Modeling Bicycle Demand as a Mainstream Transportation Planning Function

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This article examines the need for quantitative modeling of bicycle demand and reviews the techniques available for incorporating bicycles into existing transportation planning models. It is argued that there is insufficient attention paid to quantitative modeling of bicycle demand and that this results in the case for bicycle provision being poorly based. Transportation modeling, as in many other areas of research, has a traditional method of approach. Improvements in models have tended to be incremental rather than revolutionary. In improving the models of bicycle demand, it is appropriate to review the elements of the traditional approach to determine whether it is possible to tailor those models to the needs of bicycle planning. The location-specific models of traditional transportation models are characterized by considerable spatial detail and very few variables that relate to travel behavior. Although these models are unsatisfactory, particularly insofar as they have treated bicycle transportation, their results continue to be required by practitioners responsible for transportation provision. In the future, however, these models will have a different focus than the predict-and-provide approach taken in years past. This can be expected to result in improved treatment of minority modes such as bicycles. The challenge for incorporating bicycles into future models is to develop a behavioral understanding of bicycle demand that can be incorporated into the spatially defined network models. Some new tools of transportation planning and network management can also be exploited to ensure that bicycle transportation is not forgotten by mainstream transportation researchers.

Quantitative modeling of the demand for bicycles is an essential part of any coherent attempt to establish the bicycle's role in an urban transportation system. Very little progress has been made in this area and current bicycle policy is based on imprecise ideas about the effects of particular measures. Some of the approaches to transportation demand modeling that can be adopted to gain a better understanding of the role of bicycles in our cities are examined. Better understanding, backed by rigorous analysis, will improve policy-making in relation to bicycles. However, modeling bicycle demand is not a simple matter and some of the challenges specific to bicycles are substantial.

The general context adopted in this article is urban Australia. Contrary to many of the images projected abroad of an "outback" Australia, the reality for most of the population is an urban or suburban existence not too dissimilar to North America or parts of Europe. The use of bicycles in urban Australia is similar in proportion to cities in the United States. For instance, journey-to-work-mode share figures for bicycles range from approximately 0.8% in Sydney to 5% in Perth and Canberra.

Information on bicycle riding for trip purposes other than the journey to work is less well known. In this respect, bicycle riding is no different than other modes; however, it is expected that the proportion of commuter bicycle trips to total bicycle trips is lower than for other modes, given the high recreational value placed on bicycle riding by many people and the utility of bicycles for short trips. Noncommuter trips are of increasing importance to transportation planners because of their increasing importance to total travel and the change in planning philosophy away from a sole concern for capacity at the morning peak. Thus, relative interest in bicycle transportation could be expected to exceed its journey-to-work modal share.

This article first considers why formal models of bicycle demand are useful in planning for bicycles and why incorporating bicycles in mainstream transportation strategy formulation is increasingly necessary. The approaches taken to incorporating bicycles in transportation demand models and the benefits and shortcomings of particular methods are then considered.

The concept of demand in transportation is a very broad one and, as a result, many aspects are treated cursorily in this article. It is hoped that this article will serve as a frame of reference for examining bicycle demand studies and identify areas in which research has been completed or where additional work could be usefully conducted.

State-of-the-art transportation research and management methodologies that can be applied to bicycles, such as Intelligent Vehicle Highway Systems (IVHS) and Geographic Information Systems (GIS), are noted as areas to pursue if bicycle research is to become a seriously recognized area for transport research. The promotion of such an image is important in ensuring that opportunities for incorporation of bicycles and other "minority" modes within transportation systems are at least identified, and pursued, with at least the same zeal as the more "futuristic" transport solutions.

WHY MODEL BICYCLE DEMAND?

For many people, the reasons for examining bicycle demand in transportation models may be self-evident. However, it is worth briefly recapping why bicycles are a potentially important part of the transportation mix and why a formal model may be useful.

Importance of Bicycles

One of the major issues facing community and urban planners today is the need to develop sustainable urban systems. An essential aspect of urban life is the need to transport people and goods. Transportation patterns have been identified as having very negative impacts on sustainability because of the direct impacts of certain forms of transportation, particularly the private motor vehicle, and the indirect effects of the transportation system on land use patterns.

