Forecasting Bicycle and Pedestrian Travel

State of the Practice and Research Needs

CHRISTOPHER PORTER, JOHN SUHRBIER, AND WILLIAM L. SCHWARTZ

A review has been implemented on the state of the practice and research needs have been identified on methods for forecasting bicycle and pedestrian travel. The focus is on methods that forecast how many people will use a new bicycle or pedestrian facility or how many additional people will walk or bicycle in response to facility or network improvements. Overall, there appears to be a shortage of methods that practitioners with limited technical resources can use but are nonetheless accurate enough for planning purposes. In addition, existing research on the factors influencing the decision to walk or bicycle often has not been translated into usable forecasting methods. Three major recommendations are made. First, in the short term, a sketch-planning manual for bicycle and pedestrian forecasting is needed to give planners access to the basic data, tools, and methods required to estimate future demand. Second, further research is needed into specific factors influencing bicycle and pedestrian travel behavior, with an emphasis on identifying key factors that can be included in forecasting models. Third, bicycle and pedestrian considerations should be integrated into mainstream transportation models that traditionally have focused on vehicle travel. Inclusion of nonmotorized modes in travel models will improve capabilities for forecasting both motorized and nonmotorized travel and will help place bicycles and pedestrians on a "level playing field" with motorized modes in transportation planning.

The need for improved conditions for bicyclists and pedestrians has received increasing attention in transportation planning circles in recent years. Planners are recognizing a growing popular interest in bicycling and walking for health and recreation, the desire to promote alternatives to automobile travel for environmental reasons, and the need to provide safe and convenient travel options for the entire population. At the same time, the question of how many people actually will use new or improved bicycle and pedestrian facilities is gaining interest and importance. Public officials often want to be convinced that the benefits of improvements are worth the costs. Furthermore, agency officials want to know where to spend limited bicycle and pedestrian resources to get the most "bang for the buck" as measured by benefits to users.

When assessing benefits, costs, and priorities for proposed bicycle or pedestrian improvements, therefore, it is frequently helpful to have answers to some or all of the following questions:

- If we build a new bicycle or pedestrian facility, how many people will use it?
- If we improve an existing facility or network, how many more people will choose to travel by bicycle or on foot?
- How will improvements to nonmotorized travel conditions affect mobility, traffic congestion, and air quality?

Practitioners often do not have access to either the data or methodological knowledge to answer these questions with confidence. In the absence of such answers, estimates of the transportation, recreational, and air-quality benefits of a project too often are left to speculation. Advocates argue that "if you build it, they will come" and point to experiences on popular trails or in bicycle- and pedestrian-friendly cities in the United States and Europe. Skeptics argue that since Americans are unlikely to give up the convenience of their personal automobile, usage will be low and the transportation impacts of nonmotorized facilities will be minimal. In the absence of reasonable estimates of usage and corresponding benefits, worthwhile projects may go unfunded while at the same time other projects may be built but poorly utilized.

This paper arose out of a belief in the usefulness of forecasting bicycle and pedestrian travel demand, a recognition of the existing limitations to such methods, and the desire to advance the state of the practice in this area. Forecasts of demand, in conjunction with other planning methods, can help bicycle and pedestrian planners identify the most beneficial projects and can help determine which improvements will attract the most new users. Integration of nonmotorized modes into mainstream travel-forecasting models, which traditionally have focused on travel by motorized vehicles, should lead to greater acceptance of bicycling and walking as viable modes and consideration of these modes in transportation planning and programming. Finally, the process of developing better forecasting methods can in itself be a valuable learning experience. Further research into the factors influencing nonmotorized travel, and how these factors can be modeled, will greatly increase our understanding of which actions will be most effective at increasing bicycle and pedestrian trip making.

The research for this paper was conducted as part of an effort to develop a guidebook on methods to estimate nonmotorized travel for the Federal Highway Administration (*1*). The purpose of the guidebook is to summarize existing methods to predict the impacts of nonmotorized facilities and network-design factors (e.g., presence of a trail, impacts of a bicycle lane vs. separate path, etc.) on nonmotorized travel demand. Although the guidebook is focused primarily on physical facilities, studies focusing partially or primarily on other factors affecting nonmotorized travel, such as personal, land use, and policy characteristics, were reviewed as well, since it is important to consider these factors in conjunction with facility-design factors when forecasting nonmotorized travel. Also, many of the methods reviewed focus specifically on either bicycle or pedestrian travel. While there are important distinctions between the two modes, there are also enough similarities that both can be discussed within the same overall framework.

This paper focuses on research needs identified while developing the guidebook. The remainder of the paper includes an overview of existing methods to forecast bicycle and pedestrian travel, a discussion of the capabilities and limitations of these methods, a discussion of the factors influencing nonmotorized travel and the state of knowledge

Cambridge Systematics, Inc., 150 CambridgePark Drive, Suite 4000, Cambridge, MA 02140.

regarding these factors, and short-term and long-term research recommendations for better understanding and modeling nonmotorized travel.

