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TITLE: Integrating Bicycles into Applied Models of Urban Transport

ABSTRACT: Practitioners in transport planning are used to considering modes which have substantial direct infrastructure requirements, such as road provision and public transport systems. It is unusual to pay a great deal of attention to non-motorised transport modes, such as cycling, as these are typically non-intrusive and require very limited infrastructure.

However, bicycles need to be integrated into transport planning models, if only because of increasing political pressure for greater consideration of alternative and sustainable transport modes and increasing pressure to allocate resources efficiently.

It is widely recognised that extensive bicycle use requires the opportunity, or facilities, to neutralise the effect of dominating motorised traffic flows. The role of transport modelling in relation to bicycles may be considered as (i) determining the current level of demand for cycling; (ii) demand for cycling that is currently suppressed by sub-standard facilities or specific obstacles to cycle trips; (iii) determining what if any additional demand could be generated by providing facilities specifically for cycling (elasticity of demand) or changing conditions for competing modes (cross elasticity); (iv) identifying what trip distribution characteristics are observed with different cycling conditions; and, (v) how increasing the level of cycle facilities and cycling would impact on network performance.

In order to answer these questions it is necessary to have a modelling framework for cycling that dovetails with existing models of transport used for planning at micro and macro levels. This paper discusses such a framework.

KEYWORDS: bicycles, modelling, urban transport, planning

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1. INTRODUCTION

Total expenditure by entities falling within the responsibility of the New South Wales Department of Transport amounted to $3,854,760,000 (NSW Department of Transport, 1994). By contrast the RTA's budget directly attributable to bicycles in 1993/4 was in the order of $3,000,000, or less than 0.1%. While this does not reflect the total expenditure on facilities used extensively by bicycles, such as improvements to road shoulders, it is in these relativities that the importance of bicycles is often judged. This results in bicycles being considered as inconsequential.

However, bicycles are not trivial in other senses. Even in Sydney which is notoriously unfriendly for bicycles, they make up a small but significant share of the journey to work modal split (Milthorpe, Smith and Wigan, 1993) and can make up an even greater percentage of educational and other non-work trips.

Bicycles and walking are thus difficult to compare with other transport modes. At the Velo-City conference in Nottingham in 1993, the then President of the European Cyclists Federation, Gretter Aggernaes, outlined the "three paradoxes of bicycle and pedestrian planning":

- because these modes are slow you should make them quick by giving them the most direct route;
- because bikes and pedestrians take up little space therefore you should give them space; and,
- because they are cheap to promote and provide for it is important that money should be spent in promoting and providing for them

These recommendations are not uniformly accepted by transport planners in practice. The concept of bicycles as transport, rather than a third world curiosity or recreational pursuit, does not fit with many planners' views of reality. Bicycles may be perceived as obstacles to transport under some views of the world.

There are a number of pressures on planners which require them to consider bicycles, no matter what their own view of the world may be. These include:

- political pressures to be seen to be "green" and to be concerned with the well being of the disadvantaged including those not able to afford or ineligible to use cars but who may be able to use bicycles;
- economic pressures to reduce the amount spent on transport infrastructure and transit deficits;
- transport system performance pressures to limit congestion and pollution.

The paper considers why formal models of bicycle demand are useful in planning for bicycles and incorporating bicycles in mainstream transport strategy formulation. A brief review of attempts to incorporate bicycles in transport demand models is provided and a framework for improving those models is discussed. This framework is a fairly general one that could be applied to other areas of transport.

It is argued that quantitative modelling of the demand for bicycles is essential to establish their role in an urban transport system. Little progress has been made in developing a common understanding of what bicycle provision needs to be carried out and bicycle policy is based on imprecise ideas about the effects of particular measures.

Some of the approaches to transport demand modelling that could be adopted to gain a better understanding of the role of bicycles in our cities are examined. Better understanding, backed by rigorous analysis, should improve policy making in relation to bicycles. Transport modelling is not a simple matter however, and some of the challenges specific to bicycles are substantial. These challenges are also highlighted.

2. WHY MODEL BICYCLE DEMAND

The reasons for examining bicycle demand in transport models may be self-evident to those interested in either modelling or bicycles. However, not all transport planners fall into either of these categories and it is worth briefly recapping on why bicycles are a potentially important part of the transport mix and why a formal model may be useful.

