cent occurred in marked crosswalks and 14 percent occurred in unmarked crosswalks. Two-thirds (67 percent) of the sites had no traffic controls, but 22 percent of the sites had a red, green, and amber signal. Only 5 percent of the sites had a pedestrian signal. Although many of the accidents occurred at intersections, the vehicle actions were typically proceeding straight (73 percent).

Although the driver's vision of the pedestrian was not specifically indicated as blocked in 74 percent of the accidents, parked cars and standing traffic were visual obstructions in 13 percent and 5 percent of the accidents respectively. Several other driver-related characteristics were coded as follows: (a) drivers attempting evasive action (40 percent), (b) drivers engaged in a turning or merging maneuver (12 percent), (c) drivers attending to traffic and not seeing pedestrian (11 percent), (d) drivers under the influence of alcohol or drugs (3 percent), (e) drivers exceeding the speed limit (2 percent), and (f) drivers disobeying a sign or signal (1 percent).

Pedestrian behaviors were indicated for a number of variables that include the following.

Variable	Percent
Appearing suddenly in path of vehicle	44
Running	39
Walking or running into vehicle	17
Under the influence of alcohol or drugs	6

The accident-based countermeasure evaluations are aimed at detecting a change in the occurrence of specific target-accident types. Definitions were developed for a number of different accident types. There were 16 accident types developed and, when these were combined with those accidents that could not be coded, a total of 17 categories were identified as given in Table 1. As also given in Table 1, dart-outs and dashes of various kinds accounted for a total of 52 percent of the accidents.

In addition to the coding personnel who assigned each accident to a subjective accident type, automated procedures were developed to assign each accident to an objective accident type by using the taxonomy shown in Figure 3. Correlations were computed between the coder-assigned subjective code and the computer-assigned objective code. The correlations were high for all the accidents in the 1973 and 1974 sample (0.9754 and 0.9519 respectively).

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Bicycle Transportation for Downtown Work Trips: A Case Study in Davis, California

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Although there has been increasing interest in using the bicycle as a transportation mode, little is known about travel decisions that involve the bicycle, especially in U.S. cities. This paper discusses the development of modal-choice models that include the bicycle. The data used consist of a sample of 802 downtown workers in Davis, California. Age, sex, occupation, student status, and distance between workplace and residence were examined in relation to modal selection. Age and trip distance appeared to be negatively related to bicycle usage. The rate of bicycle use as a mode of transportation was lower for managers and those employed in areas such as transportation, utilities, communications, finance, real estate, and insurance than for workers employed in other areas. To analyze the contribution of these factors, we used a methodology that had been developed in disaggregate-behavioral, travel-demand studies to develop our alternative modal-choice models. Sequential binary and multinomial logit choice models were tested. The resulting models were satisfactory for exploratory purposes since many of the independent variables were useful in explaining modal choice. The results indicate that future work is needed to extend the models to other areas and to include those independent variables that are policy-sensitive. As a result, these models can be used in transportation planning to assist in making decisions relevant to bicycle use.

Main street is usually crammed with automobiles. The automobiles fill every possible place to park along the curbs, and drivers must wait in long queues to get through the next intersection. There are a lot of drawbacks in this situation. First, there are fewer visitors to businesses and governmental offices because the visitors must spend time looking for a place to leave their automobiles. The visitors also expend their emotional goodwill while waiting in the queues and competing for parking spaces. Second, everyone must breathe air that is substantially deteriorated by the admixture of noxious fumes from tailpipes, and the fact that the fossil fuels that make noxious fumes are finite and are rapidly declining does not lessen the discomfort.

Still, main street would not be main street without all those people. In most areas in the United States, the automobile is the only significant mode that is used to get people where they want to go. The search for alternative modes of transportation has progressed since the drawbacks of automobile use have been recognized. One of the many alternatives that is currently undergoing considerable evaluation is the bicycle.

In contrast to many of the mass or personal transit vehicles that are currently envisioned as alternatives to the automobile, bicycles are eminently state of the art. Bicycles are easy to make, fix, and operate. Moreover, they are easily accommodated, are inexpensive, and efficient, and rely primarily on renewable sources of energy. Bicycles are slower than cars, but a high percentage of trips currently made in the United States, especially to the downtown area, are well within their range. Despite all of these advantages, bicycles are still not seen on most main streets. Many people are arguing today that, if facilities were provided for bicycles, then people would ride them. However, will people ride bicycles if the facilities are provided?

The purpose of this paper is to discuss bicycle use in Davis, California, where there are well-established bicycle facilities. The response of citizens in Davis to using bicycles for work-trip travel indicates that, in this case, the citizens make substantial use of bicycles and their facilities. The percentage of bicycle riders for work trips in Davis exceeds the percentage of bus riders in many urban areas with strong transit systems.