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It is widely perceived that a significant change in transportation and land use patterns, away from a reliance on motor cars, is needed to meet the sustainability criteria identified by the Brundtland Commission (*1*). What is not so generally agreed on is the form of the change that should or could be introduced. Some advocates argue strongly that a greater reliance on human-powered modes, particularly bicycles, would reduce the problems of motor vehicles and ensure a greater level of sustainability. Bicycles can be identified as an alternative mode to a substantial number of motor vehicle trips currently made, either alone for short trips, or in combination with public transportation, for longer trips. Others see the private motor vehicle maintaining or even strengthening its position as the primary form of independent transportation because of its advantages in terms of comfort, convenience, and security, not to mention its industrial importance. Bicycles are often considered an obstruction to the smooth flow of motorized vehicles by the latter group.

Although the arguments supporting increased use of bicycles may be attractive, there is considerable debate about whether bicycles are really capable of providing an attractive alternative for a significant number of people and for a significant proportion of their trips. This is a vital issue for bicycle proponents and those people charged with determining transportation policy.

Reasons for Having A Formal Model

Various forms of model, or simplified views of the real world, are used in formulating or justifying particular transportation plans. A broad hierarchy of model types is:

- Mental models. These models are completely opaque to people other than the decision maker. Mental models are generally based on a small number of variables and limited data, often personal experience, relating to those variables.
- Documented qualitative models. These sorts of models identify relationships, either causal or associative. The models may identify policy objectives, a set of relevant variables and assumptions, and expected outcomes from alternative policies.
- Quantitative models. These models typically involve a set of mathematically defined relationships. They may begin with a qualitative model that is translated into a set of mathematical simplifications of the real world. Parameters and statistical confidence levels defining the mathematical relationships may be estimated given available data. As discussed below, there are numerous forms of quantitative models with very different degrees of sophistication in terms of the numbers of variables and the description of the relationships.

Perhaps the major single research project conducted into bicycle transportation in the English-speaking world in recent years has been the National Bicycling and Walking Study mandated by the United States Department of Transportation Appropriations Act 1991 (2). The research was conducted by consultants on behalf of the FHWA. It has produced a series of reports on various aspects of the human-powered modes. Most of the reports involve qualitative models of the demand for and the effects of human-powered transportation. The references to bicycles are primarily an identification of the barriers to cycle trips and the characteristics of other transportation modes that could be influenced to make cycle trips attractive either as a substitute or as a complement to other alternatives, for example, in the case of public transit.

It is recognized in the final report (2) that there is a good deal of research yet to be done in translating the visions of a transportation system more oriented toward nonmotorized modes into planning action. Noted in the report at Action Item 8, point 9 is a reference to "conducting research into patronage estimation and mode split modeling for bicycle and pedestrian services and facilities."

This acknowledgment of the need for quantitative modeling could well be argued to have received insufficient attention to date. The reasons for placing more emphasis on developing quantitative models are discussed below.

Explicit Assumptions

One reason for formalizing the modeling process is the greater likelihood of making explicit key assumptions about factors affecting demand. A well-documented model allows the developer (and users) of the model to reflect on the causal mechanisms underlying the modeled relationships. Relevance of variables included or omitted from the model, and the level of reliability it may have under different conditions and over different time periods may also be considered. This process can lead to model refinement and extension.

An illustration of the importance of explicit assumptions is in the way that land use patterns are incorporated into transportation models. The increased use of bicycles could conceivably contribute to changes in land use. An urban structure characterized by low-density residential, industrial, and other development, commonly deprecated as "urban sprawl," may be of reduced attractiveness for bicycle users compared with motor vehicle users. Adoption of the bicycle as a major transportation mode could see people making long-term decisions about residential and employment location to suit bicycle trip making. The importance of this effect, based on the premise that people choose, or are captive to, a mode of travel and then select residential location and activities suitable to that mode, requires an assumption about the sequence in which people make decisions. Transportation modeling of whatever type requires some such assumptions and their form can have very major impacts on the results of a particular model. Most transportation models take the urban form as being insensitive to mode choice. Better models make these assumptions explicit and qualify the models accordingly.