One of the major issues facing the 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. Transport patterns have been identified as having substantial negative impacts on sustainability through firstly, the direct impacts of certain forms of transport, particularly the private motor vehicle, and secondly through the indirect effects of the transport system on land use patterns.

It is widely perceived that a significant change in transport and land use patterns, away from a reliance on motor cars, is needed to meet the sustainability criteria identified in the Brundtland report (Brundtland Commission 1987). What is not so generally agreed 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 transport, for longer trips.

While the arguments supporting increased use of bicycles may be attractive, there is some question about whether significant numbers of people would consider bicycles as a transport alternative for a significant portion, or any, of their trips. The answer to this lies in views about development aspirations.

There is room for the argument that private motor vehicles will maintain or even strengthen their

supported by citing the comfort, convenience and security, not to mention industrial importance, of the automobile. Building on the view that automobiles represent the “majority” transport

motorised vehicles and therefore the “difficult” minority of cyclists should be coerced into abandoning the use of bicycles.

transport system, are alleged to be capable of being addressed through technological and pricing changes under this pro-automobile paradigm. However, to the extent that use of a bicycle is a

on automobile users - unless of course comparable constraints on bicycle use are created in the meantime.

development of formal models rather than simply by describing features of scenarios and anticipated transport outcomes. By using formal models the technological and pricing changes

model structures to determine the effect on demand for bicycle use. This can allow the view that bicycles be effectively discouraged from the road system, to be assessed against the role that

elasticities of demand, will be appropriate here.

In addition, appropriate priorities for bicycle budgets, where significant budgets exist, need to be

quality changes - level of service elasticities. The increased popularity of cycling for recreational and utilitarian use through the 1980's and the recognition of potential benefits of bicycle use have

say that budgets have been developed using *ad hoc* methods. For a variety of possible reasons, the implemented bicycle facilities in Australia have often been characterised as failures due to a lack of observed use. The analysis of the "failure" of implemented provision may be interpreted in a number of ways:

(a) providing for cycling is a waste of money;

(b) the facilities created to date have been inappropriate or insufficient to generate any noticeable demand response;

(c) cycling facilities alone will not have a significant influence on demand for cycling and it is necessary to introduce policies directed at changing attitudes, cycling behaviours and levels of service of other modes. This will influence transport demand generally in a way which favours sustainable modes such as bicycles; or

(d) 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 transport demand within overall strategic models of transport, 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 response (a), which is not infrequently heard within road authorities, is incorrect.

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

Responses (b) and (d) are unlikely to carry a rational argument on cycling provision. Response (b) leaves an open question about how much needs to be directed to cycling to have an effect on demand. The (d) response is based on an equity argument which is very difficult to win given the competing demands of transit and automobile lobbies and other government spending priorities. The intuitively attractive conclusion (c) gives rise to additional questions about bicycle demand relative to demand for other modes. These need to be considered within the context of the urban transport system as a whole.

None of the suggested responses can be accepted without additional information and different analytical approaches may give rise to different responses. Traditional transport demand modelling approaches are likely to come up with a response along the lines of (a) unless the models are specified to incorporate a range of variables not typically included in such models. The reasons for this bias in traditional modelling practice and alternative approaches are discussed below.

3. MODELS OF BICYCLE TRANSPORT DEMAND

Perhaps the major single research project conducted into bicycle transport in the English speaking world in recent years has been the National Bicycling and Walking Study mandated by the US Department of Transportation Appropriations Act 1991. The research was conducted by consultants on behalf of the Federal Highway Administration. It has produced a series of reports on various aspects of the human powered modes. Most of the reports may be said to involve qualitative models of the demand for, and the effects of, human powered transport. The references to demand for bicycles are largely in terms of;

1. an identification of the barriers to cycle trips; and,

2. the characteristics of other modes that could be influenced to make cycle trips attractive either as a substitute or as a complement in the case of public transit, to the use of other modes .