OVERVIEW OF EXISTING METHODS

A sample of the methods identified in the guidebook is presented here; the full list of references is found in the guidebook (*1*). The methods currently available to estimate demand for a proposed bicycle or pedestrian facility can be grouped into four broad categories:

- Aggregate-level methods,
- Attitudinal surveys,
- Discrete choice models, and
- Regional travel models.

Aggregate-Level Methods

Aggregate-level methods predict total trips by mode for an area served by a facility, based on characteristics of the area served such as population and land uses. Aggregate methods can further be loosely classified as measures of potential demand, comparison studies, aggregate behavior studies, and sketch plan methods.

Measures of Potential Demand

A number of methods have been developed that estimate the maximum potential demand for bicycle and pedestrian travel that may be expected given an ideal network of facilities. While these are not true forecasting methods, they are frequently used to prioritize projects based on potential usage or to place an "upper bound" on the number of trips that might be expected. Clark (*2*) estimated the potential number of bicycling and walking trips in Bend, Oregon, based on trip tables from the regional travel model and assumptions about the maximum percentage of bicycling or walking trips by trip distance and purpose. Deakin (*3*) defined a demographic target group for Bay Area commuter bicycling, based on travel surveys, a review of the literature, and interviews with local and state officials, and used these criteria to estimate a reasonable upper bound on the size of the potential bicycle commuter market.

Methods also have been developed to estimate potential demand at a facility level. For example, Landis developed a "Latent Demand Score" technique [cf. (*4*)] to rate proposed bicycle facilities based on the proximity of trip generators.

Comparison Studies

Comparison studies compare usage levels before and after a change (such as a facility improvement) or travel levels across facilities with similar characteristics. Before-and-after studies have been used widely in Europe to assess the mode-choice impacts of citywide programs to improve bicycle and pedestrian conditions. Studies also have focused on specific facilities by conducting user counts before and after an improvement to the facility. Counts on existing facilities also have been used to forecast demand for proposed facilities with similar characteristics.

Aggregate Behavior Studies

Aggregate behavior studies involve the development of models to predict mode split or other travel behavior characteristics at an area level, such as for residents of census tracts or metropolitan areas. For example, Ashley and Banister (*5*) developed a regression model to predict the percentage of ward residents (the U.K. equivalent of a census tract) bicycling to work based on census data, availability of bicycling facilities, and other ward-level data.

Sketch Plan Methods

Sketch plan methods can be defined as a series of simple calculations to estimate the number of bicyclists or pedestrians using a facility or area. These methods generally rely on existing or easily collected data and behavioral assumptions derived from other studies. They also may contain elements of the other aggregate-level methods described above.

A considerable amount of research was performed in the 1970s on pedestrian planning, some of which resulted in sketch-planning methods for forecasting travel. For example, Pushkarev and Zupan (*6*) developed equations to forecast pedestrian volumes in high-density urban areas based on existing land use characteristics and pedestrian counts. More recently, Matlick (*7*) used census and travel survey data on population, mode split, and trip lengths, in conjunction with activity center data from local land use databases, to calculate potential walking trips in specific corridors.

Sketch plan methods of varying sophistication have been developed recently for bicycle facilities, particularly for the purpose of estimating reductions in motor vehicle-kilometers traveled and emissions to obtain Congestion Mitigation and Air Quality funds. Methods generally rely on assumptions about a population served by the facility, typical bicycle trip lengths, and mode splits from surveys or empirical evidence.

Attitudinal Surveys

Attitudinal surveys ask respondents directly how they would respond to various actions (i.e., would they bicycle if bike lanes were available?) or to rate or rank their preferences for various improvements. Attitudinal surveys have been used widely to estimate the potential impacts of bicycle and pedestrian improvements and to determine relative preferences for such improvements. FHWA (*8*) and Stutts (*9*) document the results of many of these surveys and also discuss the advantages and disadvantages of this type of survey approach.

Discrete Choice Models

A discrete choice model predicts a decision made by an individual (choice of mode, choice of route, etc.) as a function of any number of variables, including factors that describe a facility improvement or policy change. Discrete choice models can be based on observed behavior (i.e., from travel surveys in which respondents are asked to record travel patterns) or on "hypothetical choice" surveys that ask respondents to choose among travel alternatives with different characteristics. By focusing on the characteristics and options at the individual level, they differ fundamentally from "aggregate-level" methods that estimate overall mode split or trip characteristics for a population.

Discrete choice modeling techniques were pioneered in the 1970s and have been applied to forecasting bicycle and pedestrian mode choice in many studies since then. For example, Wilbur Smith Associates (*10*) developed discrete choice models to estimate the effects on transit access mode of bicycle and pedestrian improvements to transit station areas in Chicago. Discrete choice modeling techniques also have been applied to predicting route choice or facility preferences as a function of route or facility characteristics (*11*). Some researchers have used discrete choice techniques to examine the influence of attitudes and perceptions as well as available facilities and environmental factors. Katz (*12*) modeled commuter bicycling in two steps: first, the choice to "participate" (consider bicycling) is modeled through factor analysis and logit regression, and, second, mode choice is modeled through logit models.

The coefficients developed in both mode choice and route choice models can be used for quantitative comparisons of the relative importance of various factors. Discrete choice models can be used for this purpose even if they are not applied across a population to evaluate overall mode-split and trip-making impacts.