Justification for Expenditure and Efficient Allocation of Resources

The increased popularity of cycling for recreational and utilitarian use through the 1980s and the recognition of potential benefits of bicycle use have been reflected in increased levels of provision specifically for bicycles. It is fair to say that this provision has been based mainly on mental or qualitative models informing the political process. For a variety of possible reasons, the measured response to many bicycle facilities implemented in Australia has been very limited. The analysis of the "failure" of provision in terms of observed demand response may be interpreted in a number of ways, for example:

1. Providing for cycling is a waste of money.
2. The facilities created may be inappropriate or insufficient to generate any noticeable demand response.

3. Cycling facilities alone will not have a significant influence on demand for cycling without policies directed at changing attitudes, cycling behaviors, and levels of service of other modes. This will influence transportation demand generally in a way which favors sustainable modes such as bicycles.
4. We should not worry about whether demand changes are observed because existing cyclists deserve a better level of service anyway.

Without developing a better understanding of bicycle transportation demand within overall strategic models of transportation, it is not possible to professionally adopt any of these responses. Certainly, before significant resources can be dedicated to cycling policies it is necessary to demonstrate that the first response, a frequently heard comment within road authorities, is incorrect.

The belief structure underlying such a response may be that cycling is unlikely to be attractive to many people because of its perceived negative attributes, such as exposure to weather, effort required (particularly for going up hills), and the level of risk of injury. Formal models would help these beliefs to be reviewed explicitly in evaluating a demand response.

The second and fourth responses are unlikely to carry a rational argument on cycling provision. The second response leaves an open question about how much, by way of resources, needs to be directed to cycling to have an effect on demand. The fourth response is based on an equity argument that is very difficult to win given the competing demands of transit and automobile lobbies and other government spending priorities. The intuitively attractive conclusion gives rise to additional questions about bicycle de-mand relative to demand for other modes. These need to be considered within the context of the urban transportation system as a whole.

All of the suggested responses require additional information to evaluate their relative and absolute values. Different analytical approaches may be biased toward particular responses. The traditional transportation demand modeling approaches are likely to come up with a response along the lines of the first response unless specified to incorporate a range of variables not typically included in such models. The reasons for this and the alternative approaches that have become more widely accepted are discussed below.

QUANTITATIVE MODELING TECHNIQUES

As noted above, quantitative modeling techniques in transportation vary widely in terms of approach and degree of rigor. Some of the techniques developed for planning, particularly at the city-wide level, involve an enormous computational effort. The particular purpose of the model will naturally influence its structure and the resources dedicated to it. By and large the specific bicycling models have been very limited in their scope and have not been readily incorporated within the strategic modeling structures of transportation and land use planning.

One approach to modeling cycling has been to compare the levels of cycling in different cities and to try to correlate these levels with the geographic features of the cities. This approach has been used to define expected levels of cycling for certain trip purposes across cities in the United Kingdom, based mainly on their topography (*3*). A regression model was estimated using the available information on cycling trips and topographical information on cities of equivalent size. Where the topography did not explain a particularly high or low level of cycling, it was suggested that accident risk as a result of poor facilities was the missing explanatory variable.

Mental models and qualitative models are often constructed on the same basis suggesting that given similarities in topography and climate between some European cities in which cycling rates are very high and cities in which rates are low, the difference lies in the level of cycling risk because of poor facilities and driver behavior. Unfortunately, this interpretation may be incorrect for the following reasons. It may be misleading because there are any number of other factors that may influence cycling rates, including attitudes, historical modal shares and, probably most importantly, service levels of other modes. It may provide insufficient guidance about the type of facilities that are required. Facilities in some cities may work well because of the characteristics of the population or city, but work badly in others. For example, a different form of bicycle parking facility may be appropriate in Australia or the United States from that required in Japan where theft is not a common problem. The different urban context of Japan means that bicycles are often used for accessing railways. This makes the provision of parking concentrated at railways particularly effective. Distribution of parking facilities in Australia and the United States would probably need to be more widespread, and thereby expensive, to be as effective from the viewpoint of the cyclist.

Given the very different characteristics of trips made, land use distributions, levels of car ownership, etc., across different cities, it is unrealistic to expect a particular type of facility to work well in one city simply because it works well in another.