Davis is a university-oriented city of about 30 000 in the central valley of California. Traditionally, a major transportation mode in Davis is the bicycle (12, 13). When growth and consequent competition with automobiles began to threaten the continuance of this tradition, a number of facilities and programs aimed at preserving the role of bicycles were established and have been in operation for several years. Consequently, it was possible to obtain the citizens' behavioral response to these facilities. Although the city of Davis possesses many special characteristics, e.g., its university orientation, terrain, and climate, the information gathered from this city gives some indication of what might be expected if similar facilities were provided in other locations.

PREVIOUS BICYCLE STUDIES

Recently, bicycle transportation has received popular and research attention. It has become apparent that bicycle transportation is a possible alternative for solving the problems of immobility, traffic congestion, air pollution, and energy shortages. However, there has been little research on the actual reasons why people choose bicycles as a transportation mode. Most research has been devoted to either the physical design of bikeway facilities or the discussion of the public-planning processes that include the location of bicycle facilities (3, 9). The state of knowledge regarding bicycle use is characterized more by what is not known than by what is known (5).

Although there has been little systematic effort in specifying the determinants for bicycle use, there have been a few studies that suggest some factors that might be related to bicycle use. Ohrn (10) made assumptions about a number of factors that might affect bicycle modal choice from a study in the Minneapolis-St. Paul area. Among the factors assumed to be important were flexibility of schedule, distance of trip, age of person, cost of parking, need for cargo storage, congestion of traffic, quality of facilities, and availability of transit. The specific nature of the assumed effects was not determined empirically, but assumptions were made on the magnitude of such effects. It was assumed that only a few people would use bicycles for work trips and trips longer than 3.2 km (2 miles). The assumption concerning the work-trip purpose seems to be contradicted by the experience in Davis and results from at least one other study.

Hansen and Hansen (5) found that the work trip was one of the strongest attractors for bicycle use in Uppsala, Sweden. In a 1971 survey, it was found that over 20 percent of all work trips were made by bicycle, and about 12 percent of all trips were bicycle trips, indicating that more importance is given to bicycles as a work-trip mode than any other mode.

Two studies took an economic approach to explain the choice between the bicycle and the automobile (4, 6). That is, it was assumed that the essential factors for explaining modal choice were trip costs and travel times. The latter factor was converted to monetary units by assuming a particular factor for the value of time. In both studies, assumptions were made about the comparative times and costs of the bicycle and automobile; however, this information was not derived by observing actual choices. The assumptions were used to analyze several hypothetical situations. It was concluded that, in most cases, the automobile is more likely to be chosen on strictly economic grounds. Since the trip times and costs were assumed to be a function of distance in both studies, the economic assumptions can be used indirectly by considering distance explicitly as suggested in other studies. This approach is taken in this study.

McGuire (9) suggested several factors that might be determinants for bicycle modal choice. Although these factors were not tested empirically, they are similar to those suggested in previously mentioned studies. These factors include trip distance, trip purpose, route quality, travel time, trip cost, age, sex, weather, and environmental pollution. It was further suggested that the approach used in disaggregate-behavioral models involving other modal choices might be useful for the bicycle case.

The disaggregate approach (11) has been thoroughly studied in the past, primarily in reference to the automobile as a modal choice. The key hypothesis is that individuals make their choice among modes probabilistically as a function of (a) characteristics of the modes in question such as time and cost; (b) characteristics of the individuals making the choice; and (c) interactions between individuals and modal characteristics, i.e., attitudes and perceptions of travel modes. Probably, the most common model of this nature is one in which the choice process is assumed to involve a trade-off between the time savings of a faster, more expensive mode and the cost savings of a slower, less expensive mode. It is apparent that the assumptions inherent in the disaggregate approach could be extended to include the bicycle as a possible alternative for a particular trip.

Such an extension was made by Ben-Akiva and Richards

(2) in a study of modal choice for work trips in the Netherlands. Among the modes included in a multinomial-logit, modal-choice model were automobile, bicycle, bus, train, moped, and walking. Since the conventional approach used in previous binary modal-choice studies was also used in this study, the key characteristics of the modes are trip times and costs.

The review of previous studies indicated that there are assumptions about the important determinants for bicycle use as a transportation mode but there is little concrete evidence that verifies these assumptions. This condition is especially true for U.S. cities where the bicycle has only recently been recognized as a viable transportation mode. This paper describes some of the data collected in Davis; the importance of various factors that affect the choice of using bicycles for commuting can be tested from these data.

BICYCLE-COMMUTING STUDY IN DAVIS

Data

Information on the use of bicycles was collected in October 1974 as part of a survey sponsored by the Davis Chamber of Commerce to determine the number of parking spaces normally used by people in the downtown area. One of us participated in expanding the survey to include data on transportation modes used for work trips to the downtown area. The downtown area is one of two major employment centers in Davis. The other center is the University of California, Davis.