Regional Travel Models

Regional travel models, commonly referred to as "four-step travel demand models," use data on existing and future population, employment, and transportation network characteristics, in conjunction with data on existing travel patterns and models of human behavior, to predict future travel patterns. Regional travel models are based on a spatial structure of zones (such as census tracts) connected by network links (transportation facilities). These models treat travel decisions as a multistage process, which typically includes (*a*) trip generation, or whether a trip is taken; (*b*) trip distribution, or where the trip starts and ends; (*c*) mode choice; and (*d*) route choice. Regional models may combine both aggregate and disaggregate behavior models.

Traditionally, regional travel models have been oriented toward predicting trips by automobile and transit. However, models in Portland, Oregon; Montgomery County, Maryland; and Sacramento, California, recently have been modified to estimate nonmotorized mode splits based on ratings of the "pedestrian friendliness" or "bicycle friendliness" of individual zones (*13,14*). Models in Albany, New York, and Edmonton, Canada, have been modified to include bicycle and/or pedestrian facility networks and to predict the route choice impacts of improving or adding facilities (Stephen Alloco, Capital District Transportation Commission, unpublished data; *15*).

The regional travel-modeling framework also has been applied specifically to model bicycle or pedestrian travel. Pedestrian demand models and planning procedures were developed for various central business districts in the United States in the 1960s and 1970s (cf. *16*). These models related pedestrian trips to land uses at a block level and assigned trips between blocks based on characteristics of the pedestrian network.

At least two bicycle network models recently have been developed in Europe to evaluate flows over a network of bicycle facilities (*17,18*). These models, which are based on the firms' vehicle travel models, require external inputs of total bicycle trips and so far have been used only for distributing these bicycle trips based on route characteristics. Modifications are under way, however, so that nonmotorized network characteristics also affect mode choice in the corresponding multimodal travel models.

CAPABILITIES AND LIMITATIONS OF EXISTING METHODS

Aggregate-Level Methods

Most aggregate-level methods have been developed by practitioners confronted with the need to obtain a rough estimate of demand. Common elements of many methods are that the practitioner defines a population served by the proposed facility or network; identifies local or national data on trip frequencies and lengths by trip purpose and/or type of traveler; and then applies assumptions about the potential increase in bicycle or pedestrian trips by length, purpose, and type of traveler as a result of the facility or network improvements. The methods are simple and use readily available data, producing a quick answer with limited financial and technical resources. The number of assumptions required, however, seriously limit their accuracy as true demand-forecasting tools or for comparing the relative benefits of different projects or improvements. The shortcuts employed mean that the majority of factors that may influence actual demand for the facility are ignored. It also is not possible to consider interactive effects—for example, the extent to which the number of users of a new bicycle facility depends on the price of gasoline or the availability of parking in the city.

Attitudinal Surveys

Attitudinal surveys are relatively easy to design and implement and have been widely used in practice. They tend, however, to be better suited for evaluating relative preferences than for predicting actual shifts in travel demand. Unless carefully designed, they can significantly overestimate the actual response to a bicycle or pedestrian improvement, since people tend to be more likely to state that they will change their behavior than to actually do so (*8*).

Discrete Choice Models

Discrete choice models have been developed primarily to investigate factors influencing travel behavior, although some also have been developed to answer specific policy questions. Discrete choice models can offer a much more sophisticated (although still technically imperfect) analysis of how various factors influence nonmotorized travel and the tradeoffs that people make between these factors. These models, however, require considerable resources and technical knowledge to develop and apply. Also, they are most useful when developed for a specific situation, although coefficients developed for one model often can be used to model similar situations in other areas. Furthermore, discrete choice models have seen little application toward forecasting nonmotorized trip changes or mode shifts at the level of a travel corridor, an analysis level commonly of interest in the planning of bicycle facilities.

Regional Travel Models

Regional travel models also require considerable data and technical expertise to implement. Furthermore, the ability of most existing regional travel models to accurately predict the demand impacts of new or improved bicycle and pedestrian facilities is somewhat limited. These models were developed at a scale appropriate for automobile travel and lack the ability to analyze short trips or smaller-scale bicycle and pedestrian facilities. The data-collection activities required for travel models, including surveys of households to determine travel patterns, also have not contained sufficiently large or reliable samples of bicycle and pedestrian trips to model trips by these modes. In addition, regional travel models consider only utilitarian travel and therefore cannot model bicycle or pedestrian trips taken solely for recreational purposes.

On the other hand, the regional travel model framework is a potentially powerful tool for analyzing travel choices and tradeoffs between modes. It has a number of advantages over other methods, including taking into consideration how the spatial patterns of trips depend on the distribution of land uses and transportation network characteristics; how characteristics of alternative modes between specific origins and destinations influence mode choice; how travel choices vary according to trip type (work, shopping, etc.); and how policies, facility characteristics, and personal and household attributes may interact to influence travel patterns and mode choice.