In view of the limitations of simple correlation type models in understanding bicycle transportation, it is natural to turn to other areas of research directed at understanding the interrelationships of population characteristics, numbers of trips made, modal shares spatial distribution of trips, and land use characteristics. Transportation research has developed a range of techniques to help in our understanding of these relationships and to model the ways in which various factors interact in an urban context. The techniques may be broadly categorized as:

1. "Traditional" land use transportation models,
2. Strategic transportation models, and
3. "Behavioral" models.

Often these models are portrayed as alternatives, with the latter models suggested as improvements on the earlier approaches; however, it needs to be recognized that these models are largely complementary. The major challenge is to integrate the different approaches to allow behavioral findings to be applied in both developing broad strategies and in the detailed provision issues faced by local engineers and planners. Before considering how integration can be achieved, the different types of models are briefly described.

Traditional Models

The classical models have a number of elements familiar to transportation planners. These are trip generation, trip distribution, mode choice, and trip assignment. These four stages address a number of reasonable questions:

1. How many trips will be made,
2. Where they will be from and to,
3. What mode they will use, and
4. Which route they will take at what time.

This sequence of analysis is represented in Figure 1 (*4*).

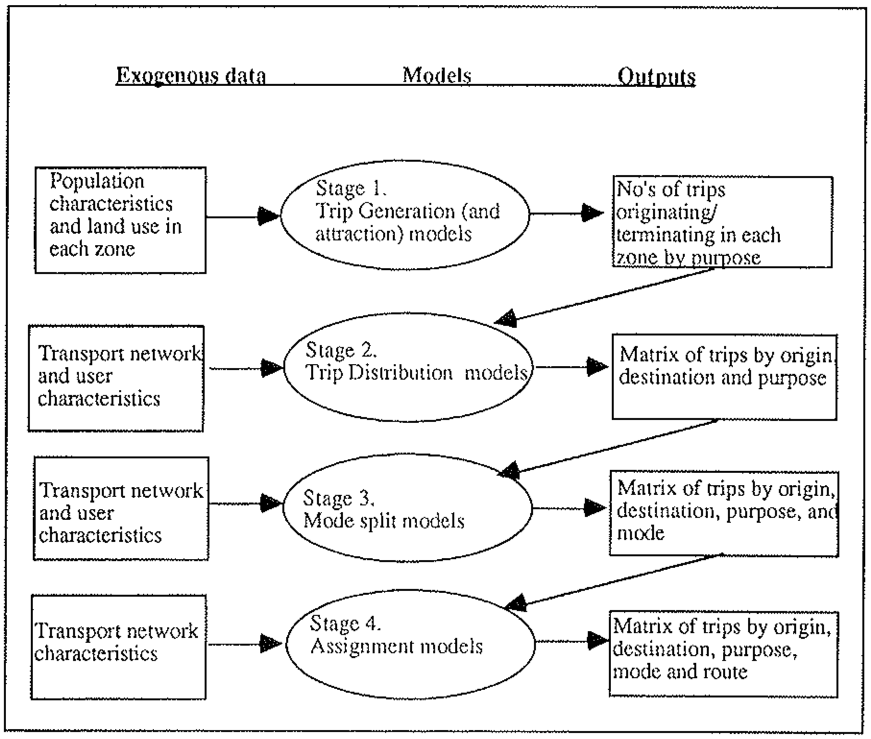

FIGURE 1 **Classical four-stage transportation model.**

A major advantage of the four-stage model is that it can be applied at a fairly fine zonal or even link-based level. This level of detail is required by many of the people involved in day-to-day transportation supply issues; however, as emphasized by Bates (*5*), this level of detail is achieved at some cost. One of the problems acknowledged by Bates is that the "slow modes" of walking and cycling are often omitted from all stages of the modeling process to reduce the complexity of the modeling structure. There is essentially no theoretical reason to exclude these modes and their omission is often attributed to an institutional and political orientation toward providing capacity for motor vehicles and transit. There have been some exceptions to the omission of bicycles from traditional models, notably as one would expect, in the Netherlands, and in isolated other instances such as Montgomery County, Maryland (*6*).

Many commentators have noted other deficiencies in the use of four-stage models (*5,7,8*). The criticisms of the state of practice in four-stage modeling may be summarized for each stage as follows.