It is recognised in the final report (Zegeer and others 1994) that there is a good deal of research yet to be done in translating the visions of a transport system more oriented towards non-motorised 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 modelling for bicycle and pedestrian services and facilities"*

This acknowledgment of the need for quantitative modelling has received insufficient attention to date.

Quantitative modelling techniques in transport vary widely in both general approach and degree of rigour. 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 quantitative models of cycling have been very limited in their scope and have not been readily incorporated within the detailed or strategic modelling structures of transport and land use planning.

One approach to modelling cycling has been to compare the levels of cycling in different cities and to try to correlate these levels to 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 UK, based mainly on their topography (Waldman 1977). 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.

Less formal models are often constructed on the same basis as the Waldman model to suggest that, given similarities in topography and climate, differences in cycling rates between cities are due to poor facilities and driver behaviour. Unfortunately this interpretation may be either;

1. misleading, given that there may be other factors influencing cycling rates including attitudes, historical modal shares and, probably most importantly, service levels of other modes; or,
2. provide little guidance as to 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. Thus a different form of bicycle parking facility may be appropriate in Australia or the USA from that required in Japan. This is partly because theft is not a common problem in Japan and the different transport context means that bicycles are often used for accessing rail. This makes the provision of

parking concentrated at railways particularly effective. Distribution of parking facilities in, say, Australia and the USA may need to be more wide spread to be effective and could be accordingly more expensive to provide.

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 in another. The reasons why facilities work in particular contexts need to be explored and the amount and optimum location need to be determined.

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

1. the "traditional" land use transportation models,
2. strategic transport models, and
3. "behavioural" models

Often these models are portrayed as alternatives with the latter models suggested to be improvements on the earlier approaches. In fact these model types are largely complementary.

The major challenge for bicycle modelling is to integrate the different approaches. Thus behavioural findings need to to be applied in developing broad strategies and assumptions underlying detailed traditional models need to be shaped accordingly. These ultimately affect the detailed provision decisions required by, say, local engineers and planners.

Before considering how integration can be achieved, the different types of models are briefly described.

