practice that may have positive environmental implications. Motorized vehicles cannot serve the same function because of the scale involved. Large vehicles require large quantities of firewood at one site in order for transportation to be economical. Small-scale farmers with only a few trees to harvest cannot be served by these vehicles.

The average distance traveled and the distribution of the production source in terms of kilometers traveled were similar for cassava and sweet potatoes. Their weight-to-value ratios are similar, and they are good substitutes in both production and consumption.

Four banana products were transported by bicycle: banana beer (Tonto), sweet banana juice, sweet bananas, and matoke (cooking bananas). However, their average distances transported and distribution of production sources, as indicated by distance transported, differed. The various types of bananas are close substitutes in production, but not in consumption. Sweet bananas can be marketed as a fresh product or converted to sweet juice and marketed. The average distance that sweet banana juice was transported was only 15 km as compared with 36 km for sweet bananas, even though banana juice has a lower weight-to-value ratio. Evidently, the difference in the distance transported was due to locations specializing in sweet banana juice production.

Like sweet banana juice, banana beer is transported in a liquid form. The average distance that banana beer was transported was greater than that of sweet banana juice by 10 km. The reason for the greater distance was probably specialization in production and not the economics of transportation.

The average distance that sweet bananas and matoke were transported conformed to expectations as indicated by their weight-to-value ratios: the distances were 30 km for matoke and 36 km for sweet bananas. The higher value for sweet bananas allowed for a longer distance in which it could be economically transported.

Eggs had the shortest average distance transported, at 11 km (Table 5). Evidently, the transportation of eggs had more to do with specialization in production location than the economics of transportation. Eggs can be economically transported much greater distances because of their high value relative to their weight. As indicated in Table 4, 66 percent of all eggs transported on the Bombo Road were hauled by motorized vehicle, largely from distant areas in the far north of the country.

Avocado and mango are the two major fruit tree crops grown in the area served by bicycles. Both products are similar in weight and perishability, but mangoes bring a higher price. However, the reason that the average distance avocados were transported (22 km) was less than that for mangoes (32 km) probably had more to do with demand within local production areas than with the economics of transportation. Locations nearer the market have a higher population density, and mangoes are highly sought after by children.

The average distances that green vegetables, eggplant, tomatoes, cabbage, and onions were transported ranged from 20 to 29 km. The reasons for these differences are unknown, as all four products can be produced within the area served by bicycles. Small-scale farmers evidently specialize in the production of these foods on a seasonal basis, which may account for the difference in production locations found.

POLICY IMPLICATIONS

The results show that bicycles play the dominant role in transporting agricultural commodities in areas within cycling distance of the

Kwempe Market. This role developed as a result of an open and competitive environment in the production and marketing of agricultural products. The many small-scale farmers needed a transportation system that was reliable, efficient, and small in scale. The market needed a regular supply of a diverse mix of food and other commodities at low prices. The bicycle contributed positively to both agricultural production and market development.

The success of bicycles in the transportation of agricultural commodities has a number of policy implications, including employment creation, use of foreign exchange, road infrastructure development, conservation and use of natural resources, and market development and food security. In addition, an important aspect of the bicycle transportation sector in Uganda is that it exists entirely within the private sector and is thus less susceptible to governmental corruption.

When compared with motorized vehicles, bicycles are labor-intensive. If the commodities found to be carried by bicycle in the study were transported by pick-up, then only 21 pick-up loads would be required each day instead of the 275 bicycle trips. In addition, a large work force of self-employed persons is involved in the maintenance of bicycles. This work force is much larger than that required to maintain the few pick-ups or trucks that could be substituted for bicycles. The use of bicycles in the transportation of agricultural commodities has resulted in the creation of a significant number of jobs. Importantly, many of these jobs are located at the village level and thus act to stem the migration of workers to congested urban areas.

Bicycles also demand less foreign exchange per unit of commodity transported. At the current price of bicycles—about $100 (U.S.) each—the 275 bicycles used on a daily basis would cost $27,500, which is slightly more than the price of a single pick-up truck. In addition, motorized vehicles require fuel, oil, and repairs, which all require foreign exchange for their purchase. Even though bicycles require some imported parts, their foreign exchange costs per unit of commodity transported would be much less than that of motorized vehicles.

If motorized vehicles were substituted for bicycles, then a better farm-to-market road network would also have to be developed. This would have several effects: first, it would require significant amounts of foreign exchange if machinery and equipment used in construction were imported. Second, it would require the use of land that is currently used for agricultural production. Finally, an extensive network of farm-to-market roads that could withstand heavy truck traffic in the rainy season would be expensive to construct and maintain. Drainage and water runoff problems associated with road construction and maintenance would contribute significantly to the already serious soil erosion problems.

Use of bicycles in the transportation of agricultural commodities can contribute to increased conservation of natural resources in another respect. The presence of bicycles has allowed farmers to diversify production over both space and time because they have access to the market. This diversification has contributed to development of cultural practices for the control of pests such as insects, diseases, and weeds (*2*). These cultural methods are direct substitutes for agricultural chemicals that often require foreign exchange for purchase and that can contribute to environmental and health problems. Soil and soil nutrients may also be conserved because of the intercropping systems used in production.

On the negative side, the increased production of agricultural products because of the reliability and efficiency of the bicycle transportation system may have increased the demand for use of natural resources in the short run. However, increased marketing opportunities have been shown to be an important factor in the development of sustainable farming systems (*3*). Over time, the area served by bicycles can only benefit from their presence.

The development of a reliable and efficient bicycle transportation system along the Bombo Road has contributed to the development of the wholesale and retail food market and hence has increased food security for both producers and consumers. The many small-scale farmers now producing for the market would have been unable to do so if they had to rely on motorized transportation. The marketing risks simply would have been too great.

In sum, bicycles create more employment, demand less foreign exchange, use less land, require a less costly road network system, and can be less environmentally damaging than motorized vehicles in the transportation of agricultural products in the area immediately adjacent to the Kwempe Market in Uganda. In addition, bicycles allow for even the smallest of farms to engage in commercial production, increasing the potential for better food security and sustainable agricultural production.

The role of bicycles in the transportation of agricultural products should be expanded in Uganda and perhaps elsewhere in sub-Saharan Africa. In many cases, the economic, environmental, and social returns from bicycles will far outweigh similar investments in motorized vehicles. More research is needed in this vital area, especially with regard to factors that limit the use of bicycles. In Uganda casual observation suggests that when bicyclists have physically safe and open access to retail markets, they will engage in transportation. Making transportation routes for bicycles in congested areas may be the single most important factor in increasing their numbers.

ACKNOWLEDGMENTS

Special thanks go to the many bicyclists who spent their time answering seemingly trivial questions about their professions and to the revenue collectors who never neglected their duty and diligently recorded the many thousands of pieces of information from the bicyclists. This was a private research effort, and all financial and economic costs incurred in data collection, preparation, and distribution were borne solely by the author.

REFERENCES

1. Malmberg-Calvo, C. *Intermediate Means of Transport, Women, and Rural Transport in Eastern Uganda.* Working Paper 3, Case Studies on Intermediate Means of Transport and the Role of Women in Rural Transport. International Labor Organization, Geneva, Switzerland, 1992.
2. Thurston, H. D. *Sustainable Practices for Plant Disease Management in Traditional Farming Systems.* Westview Press, Inc., Boulder, Colo., 1992.
3. Tiffen, M., M. Mortimore, and F. Gichuki. *More People, Less Erosion: Environmental Recovery in Kenya.* John Wiley and Sons, Chichester, England, 1994.