Trip Generation

Trips generated within a particular zone and trips attracted to a zone are generally estimated on the basis of a cross-sectional survey of numbers of trips made by households. Different types of households, based on life cycle stage, income, car ownership, or other readily observed characteristics, are correlated with different trip-generating rates. Different zonal land use characteristics (retail floor-space, office space, etc.) are correlated with trip attraction rates. This cross-sectional analysis does not provide information about changes and is unlikely to stimulate questions about what is causing changes in trip rates over time. The level of trip making itself is generally not a target of policy among transportation planners using a four-stage model, which is something of an anomaly.

The traditional models do not typically attempt to relate trip rates to changes in mode choice, system changes, or availability of different destinations. The trip generation models that emerge are insensitive to policy tools available to transportation planners and are crucially dependent on population changes. Population changes are usually taken from demographic predictions outside the transportation model.

Some trip generation models for bicycles have been calibrated using the techniques typically used in the traditional models. In one English study (*9*), a model of bicycle trip generation incorporating variables such as car ownership and household structure was estimated. Different participation rates in cycling, ranging from 6.6% to 0.4%, were identified across 10 different groups. Extension of this approach is likely to be fruitful in understanding how to maximize benefits through targeting of provision to particular bicyclist groups.

Trip Distribution

Very little progress has been made in modeling people's decisions about trip destinations and how these relate to their origins. In most models, trips generated are allocated origins and destinations based on some measure of separation. The models are then "calibrated" according to an observed matrix of movements. This procedure is unsatisfactory insofar as the reasons why a particular destination is chosen may depend crucially on a number of factors that are simply omitted from the distribution model. This may be attributed to our lack of understanding of complex human activity patterns that determine destination choice.

Although this theoretical basis for trip distribution is unsatisfactory, the lack of accurate data on movements makes calibration inaccurate or nearly impossible in the case of bicycles, which are often omitted from routine traffic movement information collection.

Inaccuracies are compounded when increases in trips generated are predicted. The additional trips are allocated through growth factors applied to origin and destination pairs. These growth factors are often not integrated with projected transportation system and land use changes, making the distribution process even more suspect theoretically and dangerous practically.

Mode Choice

The modeling of mode choice has received a large proportion of attention in research into transportation behavior. A fair amount of this research has been incorporated into the four-stage process but because of the size of areawide four-stage models, often only a limited number of variables and mode combinations are included. Frequent omissions are cycling and other "minority" modes along with variables that may be important in an individual's choice of those modes. The behavioral models often incorporate a significant number of the variables that are omitted from the sequential models for areawide planning.

A frequently neglected aspect of mode choice models in the four-stage process is the interaction of individual and household activity patterns that impose constraints on mode choice and other aspects of personal and household travel characteristics. The work in activity modeling (*10–12*) has indicated some promise in understanding constraints; however, there is still some way to go before these techniques are operational at the detailed level of the four-stage process.

The existence of the sorts of constraints commonly referred to in activity analysis, such as the need to transport children, to link journeys for different purposes in accordance with a time budget, to carry out shopping, etc., are anecdotally important. The application of an activity analysis approach could be of considerable value in understanding the constraints on bicycle use and the opportunities for increased bicycle use if facilities are provided for specific groups. For instance, currently, a parent may decide to travel by car to work at a particular time so they can take a child to school. If a cycle facility were provided allowing the child to cycle to school, the parent may choose a different departure time, possibly outside the morning peak, or have time available to consider taking an alternate form of transportation.

Assignment

Trip assignment components of the classical models tend to be dominated by questions of software and network design rather than the route choice and departure time choice considerations important for individual travelers.

The route choice issues for cyclists are particularly crucial. Inadequate routes for bicycle travel may result in no trip being made or an alternate mode being selected. A choice not to use an inappropriate facility may affect provision of additional facilities, different link characteristics may affect destination choice, and mixing of bicycles with other traffic on particular routes may affect the flow of motorized traffic. None of these interactions are dealt with satisfactorily in traditional models.

A useful discussion of the need for, and difficulties in, inclusion of bicycles in assignment models is provided by Sharples (*13*). She also notes the difficulties in incorporating bicycles within existing software packages designed predominantly for motor vehicles. Bicycles have quite different traffic characteristics from motor vehicles—saturation flows, different speed and trip length distributions, route availability, gap acceptance, propensity to obey particular road rules, etc. These characteristics are poorly understood and may be highly variable according to the context and the particular cyclist.