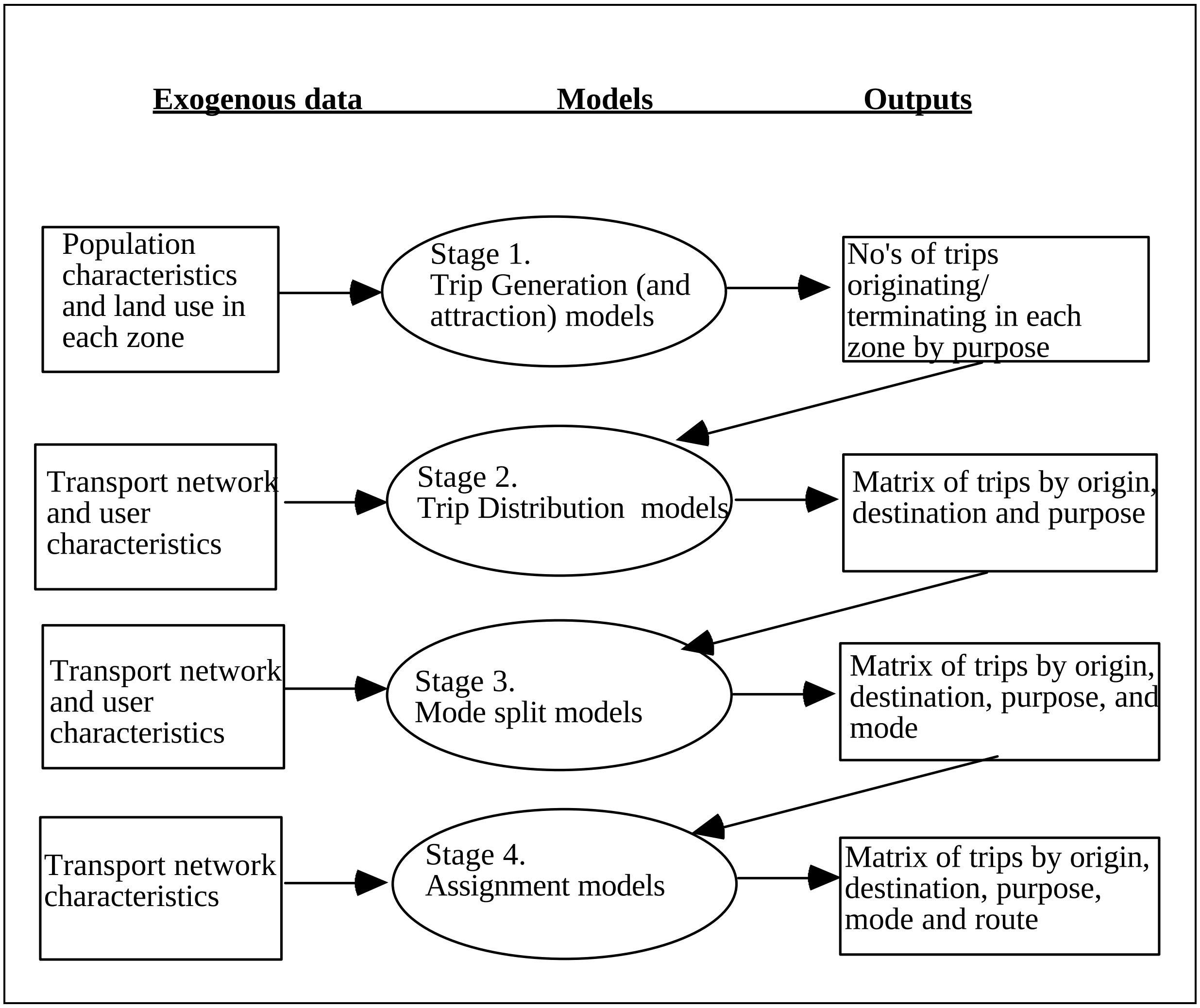
3.1. Traditional Models

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

i. how many trips will be made;
ii. where they will be from and to;
iii. what mode they will use; and
iv. which route they will take at what time.

This sequence of analysis is represented in figure 1 (page 7).

figure 1: The classic four stage transport model (after Nash 1982)



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 transport supply issues, however, as emphasised by Bates (1990), this level of detail is achieved at some cost.

One of the problems acknowledged by Bates is that the "slow modes", walking and cycling, are often omitted from all stages in order to reduce the complexity of the modelling structure. There is essentially no theoretical reason to exclude these modes and their omission is often put down to an institutional and political orientation towards 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 (The Maryland-National Capital Park and Planning Commission 1991).

A further general criticism is that traditional detailed models impose a particular sequence of travel decision making that may or may not be appropriate for all people over different periods of time. Thus a person may decide to use a principle transport mode and subsequently make decisions about residential location and employment. However the traditional transport model assumes that choice of mode comes after and is subordinate to residential and employment location choice. Some assumptions about decision hierarchies are inevitable in transport modelling but the traditional models are particularly inflexible. Most models models treat the urban form as being insensitive to mode choice and other choices, better models make these assumptions explicit.

Many commentators have noted other deficiencies in the use of four stage models (Bates, 1990; Atkins, 1987; Dasgupta, 1990). The criticisms of the state of practice in four stage modelling may be summarised for each stage as follows:

3.1.1. 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 observed characteristics, are correlated with different trip generation 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 transport 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 transport planners and are crucially dependent on population changes. Population changes are usually taken from demographic predictions outside the transport model.

Some trip generation models for bicycles have been calibrated using the techniques typically used in the traditional models. In one English study (Bird and Holden 1986) 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.

There is considerable scope for development of participation profiles across market segments. The relationship between participation in bicycle riding and bicycle trip generation rates deserves further attention. Given the wide variation in participation between the groups identified by Bird and Holden it should be possible to identify key discriminatory variables. This would be particularly useful if there is a usable relationship between market segments and zonal population distribution. Incorporation of variables that reflect attitudes to bicycle use in market segmentation could be particularly useful.

3.1.2. Trip distribution

Very little progress has been made in modelling 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 in so far as the reasons why a particular destination is chosen may depend crucially on a number of factors which are simply omitted from the distribution model. The complexity of human activity patterns that determine destination choice have defied efforts to build a satisfactory general theory of trip distribution.

While the theoretical basis for trip distribution is unsatisfactory, the lack of accurate data on movements makes calibration inaccurate. Because bicycles are often omitted from routine traffic movement information collection the calibration of trip distribution models for bicycles is rarely done.