For the purposes of demand forecasting, there are other practical reasons to focus on improving regional travel models to include bicycle and pedestrian travel. First, all major metropolitan areas maintain such models for traffic-planning purposes, so much of the data and framework for modeling nonmotorized travel already exist. Second, while considerable initial investment may be required to collect data on bicycle and pedestrian facilities and to establish behavioral relationships for the model, once this is done, proposed changes to the bicycle or pedestrian network can be evaluated with relative ease, and multiple changes can be evaluated with little additional effort.

Summary

Overall, there appears to be a shortage of methods that are widely usable with limited technical resources but are nonetheless accurate enough for planning purposes. In addition to methodological shortcomings, practitioners frequently do not have access to basic data, such as characteristics of bicyclists and pedestrians or evidence on program impacts from other areas, which could be used to derive even rough estimates of demand for a facility.

FACTORS INFLUENCING NONMOTORIZED TRAVEL

In addition to looking at methods for modeling nonmotorized travel, it is useful to examine the current state of knowledge on the factors influencing nonmotorized travel. A consideration of these factors will help point to the most useful ways to improve forecasting methods.

A Conceptual Model

Standard travel-demand modeling procedures generally predict total trip making and mode choice based on variables such as household characteristics and the time and cost of competing modes. These factors, however, only partially explain the decision to bicycle or walk. From an individual perspective, personal factors, environmental factors, and trip characteristics interact to determine whether a trip is made by bicycle, foot, or other mode. The specific factors that are important may vary depending on whether the mode being discussed is bicycling or walking. All of these factors should be incorporated in modeling exercises to the extent possible.

Figure 1 introduces a conceptual model for how these factors interact. The figure was developed particularly to show how facility-level design factors (A) combine to influence facility-level demand (K). As can be seen, the relationship is not direct, and instead there are various intervening steps and confounding factors. Ideally, all of

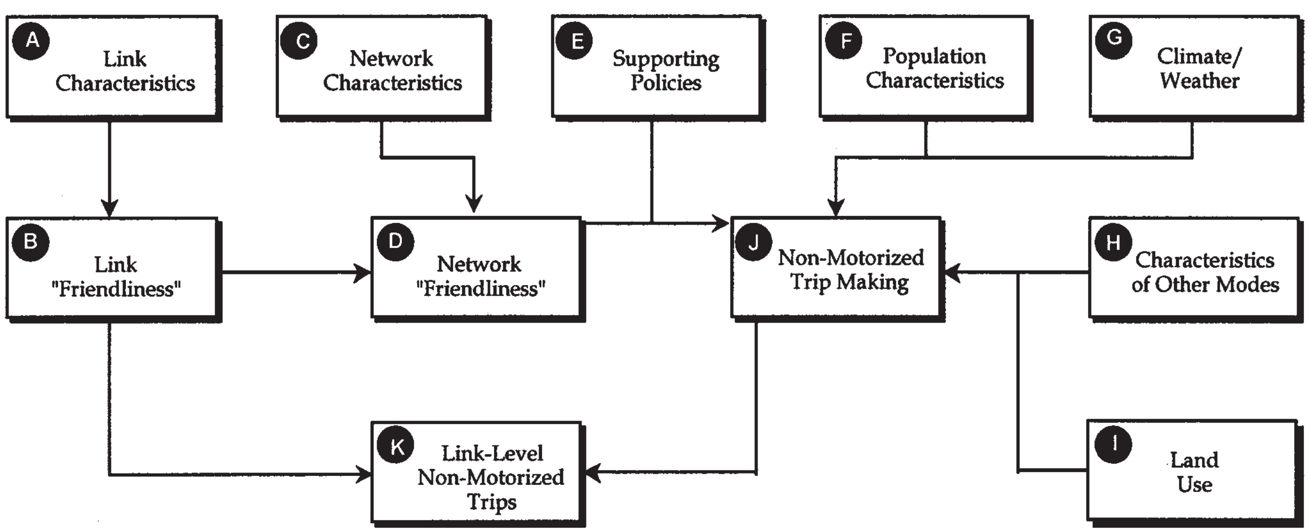

FIGURE 1 Relationship of factors influencing nonmotorized travel.

these factors would be modeled from the perspective of the individual traveler. If forecasting models are developed from an aggregate-level perspective, factors must be identified that serve as a proxy for the personal and environmental factors as faced from the individual perspective. For example, median income of an area may represent household income, or average vehicle travel speeds and parking costs in a city may serve as a proxy for the time and cost of travel by automobile for a particular trip.