Strategic Modeling

Despite the criticisms of the classical modeling approach noted previously, the state of practice in applied transportation planning remains largely based around four-stage models. Given this fact, along with the benefits discussed earlier of having a quantitative model rather than making decisions in an information vacuum, the question is how the approach can be used to understand and develop policy responses to the pressing transportation questions.

Increasingly, so-called strategic or sketch planning models have been used for analyzing major policy issues. The advantages of such models are discussed in the following sections.

Reducing Zonal Detail

One major drawback of the very detailed four-stage approach is the level of detail itself. The vast numbers of zones means that computationally there is room for only a very limited number of variables that explain behavior in the models and little or no feedback between stages of the modeling process.

Thus, the most common way of adapting the four-stage approach to strategic issues is to reduce the level of zonal detail. In Sydney, with a population approaching 4 million spread over a very large area, the major transportation model has 720 zones, 7,000 links, and a transit network of 22,000 segments. It has been recognized that to try to work at this level of detail in seeking to understand fairly broad policy implications is computationally intractable. The zonal network has been collapsed from 720 to 86 in the major recent study of strategic options, known as the Future Directions Study, undertaken in 1991 (*14*).

Even this reduced level of detail makes inclusion of a large number of policy variables or feedback mechanisms difficult. For modeling these more complex relationship structures, even smaller numbers of zones may need to be used. Also, specific market segments can be considered alone in modeling many issues, and the network assignment information can be abandoned. This is essentially the approach taken in many of the behavioral models discussed later. Where aggregated zones are used, such as in the Future Directions model, they will ideally be consistent with the detailed zones to make it possible to incorporate findings from the strategic models into the more detailed models.

Sequential Structure

One major criticism of the classical models is the sequential structure imposed on the whole population and the lack of any interaction between elements in that structure. By using a strategic model with a smaller number of zones, it is easier to incorporate the feedback effects that are important in many transportation-related choices.

Incorporating feedback between elements of the sequential process is now a reasonably well-accepted practice in the more sophisticated strategic models but is by no means universal. The order of modeling adopted: trip frequency, destination, mode choice, and route and time selection, may be varied according to different types of people or trip purposes. In the introductory discussion about why it is important to model bicycle demand, it was noted that adoption of bicycles as a primary mode of transportation by some people could affect decisions about where they live. It is difficult to incorporate such an effect in a traditional model because of the computational burden placed on those models from manipulating huge matrices of zones.

Behavioral Models

Other interactions that can also be incorporated into a model that has been freed of the burden of large numbers of zones include many aspects of the decision making process. These models are frequently of the form known as "disaggregate" or "behavioral" models (*15*). They examine the choice process undertaken by individuals in relation to a particular aspect of their travel behavior. These models draw on literature from psychology and economics relating to choice behavioral attitudes, perceptions, information integration, and decision making. This contrasts with the classical models, which are related only tenuously to any behavioral theory.

The disaggregate approaches are very useful for understanding not only what decisions people are making about travel but why they are making them. Young (*16*) presents a general model of the decision making process (Figure 2) that identifies some of the many aspects of decision making that can be investigated in behavioral research into transportation.

The bold lines in Figure 2 represent the main effects and the faint lines represent feedback effects in the decision making process in relation to transportation.

The behavioral approaches have been used most extensively in transportation for modeling mode choice alone but have also been used for other aspects of transportation demand. They could also be used for joint estimation of trip distribution and generation for particular classes of people.

Most of the models have assumed a utility maximization framework for decision making with no express acknowledgment of choice inertia effects or some of the subtleties of perception, attribute evaluation, etc. Some of these subtleties may be important for understanding the longer term potential of cycling as a transportation mode.

A number of useful studies have been conducted in relation to mode choice and route choice by cyclists. Perhaps the most comprehensive application of behavioral modeling techniques to bicycle mode choice in a minority mode share context is the study by Noland (*17*). That study seeks to test some of the hypotheses commonly put forward regarding the role of risk versus other factors, such as comfort, in relation to choice of bicycle transportation.