Inaccuracies in trip distribution models are compounded where 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 transport system and land use changes making the distribution process even more suspect theoretically, and dangerous practically.

3.1.3. Mode choice

The modelling of mode choice has received a large proportion of attention in the research into transport behaviour. The mode choice decision is undoubtedly the most interesting from a market perspective with direct commercial and competitive implications.

Some of the research into why people choose a particular mode has been incorporated into the four-stage process but, due to the size of the area-wide four-stage models, often only a limited number of variables and mode combinations are included. Frequent omissions are cycling and other "minority" modes together with variables that may be important in an individual's choice of those modes. The behavioural models, discussed below, have the scope to include a number of the variables which are routinely omitted from detailed traditional models used for area wide planning.

A frequently neglected aspect of mode choice models in the four-stage process is the interaction of individual and household activity patterns which impose constraints on mode choice and other aspects of personal and household travel characteristics. The work in activity modelling (Clarke and others, 1981; Clarke, 1986; Recker and McNally, 1985) has shown 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 to optimise a time budget, to carry 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 as to drop a child at school. If a bicycle facility were provided allowing the child to ride 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 transport. This example of the sorts of constraints examined in activity analysis illustrates the complexities underlying many travel decisions.

3.1.4. Assignment

Trip assignment components in traditional 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 travellers.

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 motorised 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 (1993). She also notes the difficulties in incorporating bicycles within existing software packages designed predominantly for motor vehicles. Bicycles have quite different traffic characteristics to 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. Some recent work has focussed on data collection and modelling micro aspects of bicyclist behaviour which may be useful for building assignment models (Brundell-Freij, 1994).

3.2. Strategic Modelling

Despite the criticisms of the classical modelling approach noted above, the state of practice in applied transport planning remains largely based around four-stage models. The four stage approach can be adapted to develop broad strategic policy responses to the pressing transport questions. So called strategic or sketch planning models have been increasingly used for this purpose.

Strategic models are a direct descendent of the traditional models. They have the same four stages but reduce the complexity of modelling through reduction in the zonal detail.

In a city such as Sydney with a population approaching 4 million spread over a very large area, there are 720 zones, 7,000 links and a transit network of 22,000 segments in the major transport model. It has been recognised that to try to work at this level of detail in seeking to understand fairly broad policy implications is computationally intractable. In the major recent study of strategic options, known as the Future Directions Study, undertaken in 1991 (Roads and Traffic Authority 1991) the zonal network was collapsed from 720 to 86. Where aggregated zones are used, such as in the NSW 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.

The vast numbers of zones in the traditional model means that there is no room for potentially important explanatory variables. Alternative sequencing is difficult to introduce and no feedback between stages of the modelling process, such as mode choice and trip generation, can be considered.

Thus, the most common way of adapting the four-stage approach to strategic issues is to reduce the level of zonal detail. However, even the simplified zonal system employed in the Future Directions model makes inclusion of a large number of policy variables or alternative structural relationships difficult. For modelling more complex structures even smaller numbers of zones need to be used or zonal systems dispensed with completely. One way to do this is to model narrowly defined market segments separately. Alternatively, separate stages can be considered in isolation. These are essentially the approach taken in many of the "behavioural" models discussed below. At some stage however, models need to be brought back to the physical network for implementing specific provision and for reviewing the overall network impact of major provision or strategies.

As discussed above one major criticism of the classic model approach is the sequential structure. This effectively assumes a decision making sequence for the whole population with little if 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 which may be important in many transport related choices, particularly over an extended period of time.

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 modelling 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 relating to why it is important to model bicycle demand it was noted that adoption of bicycles as a primary mode of transport by some people could affect decisions about where they live. This would affect the subsequent stages in the classical framework. It is difficult to incorporate such an effect in a traditional model due to the computational burden placed on those models from manipulating huge matrices of zones.