State of Knowledge

To date, studies performed and methods developed for forecasting bicycle and pedestrian travel have focused primarily on relationships among the following factors, as illustrated in Figure 1:

- Describing "link friendliness" (B) based on link characteristics (A). "Link" refers to a segment of a street or path and "friendliness" refers to the relative attractiveness for bicycling or walking. These studies include supply-side efforts to develop bicycle and pedestrian "levels of service" and "stress levels." For example, the Federal Highway Administration (*19*) has developed a "bicycle compatibility index" (BCI) that rates the compatibility of an individual roadway link for bicycling based on factors including traffic volume, speed, presence of a bicycle lane, bicycle- and curb-lane widths, presence of a parking lane, and type of roadside development. Measures similar to the BCI and used in BCI development, such as the "Bicycle Level of Service" (*20*), have been applied in a number of states and metropolitan areas to rate the quality of roadway segments. Attitudinal surveys and discrete choice models also have been used to assess relative preferences for different types of facilities.
- Describing the quality of the pedestrian environment (C), or pedestrian "network friendliness," and relating it to travel behavior. Recent travel behavior research has focused on identifying the impacts of land use, neighborhood design, and other area-level environmental characteristics on the propensity to make nonmotorized (primarily walking) trips. Some of this research has resulted in quantitative factors to describe the friendliness of an area such as a census tract, or traffic analysis zone, for walking and/or bicycling. Known as pedestrian or bicycle "environment factors" or "friendliness factors," these have been developed primarily for use in regional travel models (*13*).
- Relating levels of bicycle or pedestrian use (J) to population and land use characteristics (F, I), as in the aggregate behavior studies discussed above.
- Determining attitudinal characteristics and preferences affecting the decision to bicycle (F), primarily through attitudinal surveys and discrete-choice modeling techniques focused on identifying factors influencing the willingness to bicycle or walk.

Much of the research conducted on these factors, however, has not been translated into usable forecasting methods. Furthermore, other factors affecting nonmotorized travel have received relatively little study:

- Combining measures of "link friendliness" (B) into an overall measure of "route friendliness" or "network friendliness" (E), particularly for bicyclists. For example, how does a route with a difficult intersection and a steep hill compare to a route with a mile of rough pavement? Ultimately, it is the attractiveness of the overall route options available to the bicyclist—not just individual street segments—that determines not only which route is taken but whether the trip is even made by bicycle at all.
- Linking zone- or area-level studies of travel behavior (J) to actual levels of travel on specific network links (K).
- Integrating facility/environment, policy, and personal/attitudinal variables into an overall modeling framework.
- Modeling recreational, as opposed to utilitarian, travel. In contrast to automobile and transit trips, a significant proportion of nonmotorized trips are taken for purely recreational purposes (i.e., for their own sake). All of the identified methods, however, either ignore recreational travel altogether or do not make an explicit distinction between the two.

Finally, it should be kept in mind that the factors shown in Figure 1 may influence an individual's travel behavior decisions at a variety of stages, not just on a trip-by-trip basis. For example, the individual must first decide to even consider bicycling or walking as a viable travel option. Only when this is done does the question of whether to bicycle or walk for a particular trip become relevant. Concepts from the public health and social marketing fields increasingly are being applied to understand this aspect of travel behavior. Within the public health framework, changing an individual's behavior—whether quitting smoking or taking up bicycling—is viewed as a multistage process. People can be classified into different "market segments" depending on where they are in this process and according to other factors, such as stage of life, which influence the likelihood of changing their behavior. In the United Kingdom, Davies et al. (*21*) examine attitudes toward bicycling and factors that would influence people to bicycle, based on interviews, focus groups, and stated preference surveys. Public health researchers in the United States also are examining the link between environmental variables such as neighborhood design and the decision to walk or bicycle for both travel and recreation (Rich Killingsworth, Centers for Disease Control, unpublished data).

RESEARCH NEEDS FOR FORECASTING BICYCLE AND PEDESTRIAN TRAVEL

The following recommendations are based on (*a*) an assessment of the capabilities and limitations of existing methods; (*b*) consideration of the state of knowledge on the factors influencing walking and bicycling and on techniques for modeling these factors; (*c*) an assessment of the needs of practitioners, including bicycle and pedestrian planners, involved in planning and selecting projects; and (*d*) a recognition of the need for both short-term "practical" and long-term "ideal" advances in methodologies for forecasting nonmotorized travel. These recommendations include the following:

- **Development of a manual for bicycle and pedestrian sketch planning.** In the short term, practitioners with neither the resources nor the expertise to conduct an in-depth forecasting study need a simple yet effective set of tools and data for estimating future demand.
- **Further research on factors influencing nonmotorized travel behavior.** Ongoing research into the specific factors that influence decisions to bicycle and walk will improve the quality of both sketch planning and more advanced modeling techniques. Research should focus not just on identifying specific factors but on how these factors interact and how they can be modeled to assist in forecasting bicycle or pedestrian travel for specific projects.

• **Integration of bicycle and pedestrian considerations into mainstream transportation models and planning.** Future improvements to regional travel models hold great promise to improve the quality of nonmotorized travel modeling. Inclusion of these modes also will help place bicycles and pedestrians on a "level playing field" with motorized modes of travel in transportation planning.