Other applications of behavioral techniques have been in the area of route choice (*18–20*). These studies have frequently used stated preference techniques to try to elicit information about the value cyclists place on various attributes of routes when making route choices. Stated preference techniques have a considerable potential for future modeling work in other areas related to bicycles in addition to route choice.

INTEGRATING BEHAVIORAL MODELS

The challenge for those seeking to improve our understanding of bicycle use is to integrate insights from behavioral models into areawide transportation planning. The link between behavioral models and system characteristics in networks is often unclear. This

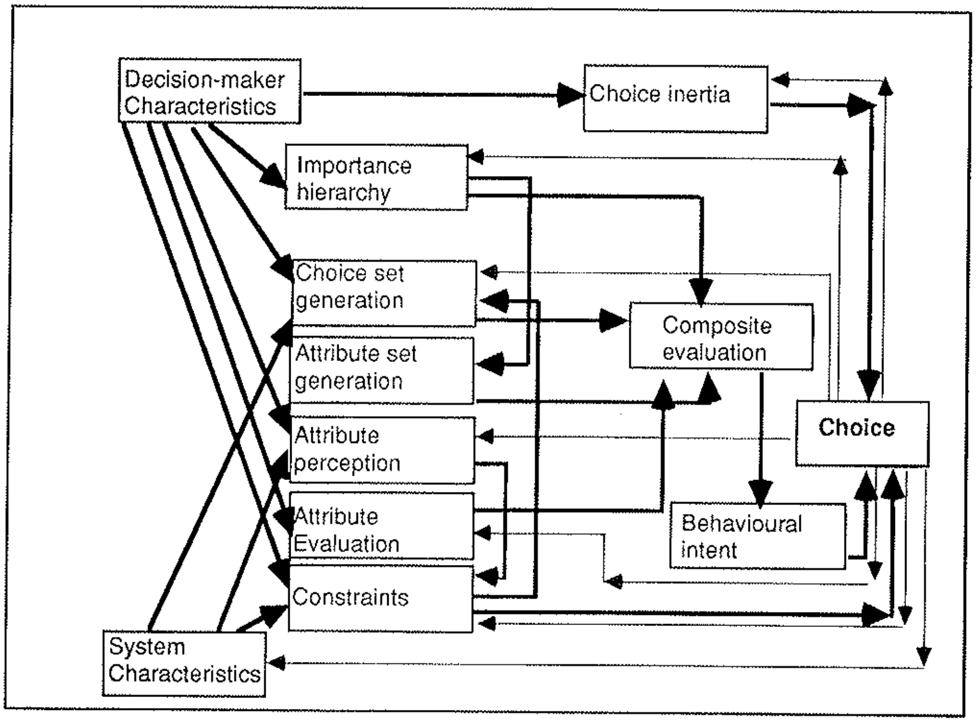

FIGURE 2 A general transportation model (*16*).

is particularly the case for bicycles, as discussed by Sharples (*13*). One method that may be explored as the mechanism for incorporation of variables identified in behavioral models, for instance risk associated with a particular link, is incorporation of specific bicycle factors within the concept of "generalized cost." Information on these factors would need to be available on a network-wide basis.

A key ingredient to such integration is collection of appropriate data relating to the network. This is costly and requires a systematic inventory of our road systems based on factors that are good predictors of bicycle demand. Additional exploratory research would be useful in identifying these predictors.

Inventories of our road networks are constantly being improved. The management of road inventory information has recently become a high priority as its use within GIS systems and for IVHS is being expanded. Already attempts are being made to ensure that bicycles are not ignored in developing such technologies (*21*). However, there is a strong likelihood that they could be omitted from practical applications of these techniques if the possibilities are not considered well in advance and a modeling framework is not established.

CONCLUSION

This article argues that a high priority needs to be given to incorporating bicycles into quantitative transportation models. This contrasts with an alternate view that mathematical modeling of transportation is not an appropriate way to plan urban transportation systems because models are overly restrictive in the variables they are able to include.

The need to incorporate bicycles in quantitative models stems from the need to ensure that planning is fully thought through and therefore resources are efficiently allocated. The successes and failures of implemented bicycle policies may also be better understood and less susceptible to the modal bias of particular institutions or traditional approaches.