Questionnaires were distributed to all downtown employees by the 168 employers. A total of 1413 persons were said to be employed in March 1974 in the area. The eventual rate of return was high. There were 1049 downtown workers (74 percent) who returned information on their usual transportation modes and parking locations. Failure to fill out or return the questionnaire seemed to be correlated with (a) employers who experienced difficulty getting part-time workers to return their questionnaires and (b) employees who did not fill out a questionnaire because they did not arrive by automobile and felt the study was not relevant to them. Since both these categories of workers showed an above-average incidence of using bicycles as their transportation mode, there is reason to believe that the reported rate of bicycle usage is an underestimate of the actual rate. Unfortunately, it does not seem possible to give a useful estimate of the magnitude of the underestimate.

In analyzing the degree of bicycle use as a transportation mode in the population that did respond, we considered only the incidence in the area where this mode would most likely be used. In this case, it was easy to discriminate between residents and nonresidents of Davis. This corresponds to the areas where bicycle use is likely because Davis has no significant unincorporated residential areas that are within range for using bicycles and it is 17.7 km (11 miles) from the nearest area where nonresident workers might live. There were 802 questionnaires returned from local residents.

These data are reported and analyzed in two stages. The first stage is a simple description (tabular) extracted from the survey data, and we did not attempt to make a statistical evaluation of these data in this section. Second, the development of modal-choice models is analyzed. Since these two stages have slightly different goals, the variables are defined or categorized slightly differently in the description as compared to the analysis. These differences are identified at the appropriate points in the text.

For the first step in this stage, the overall contribution of various modes of transportation for work travel to downtown Davis is reported. Table 1 gives the number and percentage of respondents who use the various modes or combinations of modes. An individual is assigned to a category if the mode(s) in the category was used at least once a week.

Although the automobile is the dominant mode, the bicycle is used for a substantial proportion of work trips. About 25 percent of the respondents use the bicycle at least once a week, and more than 6 percent of the respondents walk at least once a week. Therefore, non-motor-vehicle modes are important for work trips in Davis. The following is the relative contribution to transportation of each of the three principal modes: automobile, bicycle, and walk. The role of each is described by the number of work trips made per week and the number of work-trip kilometers traveled per week (1 km = 0.6 mile).

Transportation Mode	Kilometers Traveled per Week		Trips Made per Week	
	Number	Percent	Number	Percent
Automobile	7422	83	2879	77
Bicycle	1347	15	671	18
Walking	182	2	188	5
Total	8951	100	3738	100

The motor-vehicle mode of transportation accounted for a greater percentage of the total kilometers traveled than of the total trips made. Thus, there appears to be a difference in the length of trips by the different modes. To facilitate comparisons of the distances traveled by each mode, we sorted the respondents into three classes that correspond with the mode most frequently used. Those choosing automobiles as their most frequent mode had the longest trip distance [$\bar{x}$ = 2.85 km (1.77 miles)]; those choosing bicycles as their most frequent mode had the second longest trip distance [$\bar{x}$ = 2.12 km (1.32 miles)]; and those choosing walking as their most frequent mode had the shortest trip distance [$\bar{x}$ = 1.27 km (0.79 mile)]. Each group was paired with each of the other groups by using a Student's t-test to evaluate the reliability of the observed differences. All differences proved reliable as follows:

Item	t-Test	df	p
Automobile versus bicycle	6.11	651	<0.001
Automobile versus walking	7.89	557	<0.001
Bicycle versus walking	4.39	180	<0.001

In addition to the fact that trips of different length are normally made by each mode, the frequency of bicycling among those who chose to bicycle at all is slightly influenced by the length of the trip. Shorter trips were made more often. This relation is given below (1 km = 0.6 mile).

Number of Days per Week	Number of Bicyclists	Mean Distance (km)	Number of Days per Week	Number of Bicyclists	Mean Distance (km)
1	28	2.78	5	39	2.12
2	39	2.17	6	11	1.58
3	39	2.40	7	2	0.93
4	35	2.08			

These two lines of evidence converge in support of the view that work-trip length is a predictor of bicycle use as a transportation mode.

Age is also regarded as an important variable that affects the choice of bicycles as a transportation mode. This relation is described by classifying the three groups according to their most frequently used transportation mode and according to their ages, which are divided into seven classifications. These data are given in Table 2.

Since workers under age 24 are more likely to ride bicycles to work than other workers are, and since students are an important subgroup in that age classification, we determined whether the relation between student status and modal choice was a function of student status or student age. When age was controlled, student status did not appear to be related to bicycle use.