Development of a Manual for Bicycle and Pedestrian Sketch Planning

In the absence of better methods, practitioners who need to estimate usage on a nonmotorized facility generally resort to back-of-the-envelope calculations based on readily available data and rules of thumb on travel behavior. These methods are somewhat crude and generally have not been tested for accuracy, but they nevertheless may be the best that is possible given limitations on data, resources, and expertise. Development of a manual for bicycle and pedestrian forecasting immediately would improve the state of the practice in this area and could be widely useful for bicycle and pedestrian planners. Such a manual would contain methods and supporting data for developing local estimates of demand and specifically might include the following:

- A summary of available bicycle and pedestrian travel characteristics, including trip length distributions by type of trip, personal and household characteristics of travelers, etc.;
- A summary of studies that have evaluated the effects of various bicycle or pedestrian facility or policy improvements on nonmotorized travel;
- Identification and description of existing data sources, such as the census, travel surveys, and land use databases, which can support the estimation of nonmotorized travel demand;
- Guidelines for collecting local data, including user counts and surveys of existing and potential users;
- Applications of new technologies, including geographic information system methods and intelligent transportation system (ITS) technologies, for data collection and analysis; and
- A set of sketch-planning calculation procedures for using these various data sources to obtain rough estimates of demand.

The sketch-planning techniques outlined in the last element could, at a minimum, draw from techniques that already have been developed by practitioners. Ideally, such techniques would be further developed and tested in practice to ensure that they are applicable to a variety of areas and that they give reasonable results. Additional research for such a manual might include analysis of existing data sources, such as trail-user counts and surveys in conjunction with other trail-related data, to look for patterns in facility usage and to provide information useful for the planning of comparable facilities.

Further Research on Factors Influencing Nonmotorized Travel Behavior

Along with the short-term development of planning methods and data for practitioners, more fundamental research is needed into the factors influencing nonmotorized travel behavior and how these factors can be modeled to support demand forecasting. Particular attention should be given to identifying factors that both are of significance in predicting nonmotorized travel behavior and can be collected or created with relative ease from existing data sources or future survey efforts. Factors also should be investigated that are useful in a variety of forecasting methodologies ranging from sketch-planning techniques to travel demand and network modeling. Focusing on the individual traveler as the unit of analysis, rather than conducting aggregate-level studies, will provide richer information that will be useful not only for improvements to current efforts but to future modeling efforts such as activity-based analysis and microsimulation. Specific factors to investigate and model include the following:

- **Facility design characteristics.** Significant research has focused on developing quantitative measures of the quality or compatibility of facilities for bicyclists and pedestrians. The next step is to integrate these measures into methods of forecasting travel demand. Research is needed into how to aggregate facility-level compatibility measures into an overall route or network compatibility measure, including facilities of varying quality as well as intersections and other discontinuities. Ultimately, the overall route or set of route options, rather than just individual facility characteristics, determines whether the bicyclist or pedestrian makes the trip.
- **Environment factors.** Area-level composite factors that describe, or act as a proxy for, the relative attractiveness of bicycling or walking at an area/zonal level are potentially useful and should be further developed and tested. "Pedestrian environment factors" should be further refined and tested to verify their predictive capability. Efforts in this area should build on recent research relating neighborhood design factors to levels of walking. "Bicycle environment factors" also should be developed and tested for predictive capability. Other possibilities include the "quality" or impedance of alternative modes (traffic speeds, level of service, cost of parking, etc.) and the potential demand based on trip-end characteristics (population, employment, special generators, etc.). These factors should be useful both in sketch-planning techniques and in regional travel models in which the scale of resolution is too coarse to model every facility in the network.
- **Attitudinal and perceptual factors.** The relative importance of attitudinal and perceptual factors in the choice to walk or bicycle, as well as their potential uses in modeling, should be investigated. While gathering such data requires additional collection efforts, factors of this type have been found to be highly significant in determining travel behavior. Research in this area should focus on which factors are most important, how they can best be described/standardized, what level of resources are required to collect these data on an ongoing basis, how the factors may change over time, how they can most effectively be influenced, and how they can be integrated into modeling/forecasting techniques to predict the impacts of various policies. Research in this area can build on behavioral research from the public health field as well as on existing studies of attitudes and perceptions regarding bicycling and walking.
- **Factors influencing recreational travel.** Existing methods do not make an explicit distinction between recreational and utilitarian travel. Many aggregate-level methods consider both types implicitly by looking at overall travel on a facility; the accuracy of these methods could be improved by separately considering utilitarian and recreational travel, since the factors driving each may differ considerably (*22*). Other methods give little if any consideration to recreational travel. In the development of regional travel models, for

example, trips made to go to a recreational activity are generally identified but not modeled separately, while trips taken purely as a recreational activity (e.g., a neighborhood stroll) are not identified at all. Forecasting recreational travel at the individual or disaggregate level requires a different analysis framework, involving lifestyle and activity patterns, than is generally used in transportation modeling. Approaches from the public health arena that model the decision to exercise as a function of various personal/attitudinal characteristics and social factors should be helpful for incorporating recreational travel in transportation modeling.

- **Market research.** Marketers in competitive industries have long recognized that marketing success depends on targeting the right customer with the right product. State-of-the-art techniques from the field of market research can be used to better identify the "market segments" for nonmotorized travel, the travel characteristics of each market segment, and the design factors that are important in attracting increased usage from each segment. The trip and personal characteristics of recreational travelers, for example, should be differentiated from those of utilitarian travelers, and utilitarian users may be further distinguished as necessity versus discretionary, commute versus noncommute, and so forth. While some research has been conducted in defining nonmotorized market segments, planners have not adequately identified the differences in techniques required for identifying the needs and predicting the behavior of these various groups.
- **Integration of facility/environment, policy, and personal/attitudinal variables into an overall modeling framework.** Insights from the public health and social marketing fields suggest that personal attitudes and beliefs interact strongly with environmental and policy variables to influence travel behavior and mode choice, particularly for bicycling. Accurate forecasting of bicycle travel will require integrating these variables into a modeling framework that can include personal/attitudinal variables and that can account for the fact that the effects of facility/environmental improvements will depend on (as well as influence) the levels of these other variables.