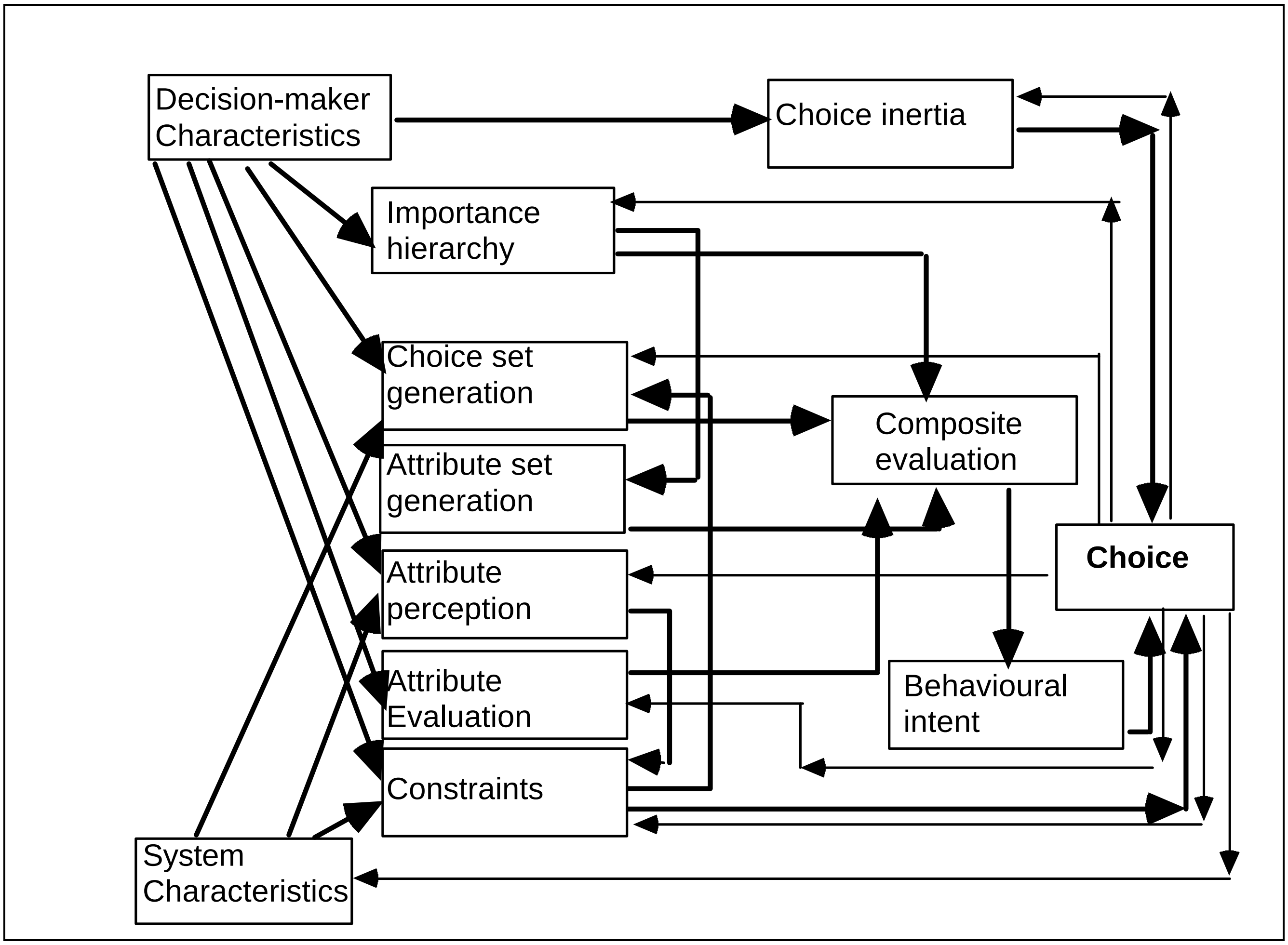
The treatment of bicycles in strategic models has been very limited, certainly in Australia. Bicycles are however fairly readily incorporated into such models. The accuracy of strategic models in predicting numbers of bicycle trips made, where they will be made, what mode split characteristics can be expected and which parts of the network will be used by bicycles are largely dependent on endogenous variables included in the models and accuracy of assumptions about exogenous variables. Guidance as to what are the best variables to use are provided by some of the behavioural analysis discussed below.