The final predictors of bicycle use for work trips were job title and type of employment of the workers. The classifications used for this analysis were those used by the U.S. Bureau of the Census for job titles and employment categories. These categories were used because they reflect socioeconomic similarity and because information about the work force in any community is available to that community through the census description. Table 3 reports the number and percentage of bicyclists by type of employment and job title. Bicycle use as a mode of transportation was substantially lower for the managerial group than for the other group. The rate of bicycle use as a mode of transportation is lower for workers in areas such as transportation, utilities, communications, real estate, finance, and insurance than for workers in the other areas.

Table 1. Downtown commuter modal choice of Davis workers by sex and student status.

Transportation Mode	Student		Nonstudent		Total	
	Male	Female	Male	Female	Number	Percent
Automobile only	36	29	235	205	505	63.0
Automobile-car pool	1	0	4	6	11	1.4
Automobile-walking	3	4	4	7	18	2.2
Automobile-motorcycle	0	1	1	0	2	0.2
Bicycle only	8	19	20	27	74	9.2
Bicycle-automobile	18	13	46	34	111	13.8
Bicycle-car pool	1	0	3	4	8	1.0
Bicycle-walking	0	1	3	2	6	0.7
Bicycle-motorcycle	1	0	0	0	1	0.1
Walking only	5	2	9	12	28	3.5
Car pool only	1	0	4	11	16	2.0
Bus only	1	0	0	1	2	0.7
Motorcycle only	2	0	4	1	7	0.9
Other	3	1	5	4	13	1.6
Total	80	70	338	314	802	100.0

Table 2. Most frequent modal choice by age classification.

Age Group	Automobile		Bicycle		Walking		Total	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
<18	17	58.6	10	34.5	2	6.9	29	4.3
18 to 25	133	60.2	72	32.6	16	7.2	221	32.4
25 to 35	161	76.7	37	17.6	12	5.7	210	30.8
35 to 45	98	87.5	13	11.6	1	0.9	112	16.4
45 to 55	63	86.3	7	9.6	3	4.1	73	10.7
55 to 65	25	86.2	0	0.0	4	13.8	29	4.3
65 to 74	6	75.0	0	0.0	2	25.0	8	1.2
Total	503	73.8	139	20.4	40	5.9	682	100.0

Table 3. Number and percentage of bicyclists by type of employment and job title.

Item	Number of Respondents	Ride at Least Once per Week	
		Number	Percent
Type of employment			
Transportation, utilities, and communications	58	7	12
Government	164	43	26
Services	130	36	28
Finance, real estate, and insurance	130	19	15
Retail trade	195	60	31
Bar and cafe	115	35	30
Total	792	200	25
Job title			
Professional and technical	168	48	29
Managerial	105	12	11
Sales worker	143	46	32
Clerical and cashier	188	49	26
Service worker	122	31	25
Laborer	60	13	22
Total	786	199	25

Modeling Analysis

The previous section indicates that several of the variables suggested by previous researchers might be useful for explaining the choice of bicycles as a transportation mode. Although these separate bivariate relations are informative, a multivariate analysis of the contribution of the independent variables to modal choice would account for possible intercorrelations among the independent variables. This analysis was done by constructing binary and multinomial-logit, modal-choice models that use the independent variables described below.

Since facility quality and weather condition data were not available for the study in Davis, they were not used as variables. Also, it was thought that these variables might not affect the work-trip travel in Davis for two reasons. First, the bicycle lanes and paths established in Davis make all trips to the core area equally feasible; thus facilities were not a variable. Second, the weather conditions for commuting trips are not as important as the weather conditions for other trips.

Undoubtedly, weather conditions influence the frequency of bicycling throughout the year; however, our goal, in this stage of the study, was to emphasize the characteristics of the situation that accounted for choices among a population all of whom were subject to the same weather considerations.

The variables available are divided into characteristics of the trip and characteristics of the individuals making the trip. Trip distance is the variable in the first class. There are two measures of trip distance. The first is an estimate of home-to-work distance that is reported by each respondent. Home and work addresses were also reported by the respondents. Therefore, the home-to-work distance was also determined by measuring it.

Distance is widely thought to be an important variable in determining the use of bicycles as a transportation mode. It can be assumed to have a direct effect on modal choice. Alternatively, since data on the times and costs for the alternative modes were not available, the distance variable can be used as a surrogate for a generalized price variable (1). Generalized price is a function of time and cost, and both of these variables are related to trip distance. Hence, distance should be related to generalized price (4, 6).

The remaining independent variables are characteristics of the trip makers. These variables are sex, age, and occupation, which measures the socioeconomic status. For the purposes of this analysis, the job title classification system of the Bureau of the Census was simplified to include five categories:

1. Professional and technical,
2. Managerial,
3. Sales,
4. Clerical and cashier, and
5. Blue collar (combination of laborers and service workers).

Each classification has roughly equal numbers of respondents.