Integration of Bicycle and Pedestrian Considerations into Mainstream Transportation Models and Planning

As a final recommendation, further development of modeling techniques and data sources is needed to better integrate bicycle and pedestrian travel into mainstream transportation models and planning activities. Regional travel models have the unique advantage of representing an integrated framework for predicting travel decisions, considering all trips and modal options, as well as personal and household characteristics, within the spatial structure of the surrounding area. Furthermore, they are widely used and accepted as demand forecasting methods for the purposes of automobile and transit planning. Improvements to existing models should significantly increase their usefulness for analyzing nonmotorized policies and facility improvements. Specific near-term and long-term improvements might include the following:

- **Data collection on bicycle and pedestrian travel.** A general need for all types of bicycle and pedestrian planning is better data on trip and personal characteristics of travelers. Household travel surveys performed for modeling purposes are a potentially effective means of collecting these data but usually are not designed with nonmotorized modes in mind. Nonmotorized data requirements for travel surveys should be defined, and the possibility of collecting stated-preference data in conjunction with household travel surveys should be investigated. The potential for nonmotorized data collection using emerging ITS information technologies also should be investigated. Low-cost methods for counting bicycles and pedestrians will be a key component in developing and calibrating models that include nonmotorized travel.
- **Spatial scales of models.** The scale at which travel is modeled should be refined to be more relevant to the short distances involved in bicycle and pedestrian travel. Improvements in computational power and in data management tools will make it easier to analyze smaller-scale networks of bicycle and pedestrian facilities rather than just major roadways. Refinement of spatial scales also will make it easier to apply modeling techniques to the prediction of mode shifts along a potential bicycle or pedestrian travel corridor, a policy question of interest to many practitioners.
- **Facility design factors.** For travel models in which bicycle and pedestrian networks can be accurately represented, the most important design variables for predicting mode and route choice should be identified and included in the network link characteristics in the model. This inclusion will require quantifying trade-offs between these variables and link travel time or distance. Travel time penalties also need to be developed for major intersections or other discontinuities in the network. The validity of aggregating link-level factors across routes and networks to produce an overall "utility" or "compatibility" should be tested. In addition, the potential for transferring facility design weights from studies conducted in one area to other areas, in order to avoid the need for locally specific surveys, should be investigated.
- **Environment factors.** For regional models in which zones are too large to model local nonmotorized networks, further development and testing of zone-level "environment factors" are needed to validate the usefulness of these models for analyzing nonmotorized travel. These efforts can build on the outcomes of basic research into these factors. Also, factors should be developed for bicycles as well as pedestrians.
- **Other environmental and policy variables critical to nonmotorized modeling.** Factors such as the presence of bicycle parking and workplace showers and lockers may be just as important as facility and network design factors in determining the decision to walk and, particularly, to bicycle. Methods should be investigated for collecting data on these factors, describing them in a way in which they can be included in travel models, and verifying the relationship of the identified factors with levels of nonmotorized travel.
- **Modeling behavioral change in multiple stages.** Methods and data requirements for modeling bicycle use in multiple stages—for example "participation" (the equivalent of auto ownership) prior to trip-level mode choice—should be investigated. These methods should be tested for improving the sensitivity and predictive power of travel models. The results of research into attitudinal and perceptual factors, as well as modeling approaches from the public health and market research areas, can inform this process.
- **Inclusion of recreational travel.** To be useful for modeling nonmotorized travel particularly on separate facilities, travel models will need to be capable of modeling recreational as well as utilitarian travel. Advances in activity-based modeling, which looks at personal and household activity patterns rather than simply trip-making patterns, may be useful in this effort. Research and methods from the public health arena also are relevant to modeling recreational travel.

- **Long-term travel model improvements.** Research currently is under way to develop new modeling frameworks to improve upon the current four-step, zone-based process. These frameworks include microsimulation, in which behavior of a representative sample of households is modeled and expanded to the entire population, and activity-based analysis, in which personal or household activity patterns rather than simply total trips are surveyed and modeled. These approaches should have strong advantages for modeling nonmotorized travel. New techniques, however, must still be supplemented with basic data collection on nonmotorized travel characteristics and facilities as well as with research into the key factors influencing nonmotorized travel and how these factors can be modeled to predict behavior. Factors relevant to nonmotorized travel should be explicitly included in these long-term travel model improvement efforts.

ACKNOWLEDGMENTS

The research documented in this paper was performed under subcontract to the University of North Carolina-Chapel Hill, Highway Safety Research Center (UNC-HSRC), for the Federal Highway Administration. The Bicycle Federation of America and Michael Replogle also provided assistance.