3.3. Behavioural Models

During the 1970’s the assumptions underlying the four stage models were increasingly questioned. In particular, the factors affecting personal choices about transport came under increasing scrutiny and theoretical frameworks applicable to transport decision making were increasingly developed.

The resulting family of models are frequently known as "disaggregate" or "behavioural" models (McFadden 1976). They examine the choice process undertaken by individuals in relation to particular aspects of their travel behaviour. The models draw on literature from psychology and economics relating to choice behaviour, attitudes, perceptions, information integration and decision making. This contrasts with the classical models which are related fairly tenuously to any behavioural theory.

figure 2: A general transport model (after Young, 1986)



The disaggregate approaches are very useful for understanding not only what decisions people are making about travel but why they are making them. Young (1986) presents a general model of the decision making process which identifies many aspects of decision making which can be investigated in behavioural research into transport.

The bold lines in figure 2 represent primary sequences in decision making and the faint lines represent feedback effects. It is relatively easy to put forward such a framework describing the process, it is much harder to estimate a model, using available data, that approximates it.

The behavioural approaches have been used most extensively in modelling mode choice but have also been used for other aspects of transport demand. Most of the models have assumed a utility maximisation framework for decision making with no express acknowledgment of choice inertia effects or some of the subtleties of perception, attribute evaluation etc.. These subtleties may be important for understanding the longer term potential of cycling as a transport mode.

A number of behavioural models have been estimated in relation to mode choice and route choice by cyclists. Perhaps the most comprehensive application of behavioural modelling techniques to bicycle mode choice in a minority mode share context is the study by Noland (1992). That study seeks to test some of the hypotheses put forward regarding the role of risk versus other factors, such as comfort, in relation to choice of bicycle transport.

It appears clear from the work of Noland (1992) and others that there are very significant differences in attitude towards cycling by different groups and these have important effects on cycling behaviour. Segmentation of the population according to bicycling attitudes and abilities is, again, a useful first step in modelling bicycle demand using behavioural techniques.

Other applications of behavioural techniques have been in the route choice area (Axhausen and Smith, 1992; Bradley and Bovy, 1984; Osborne, 1993) 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 considerable potential for generating data in other bicycle related areas, in addition to route choice.

4. INTEGRATING BEHAVIOURAL MODELS

The challenge for those seeking to improve our understanding of bicycle use is to integrate insights from behavioural models into area wide transport planning. The behavioural models can identify variables which need to be incorporated in traditional or strategic models. Relationships between variables important in influencing demand for bicycles may also be better understood to guide provision.

Translating between behavioural models and system characteristics in networks is often difficult. As discussed by Sharples (1993), this is particularly the case for bicycles where the subtleties of network effects on demand are not immediately apparent.

One mechanism for incorporation of variables identified in behavioural models is generalised cost. This concept is frequently employed in transport models. An estimate of generalised cost of cycling, associated with particular links, could be used in describing a network for different categories of bicyclists. Information on those factors affecting generalised cost of cycling would need to be available on a network wide basis and measurement models constructed to translate various factors into common cost units.

A key ingredient is therefore development of network specifications. This is costly and requires a systematic inventory of road systems including factors which may be predictors of bicycle demand as determined by measurement models.

Inventories of our road networks are constantly being improved. The management of such information has recently become a high priority as GIS systems and IVHS is expanded. Already attempts are being made to ensure that bicycles are not ignored in developing such technologies (Betz and others 1994). However, there is a strong likelihood that bicycles could be omitted from practical applications of these techniques if the opportunities and problems are not considered well in advance and a modelling framework is established.

5. CONCLUSION

This paper argues that a high priority needs to be given to incorporating bicycles in applied transport models. This will serve to inform the debate on the value of bicycles within the transport system and to ensure that provision is made with clear objectives.

The need to incorporate bicycles in models is driven by the scarcity of resources available for transport, particularly minority modes. This means that there is a 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 personalities and institutions.

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

One approach to developing the behavioural models is to break down the market into different types of cyclists according to attitudes and abilities. This is likely to provide very rich information about differences between groups of cyclists and their different requirements. This in turn has important policy implications.

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 transport 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 considered that this is where they rightly belong given the issues of sustainability currently facing our cities.