Modal-Choice Models

The data given in Table 1 indicate that the work trips in Davis can be assigned to three major modes with little loss of information. These modes are motor vehicle, bicycle, and walking. The first category includes automobiles, car pools, and motorcycles. The last two categories are aggregated to yield a motor or non-motor-vehicle modal-choice situation. Therefore, modal-choice models can be developed that include either two or three alternative modes.

The inclusion of only Davis residents in the sample carries with it the implicit assumption that all employees in Davis have a viable choice among the three modes. This assumption might be unrealistic for those respondents who are captive to one of the work-trip modes; however, no information was available to screen those respondents. Therefore, the results should be interpreted in light of this assumption.

The use of modeling techniques developed in behavioral modal-choice studies is useful in developing the bicycle modal-choice model. Specifically, logit analysis is used. The logit model is used to model either the two or three-alternative situation described above. In the former case, it is assumed that the individual's first decision is to use a motor vehicle or a nonmotor vehicle. Once the decision between the broader classifications is made, a specific mode is selected within the chosen classification. For purposes of this analysis, the choice between walking and bicycling is of interest. Two binary models were developed for the modal choice of motor or non-motor vehicle and the bicycle-walking modal choice. This approach is a variation of McFadden's maximum model (8, 14). The model for three alternatives assumes that the choice among the three modes is made simultaneously rather than in a hierarchical manner. Consequently, the multinomial-logit model is used.

The independent variables used in the models were defined earlier. Not all the variables examined in the descriptive section were considered in the modeling analysis, but the variables that were included correspond with some of the most important variables found in traditional modal-choice studies. Of special interest is the preliminary finding that involves the occupation variable; i.e., only particular categories appeared to be related to bicycle modal choice. This finding suggests that dummy variables be used to represent occupation. Since there are five categories, four dummy variables are necessary. In addition, it is possible to use both the respondent's perceived home-to-work distance and the measured distance. Separate models that use the alternative distance measures are also developed. The independent variables are as follows:

Symbol	Definition
PDIS	Home to work distance that is perceived by respondent
MDIS	Home to work distance that is measured
DOC1	Occupation dummy 1 equals one if the respondent is a manager; other occupation equals zero
DOC2	Occupation dummy 2 equals one if the respondent is a sales worker; other occupation equals zero
DOC3	Occupation dummy 3 equals one if the respondent is a clerical or cashier worker; other occupation equals zero
DOC4	Occupation dummy 4 equals one if the respondent is a blue collar worker; other occupation equals zero
AGE	Respondent's age in years
SEX	Equals one for males and two for females

The models can be represented symbolically, and the hierarchical binary approach is used to estimate the following equations:

$$P(\text{motor vehicle}) = \exp[L_1(x)]/\{1 + \exp[L_1(x)]\} \quad (1)$$

where $L_1(x)$ is a linear function of the independent variables given above. The second model in the set is

$$P(\text{bike}) = \exp[L_2(x)]/\{1 + \exp[L_2(x)]\} \quad (2)$$

where $L_2(x)$ is a second linear function of the independent variables.

The simultaneous three-alternative model can be represented by the following equations:

$$P(\text{motor vehicle}) = \exp[L_3(x)]/\{\exp[L_3(x)] + \exp[L_4(x)] + 1\} \quad (3)$$

$$P(\text{bike}) = \exp[L_4(x)]/\{\exp[L_3(x)] + \exp[L_4(x)] + 1\} \quad (4)$$

$$P(\text{walk}) = 1/\{\exp[L_3(x)] + \exp[L_4(x)] + 1\} \quad (5)$$

where $L_3(x)$ and $L_4(x)$ are two additional linear functions of the independent variables.

The linear functions in all of the alternative models are of the following forms:

$$L_i(x) = a_{0i} + a_{1i}\text{DIS} + a_{2i}\text{DOC1} + a_{3i}\text{DOC2} + a_{4i}\text{DOC3} + a_{5i}\text{DOC4} + a_{6i}\text{AGE} + a_{7i}\text{SEX} \quad (6)$$

where the a_{ji} are coefficients.

The coefficients of the linear functions are interpreted in a manner similar to that of the standard regression coefficient. That is, the magnitude of the coefficient indicates how the linear function changes with a unit change in the corresponding independent variable, and the ratio of the coefficient to its standard error yields a t-statistic that is used to test whether the coefficient is significantly different from zero (the critical values are 1.96 for the 0.05 level and 2.57 for the 0.01 level for two-tailed testing in large samples).

The coefficient values of the dummy variables indicate how much the given linear function for a person from a particular occupational category differs from the linear function of a person in the professional category, if all the independent variables are the same. For example, if the coefficient of DOC1 is negative, then the linear function for a managerial worker is smaller than the linear function of a professional worker with a difference of a_{21}.