REFERENCES

1. Cambridge Systematics, Inc., and Bicycle Federation of America. *Guidebook on Methods for Forecasting Non-Motorized Travel.* Prepared for Federal Highway Administration under subcontract to University of North Carolina–Chapel Hill, Highway Safety Research Center, forthcoming.
2. Clark, D. E. Estimating Future Bicycle and Pedestrian Trips from a Travel Demand Forecasting Model. 67th Annual Meeting of the Institute of Transportation Engineers, 1997.
3. Deakin, E. A. *Utilitarian Cycling: A Case Study of the Bay Area and Assessment of the Market for Commute Cycling.* ITS Research Report. University of California, Berkeley, 1985.
4. Landis, B., and J. Toole. Using the Latent Demand Score Model to Estimate Use. In *Pro Bike Pro Walk 96: Forecasting the Future.* Bicycle Federation of America/Pedestrian Federation of America, Sept. 1996, pp. 320–325.
5. Ashley, C. A., and C. Banister. Cycling to Work from Wards in a Metropolitan Area. *Traffic Engineering and Control,* Vol. 30, Nos. 6–8, June to Sept. 1989.
6. Pushkarev, B., and J. M. Zupan. Pedestrian Travel Demand. In *Highway Research Record 355,* HRB, National Research Council, Washington, D.C., 1971, pp. 37–53.
7. Matlick, J. M. If We Build It, Will They Come? (Forecasting Pedestrian Use and Flows). In *Pro Bike Pro Walk 96: Forecasting the Future.* Bicycle Federation of America/Pedestrian Federation of America, Sept. 1996, pp. 315–319.
8. Goldsmith, S. A. *Case Study No. 1: Reasons Why Bicycling and Walking Are Not Being Used More Extensively as Travel Modes.* National Bicycling and Walking Study, Report FHWA-PD-92-041. FHWA, U.S. Department of Transportation, 1992.
9. Stutts, J. C. *Development of a Model Survey for Assessing Levels of Bicycling and Walking.* University of North Carolina, Highway Safety Research Center, Nov. 1994.
10. Wilbur Smith Associates. *Non-Motorized Access to Transit: Final Report.* Prepared for Regional Transportation Authority, Chicago, Ill., July 1996.
11. Hunt, J. D., and J. E. Abraham. Influences on Bicycle Use. Submitted for presentation at the 1998 Transportation Research Board Annual Meeting, July 1997.
12. Katz, R. *Demand for Bicycle Use: A Behavioral Framework and Empirical Analysis for Urban NSW.* Doctoral thesis. The Graduate School of Business, University of Sydney, NSW, Australia, Dec. 1996.
13. Cambridge Systematics, Inc. *Short-Term Travel Model Improvements, Travel Model Improvement Program.* Publication DOTT-9505. U.S. Department of Transportation, Oct. 1994.
14. Stein, W. R. *Pedestrian and Bicycle Modeling in North America's Urban Areas: A Survey of Emerging Methodologies and MPO Practices.* M.S. thesis. Georgia Institute of Technology, March 1996.
15. Hunt, J. D., A. T. Brownlee, and L. P. Doblanko. Policy Evaluation Using Edmonton Transport Analysis Model. Presented at the 77th Annual Meeting of the Transportation Research Board, Washington, D.C., 1998.
16. Kagan, L. S., W. G. Scott, and U. P. Avin. *A Pedestrian Planning Procedures Manual.* Reports FHWA-RD-79-45, FHWA-RD-79-46 and FHWA-RD-79-47 (three volumes). FHWA, U.S. Department of Transportation, 1978.
17. DHV Environment and Infrastructure. *QUOVADIS-BICYCLE User's Manual.* Amersfoort, The Netherlands, no date.
18. MVA. *Leicester Cycle Model Study.* Final Report, prepared for Leicestershire County Council, Contract No. 02/C/1428, Oct. 1995.
19. Turner-Fairbank Highway Research Center. *Development of the Bicycle Compatibility Index: A Level of Service Concept,* Volume I: Final Report. Publication FHWA-RD-98-XXX. FHWA, U.S. Department of Transportation, 1998.
20. Landis, B. W., and V. R. Vattikuti. *Real-Time Human Perceptions: Toward a Bicycle Level of Service.* Sprinkle Consulting Engineers, Inc., Tampa, Fla., Sept. 1996.
21. Davies, D. G., M. E. Halliday, M. Mayes, and R. L. Pocock. *Attitudes to Cycling: A Qualitative Study and Conceptual Framework.* TRL Report 266. Transport Research Laboratory, Crowthorne, Berkshire, United Kingdom, 1997.
22. Epperson, B., S. J. Hendricks, and M. York. *Estimation of Bicycle Transportation Demand from Limited Data.* Compendium of Technical Papers from the Institute of Transportation Engineers 65th Annual Meeting, 1995, pp. 436–440.

The opinions and findings expressed or implied in this paper are those of the authors alone. They are not necessarily those of UNC-HSRC, FHWA, Bicycle Federation of America, or Michael Replogle.

Publication of this paper sponsored by Committee on Bicycling.