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REFERENCES

Atkins, Stephen T. "The crisis for transportation planning modelling." Transport Reviews 7 (4 1987): 307-325.

Atkinson, J E and P M Hurst. A study of adult bicycle use in Christchurch and Palmerston North. Ministry of Transport, Wellington, NZ, 1983. Traffic Research Report 34.

Axhausen, K.W and R.L. Smith Jr. "Bicyclist Link Evaluation." Transport Research Record 1085 (Travel Demand and Behaviour 1992).

Bates, J. "An integrating framework for the four-stage model." In Longer term issues in transport in Crowthorne Berkshire, edited by J H Rickard and J Larkinson, Avebury, 431-467.

Betz, J, J Dustrude, and J Walker. "Intelligent Bicycle Routing in the United States." Transportation Research Record 1405 (1994): 21- 27.

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.

Bradley, M A and P L Bovy. "A stated preference analysis of bicyclist route choice." In Tranportation Planning Methods in PTRC 12th Summer Annual Meeting, July 1984, edited by PTRC.

Brundell-Freij, K. Bicyclist time consumption and micro level route choice through intersections. Swedish Transport and Communications Research Board, 1994. TFBs/KFBs dnr 85-58-62.

Brundtland Commission and The World Commission on Environment and Development. Our Common Future. Oxford: Oxford University Press, 1987.

Clarke, Mike. "Activity Modelling - A research tool or a practical planning technique." In The 1985 International Conference on Travel Behaviour in Noordwijk, The Netherlands, edited by Aad Ruhl, VNU Science Press, Utrecht, 3-15.

Clarke, MI, MC Dix, PM Jones, and IG Heggie. "Recent Advances in Activity -Travel Analysis." In 60 th Annual Meeting of The Transportation Research Board in Washington.

Dasgupta, M. "Modelling urban travel demand." In Longer term issues in transport in Crowthorne Berkshire, edited by J H Rickard and J Larkinson, Avebury, 471-508.

McFadden, Daniel L. "The Theory and Practice of Disaggregate Demand Forecasting for Various Modes of Urban Transportation." In Seminar on Emerging Transportation Planning Methods in Daytona Beach Florida, edited by William F Brown, US Department of Transportation.

Milthorpe, Frank, Nariida Smith, and Marcus Wigan. Facts about Bicycles in NSW. 1993. Institute of Transport Studies, NMT-93-R7.

Nash, Christopher. Economics of public transport. Modern Economics, ed. David Pearce. Harlow: Longman Group, 1982.

Noland, Robert B. "The Role of Risk in Policies to Promote Bicycle Transportation." Ph.D, University of Pennsylvania, 1992.

Osborne, Paul. "Cycling, Health and Civilised Cities: The promotion of cycling in a hilly Northern city." In Velo-City in Nottingham, Year.

Recker, W.W. and M.G. McNally. "An Activity Based Modelling Framework for Transportation Policy Evaluation." In The 1985 International Conference on Travel Behaviour in Noordwijk, The Netherlands, edited by Aad Ruhl, VNU Science Press, Utrecht, 31-52, Year.

Roads and Traffic Authority. Road Transport Future Directions - Report on Options. RTA, 1991.

Sharples, Rosemary. "Modelling Cyclists in SATURN." Traffic Engineering and Control (1993): 472-475.

The Maryland-National Capital Park and Planning Commission. A Transportation Planning Model For Montgomery County. 1991. Draft

The New South Wales Department of Transport. Annual Report 1993/94. 1994.

Waldman, J A. Cycling in towns: a quantitative investigation. Department of Transport, 1977. LTR1 Working Paper 3.

Young, William. “The role of thresholds in transport choice.” In <u>The 1985 International Conference on Travel Behaviour in Noordwijk, The Netherlands</u>, edited by Aad Ruhl, VNU Science Press, Utrecht, 153-170.

Zegeer, Charlie, Jane Stutts, Bill Hunter, Wayne Penn, C David Feske, David Cheeney, Pamela McCarville, and Christina Geiger. <u>Final Report: The National Bicycling and Walking Study</u>. Federal Highway Administration, 1994. National Bicycling and Walking Study 23.