The linear functions are inserted into one of the equations (1 through 5) to estimate the probability of a given individual selecting a particular mode or category of modes. These individual probabilities are conceptually similar to the aggregate modal splits for the entire population. As the linear function in the numerator of Equations 1 through 4 increases, the corresponding probability will also increase. Therefore, an increase in a variable in the appropriate linear function that has a positive coefficient will also increase the corresponding probability, and an increase with a negative coefficient will decrease the corresponding probability. For example, if the coefficient for the managerial dummy variable is significantly positive in the first linear function, then managerial workers are more likely to use motor-vehicle modes than professional workers are. Similarly, if the distance variable has a positive coefficient, then individuals with longer work trips are more likely to use a motor-vehicle mode. This will be the case if everything else in the linear function remains equal.

The three-alternative model is different from the usual approach to the multinomial-logit model. In these applications, there are separate characteristics of attributes that correspond to each alternative. In the current model, alternatives are distinguished by separate linear functions. In interpreting the linear functions, the walking mode is treated as the base case. Thus, the generalized price interpretation of distance is informative.

Table 4. Coefficients and standard errors of linear functions for the binary and three-alternative models.

	Binary Model								Three-Alternative Model							
	$L_1(\bar{x})$				$L_2(\bar{x})$				$L_3(\bar{x})$				$L_4(\bar{x})$			
	PDIS		MDIS		PDIS		MDIS		PDIS		MDIS		PDIS		MDIS	
Item	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Variable																
PDIS	1.00[a]	0.060			2.60[a]	0.26			3.60[a]	0.24			2.91[a]	0.24		
MDIS			1.15[a]	0.070			2.44[a]	0.25			3.34[a]	0.22			2.55[a]	0.23
DOC1	0.61[a]	0.18	0.55[a]	0.19	-0.19	0.51	0.18	0.53	0.47	0.44	0.47	0.45	-0.17	0.46	-0.12	0.48
DOC2	-0.16	0.14	-0.34[b]	0.14	-1.83[a]	0.44	-1.73[a]	0.43	-1.20[a]	0.38	-1.53[a]	0.37	-1.25[a]	0.39	-1.44[a]	0.38
DOC3	-0.200	0.14	-0.12	0.14	-1.17[a]	0.44	-1.16[a]	0.43	-0.98[b]	0.39	-1.13[a]	0.38	-1.14[a]	0.40	-1.19[a]	0.39
DOC4	0.079	0.14	0.12	0.14	-0.99[b]	0.43	-0.96[b]	0.42	-0.61	0.38	-0.81[b]	0.37	-0.92[b]	0.39	-1.19[a]	0.38
AGE	0.033[a]	0.0045	0.036[a]	0.0046	-0.075[a]	0.011	-0.063[a]	0.0099	-0.030[a]	0.0077	-0.018[b]	0.0073	-0.086[a]	0.0091	-0.077[a]	0.0088
SEX	-0.013	0.097	0.060	0.10	0.34	0.24	0.38	0.24	-0.21	0.20	0.032	0.20	-0.078	0.21	-0.021	0.21
Constant	-1.29[a]	0.25	-1.68[a]	0.26	1.58[b]	0.62	1.29[b]	0.62	0.66	0.53	0.47	0.52	2.07[a]	0.57	2.25[a]	0.55
Number	691		646		227		221		691		646		691		646	
ρ^2	0.15		0.14		0.32		0.29		0.19		0.18		0.19		0.18	

Note: $\rho^2 = 1 - L^*(\beta)/L^*(c)$, where $L^*(\beta)$ is the logarithm of the likelihood function at convergence and $L^*(c)$ is the logarithm of the likelihood function when all the coefficients of the independent variables, excluding the constant, are zero.

[a]Signifcant at $p < 0.01$. [b]Significant at $p < 0.05$.

Table 5. Prior modal split for linear functions.

Linear Function	Mode	Trips With PDIS Number	Trips With PDIS Percent	Trips With MDIS Number	Trips With MDIS Percent
$L_1(\bar{x})$	Motor vehicle	2615	77	2418	76
	Nonmotor vehicle	800	23	774	24
$L_2(\bar{x})$	Bicycle	628	79	605	78
	Walking	172	21	169	22
$L_3(\bar{x})$ and $L_4(\bar{x})$	Motor vehicle	2615	77	2418	76
	Bicycle	628	18	605	19
	Walking	172	5	169	5

The distance coefficient of the linear function corresponding to the motor-vehicle mode can be thought of as the scaling factor that converts distance to the generalized price difference between the motor vehicle and walking modes. A similar interpretation can be placed on the distance coefficient of the other linear function with respect to the generalized price difference between the bicycle and walking modes. In this way, the particular attributes of the modes such as generalized prices are approximated by distance and its coefficients. This interpretation makes the present approach similar to previous applications.

Although the sequential binary model and the simultaneous three-alternative model both generate two separate linear functions, it is likely that the functions will be different for the two approaches. These functions are different because the approaches assume different choice mechanisms and are calibrated differently: The sequential binary model involves the estimation of two separate models while the three-alternative model estimates the two linear functions simultaneously.