Traditional modeling techniques, and even the more recent strategic modeling techniques that have evolved from them, have not been effective in modeling minority modes such as cycling. The challenge in modeling bicycle demand lies in integrating the many subtle factors affecting the demand for cycling into strategic planning models and detailed areawide planning models. This calls for a concentrated research effort to develop behavioral models whose parameters can be incorporated into the models that are spatially linked.

This research requirement does not currently appear to be receiving a great deal of attention. The time is now right to pursue such research through data collection in conjunction with the information requirements of new transportation research areas such as IVHS and GIS. This has the potential to place research into demand for minority modes, such as cycling, into the research mainstream. It may be that this is where they rightly belong given the issues of sustainability currently facing our cities.

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REFERENCES

1. Brundtland Commission and T.W.C.o.E.a. *Development, Our Common Future*. Oxford University Press, Oxford, U.K. 1987.
2. Zegeer, C. *Final Report: The National Bicycling and Walking Study*. FHWA, 1994
3. Waldman, J. A. *Cycling in Towns: A Quantitative Investigation*. Department of Transport, 1977.
4. Nash, C. *Economics of Public Transport. Modern Economics* (D. Pearce, ed.). Longman Group, Harlow, 1982.
5. Bates, J. An Integrating Framework for the Four-Stage Model. In *Longer Term Issues in Transport*. Avebury, Crowthorne Berkshire, 1990.
6. *A Transportation Planning Model For Montgomery County*. The Maryland-National Capital Parks and Planning Commission, 1991.
7. Atkins, S. T. The Crisis for Transportation Planning Modelling. *Transport Reviews*, Vol. 7, 1987, pp. 307–325.
8. Dasgupta, M. Modelling Urban Travel Demand. In *Longer Term Issues in Transport*. Avebury, Crowthorne Berkshire, 1990.
9. Bird, J. and D. J. Holden. *A Model for Estimating Bicycle Use in Local Authority Areas in England*. Transport Studies Group, University College, London, 1986.
10. Clarke, M. Recent Advances in Activity-Travel Analysis. Presented at 60th Annual Meeting of the Transportation Research Board, Washington, D. C., 1981.
11. Clarke, M. Activity Modelling—A Research Tool or a Practical Planning Technique. *Proc., 1985 International Conference on Travel Behaviour*, Noordwijk, The Netherlands. VNU Science Press, Utrecht, The Netherlands, 1986.
12. Recker, W. W., and M. G. McNally. An Activity Based Modelling Framework for Transportation Policy Evaluation. *Proc., 1985 International Conference on Travel Behaviour*, Noordwijk, The Netherlands. VNU Science Press, Utrecht, The Netherlands, 1986.
13. Sharples, R., *Modelling Cyclists in SATURN*. Traffic Engineering and Control. 1993, pp. 472–475.
14. Roads and Traffic Authority. *Road Transport Future Directions—Report on Options*. RTA, 1991.
15. McFadden, D. L. The Theory and Practice of Disaggregate Demand Forecasting for Various Modes of Urban Transportation. *Proc., Seminar on Emerging Transportation Planning Methods*, Daytona Beach, Fla. U.S. Department of Transportation, 1976.
16. Young, W. The Role of Thresholds in Transport Choice. *Proc. 1985 International Conference on Travel Behaviour*, Noordwijk, The Netherlands. VNU Science Press, Utrecht, The Netherlands, 1986.
17. Noland, R. B. *The Role of Risk in Policies to Promote Bicycle Transportation*. University of Pennsylvania, Philadelphia, Pa., 1992.
18. Axhausen, K. W. Bicyclist Link Evaluation. In *Transport Research Record 1085*, TRB, National Research Council, 1992.
19. Bradley, M. A. and P. L. Bovy. A Stated Preference Analysis of Bicyclist Route Choice. Presented at Tranportation Methods. PTRC 12th Summer Annual Meeting, July, 1984.
20. Osborne, P. Cycling, Health and Civilised Cities: The Promotion of Cycling in a Hilly Northern City. In *Velo-City*. Nottingham,. 1993.
21. Betz, J., J. Dustrude, and J. Walker. Intelligent Bicycle Routing in the United States. In *Transportation Research Record 1405*, TRB, National Research Council, 1994, pp. 21–27.

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