Data were collected on the number of weekly work trips by various modes; therefore, repeated observations were made for each respondent. As given in Table 1, there are a substantial number of people who use a combination of modes. Thus, for the logit models, sample size is increased by treating each trip as a separate observation. For example, a respondent who made three automobile trips, one bicycle trip, and one walking trip would contribute five observations.

RESULTS

Table 4 gives the coefficients and standard errors of linear functions for the binary and three-alternative models. The two equations considered are the perceived distance variable and the measured distance variable. Table 5 gives the prior modal split for the linear functions. Fewer than 802 cases were used to estimate these models. This reduction in sample size is due to data missing on the key variables and the inclusion of only the motor-vehicle, bicycle, and walking modes.

Several general conclusions emerge from the estimation of the models. First, although the perceived distance variable yields slightly stronger models than does the measured distance variable, the overall similarity of the corresponding models is striking. This similarity is not surprising since there is a strong correlation between measured and perceived distance in the sample.

Second, the importance of distance and age hypothesized in earlier studies and suggested by the tabular description of these data is confirmed by the multivariate analysis. These two variables are strongly significant in all models. On the other hand, the sex variable is statistically insignificant in all cases.

The remaining conclusions deal with some specific features of the alternative models. In the sequential binary models, motor-vehicle users tend to have longer trips, be in the managerial occupation category, and be older. Within the non-motor-vehicle category, bicycle users tend to have longer trips, are less likely to be sales workers, clerks and cashiers, or blue collar workers, and are more likely to be younger than the walkers.

It is apparent that the independent variables have different effects in determining the sequential choice processes. The role of age is reversed in the two cases. Also, the managerial category is the major distinction in the motor or non-motor-vehicle modal choice. However, in the bicycle-walking choice, three other categories generate different trip patterns and the managerial category is not statistically significantly different from the professional category.

The simultaneous three-alternative models given in Table 4 can be interpreted by regarding the linear functions as distinguishing motor-vehicle users from walkers and bicycle users from walkers respectively. The results here are qualitatively similar to the bicycle-walking model also given in Table 4. That is, both motor-vehicle users and bicycle users are distinguished from walkers in that they tend to have longer trips, are less likely to be sales workers, clerks and cashiers, or blue collar workers, and tend to be younger. For this model, the difference between motor-vehicle drivers and bicyclists can be determined by comparing the respective linear functions given in Table 4.

The most interesting difference between the linear functions in Table 4 is the larger coefficient for distance in the function corresponding to motor-vehicle users. This difference is consistent with the generalized price interpretation, since it appears reasonable that the generalized price difference between automobile use and walking would be larger for a given distance than the difference between bicycling and walking.

In assessing the relative merits of the sequential binary models versus the simultaneous three-alternative models, it is possible to use the fact that overall the likelihood functions for the sequential models are equal to the sum of the likelihood functions for the two binary models constituting the sequence (1). By using this criterion, we found that the simultaneous models have a slightly better overall statistical fit than do the sequential models. The slight statistical difference, together with the qualitative similarity of the alternative-choice structures, leads to the conclusion that the data do not indicate a clear-cut preference for either approach. This fact and the additional observation that the simultaneous approach was much more expensive computationally might indicate a practical advantage for the sequential binary approach.

In theoretical terms, the determination of whether the sequential binary or simultaneous three-alternative approach is superior depends on how validly each approach models the actual decision processes. The former model assumes a hierarchical process and that alternatives within broad categories are more similar than alternatives in different categories. In this case, people are assumed to make a choice between motor and non-motor-vehicle modes; therefore, the bicycle and walking modes are more similar to each other than either is to the motor-vehicle modes. The simultaneous three-alternative model assumes a single decision among alternatives that are equally similar (or different).

Since the empirical results indicate a qualitative similarity among the alternative approaches and the results are similar in statistical strength, the current results do not indicate a clear-cut preference for either hypothesis. However, both are based on particular decision rules and the results should be interpreted in this light.

SUMMARY AND CONCLUSIONS

This paper described the role of the bicycle as a transportation mode to work in Davis, California, and discussed the development of alternative, logit-choice models for determining bicycle use. The description of the role of the bicycle revealed that a substantial percentage of the trips were made by bicycle and that for trips up to 3.2 km (1.5 miles) the bicycle was readily accepted as a transportation mode by this segment of the general travel population under these conditions. There are a number of reasons for being cautious in using these results to forecast rates of bicycle usage in other areas or among other groups. First, the sample is probably not representative of the general travel population; Davis has several unusual attributes. Even here, the sample did not include workers at the university, which is a larger employment center than the downtown area is and has a heavier rate of bicycle users for work trips. Further, Davis has well-established bicycle facilities. Quantitative projections of riding rates among downtown workers made on the basis of the data reported here will be accurate in places that are similar to Davis. For such towns without well-established bicycle facilities, the model might estimate the ultimate potential for bicycle use as a transportation modal choice by downtown workers rather than the immediately obtainable results. The extension of the model, in quantitative terms, to areas not similar to Davis should await some data on usage under different circumstances. In the meantime, the identification of variables that are related to and not related to the use of bicycles for work trips may prove helpful in making decisions about relative rates of usage by subpopulations in other areas.

The major contribution of the development of the alternative, logit-choice models for bicycle use as a transportation mode appears to be in two cases. First, some of the variables that were assumed to be important in bicycle modal choice by other researchers were tested and found to be generally useful. Second, this study is one of the first attempts to model bicycle use from data taken from an American city. The results seem to indicate that behavioral-demand modeling was extended successfully in this case.

A feature of the model that limits its practical usefulness is the fact that none of the independent variables are easily controlled by transportation decision makers. For this reason, an improved model might include variables such as modal travel times and costs and route quality, which can be changed through transportation policies. The effect of the quality of available bicycle routes on overall modal choice would be especially useful here. As mentioned earlier, this variable was not available in this study because of the uniform quality of Davis bikeway facilities. However, such a variable might be important for improving models on bicycle policy analysis. Finally, bicycle modal choice is influenced by certain sociological variables (7). Inclusion of more variables of this type would also strengthen the models. All of these influences on modal choices might also bear on modal choice at the level of purchase. The unusually low number of two-car families in Davis may be a reflection of the operation of these influences. Unfortunately, our data do not illuminate this issue.

Therefore, the results indicate that there is potential for incorporating information on bicycle use in transportation planning models. Further work to develop models in other areas and to make such models more policy-sensitive could generate valuable planning tools that could be used for effectively allocating resources for bicycle transportation.

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Citizen Participation in Planning and Designing Bikeways

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The United States has recently experienced a sharp resurgence in bicycling activities. Public agencies are actively planning and constructing bicycle facilities. However, these facilities may have some adverse as well as beneficial community impacts. More citizen participation in the planning of bikeways can help provide better facilities. Several citizen participation techniques are discussed, and an example of a bikeway planning program that incorporates citizen participation is also presented. The use of these techniques can help provide safer, more efficient, effective, and compatible bikeway systems.

The United States has experienced a sharp resurgence in bicycling activities that has brought into view the potential usefulness of bicycling for transportation—a usefulness that bicycling has known in many foreign countries. In response to the increase in bicycling, many bicycle facilities are being planned and constructed. Unfortunately, environmental impact analysis and citizen participation have not been adequately considered in the planning of many bicycle facilities.

From the experience of highway planners in 1950 through 1960, the importance of adequately incorporating environmental impacts into the planning of major transportation projects, especially in urban areas, was revealed. Moreover, planners found that it was difficult to adequately incorporate qualitative impacts and information into the analysis and decision-making process. Consequently, methods of citizen participation were implemented to acquire better planning information and produce more compatible, effective, and desirable transportation facilities.

The impacts of bicycle facilities are not as great as the impacts of highways. However, if bicycling is to be a safe and effective means of transportation that is compatible with the nature and goals of the community, the environmental impacts of bicycle facilities should be analyzed, and the citizens affected should participate in the bikeway planning process. Bikeways have both potentially adverse and potentially beneficial impacts. Some of the adverse impacts are bicycle and motor-vehicle conflicts in traffic, loss of privacy to residents along the bikeway, decrease in business activity caused by bikeways eliminating street parking, replacement expenses for storm-sewer inlet grates, and expenses for major construction and maintenance. The beneficial impacts from bicycle use are providing an inexpensive short-range mode of transportation that is practical in good weather, reducing traffic congestion and air pollution, promoting a healthy activity, and creating a friendly, prosperous community atmosphere. Environmental analysis has shown that there is a potential for both adverse and beneficial impacts associated with bikeways. However, the degree of significance of these impacts cannot be completely determined. Bicycling is in its infancy in the United States, and this prohibits or hinders the gathering of significant data for determining demand, potential conflict, noise pollution, and other factors relevant to bikeway impacts. Although some impacts could be quantified by experimentation (e.g., delay to motorists caused by bicyclists in the roadway), most other impacts are not quantifiable because of the relative lack of experience with bikeways and the uncertainty of the popularity of bicycling, the values of the community, and the interaction of bikeways in communities.

COSTS AND BENEFITS OF CITIZEN PARTICIPATION

The agencies responsible for bikeway planning and implementation (including construction and maintenance) are typically traffic, public works, and planning departments. These agencies should be aware of the potential impacts that bikeways could have on communities and may be able to minimize certain impacts by design and route considerations. However, many of these impacts cannot be quantitatively measured but are still critical to an effective, environmentally compatible bikeway