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Evaluating the Impact of Weather on Bicycle Use

Susan Hanson, Department of Geography and Department of Sociology, State University of New York, Buffalo
Perry Hanson, Department of Geography, State University of New York, Buffalo

Weather is one factor that is believed to have a significant impact on bicycle use as a transportation mode. This paper presents a method for exploring the sensitivity of two types of bicycle use to variable weather conditions. The results of studies such as this one can be used in conjunction with previous findings to estimate the proportion of present-day automobile travel that could be transferred to bicycle travel, if appropriate bicycle facilities are provided. The study uses travel data collected in Uppsala, Sweden, over a 39-day period in the spring of 1971. The daily proportion of bicycle travel for discretionary purposes and journey to work is compared to daily weather data. Correlation and regression analyses were used to assess the impact of weather on bicycle use. The study indicates that temperature and cloud coverage do affect the proportion of daily travel made by bicycle and that the weather variables have a different impact on each of the two types of bicycle travel. The study also examines the alternative modes used on the days when little travel is done by bicycle. The study reveals that a larger proportion of travel to work is done by bicycle than of travel for discretionary purposes regardless of weather conditions. When the temperature is below freezing, between 20 and 25 percent of all trips to work are made by bicycle.

During the past few years there has been a growing realization among transportation planners that the bicycle has a great deal of promise as a viable mode for urban transportation (1). As an inexpensive, energy-efficient, nonpolluting, quiet, healthful means of transportation, the bicycle is becoming an increasingly attractive alternative, or at least a supplement, to the automobile for substantial portions of intraurban travel. However, when the potential of the bicycle is discussed as a transportation mode, the issue of the weather is inevitably advanced as a major deterrent to using bicycles as a serious transportation alternative. The usual argument, which has been unexamined, is that people cannot or will not ride bicycles when weather conditions are too cold, too hot, too wet, or too icy, and, therefore, investments in bicycle facilities in areas where there is a susceptibility to any of these conditions are unwise, since the facilities will essentially be unused when the weather is unsuitable.

The purpose of this paper is to present a method for empirically examining the impact of daily weather con-

ditions on the use of the bicycle as an urban transportation mode. For such an endeavor, three questions in particular need to be addressed.

1. How does the weather affect the volume of discretionary travel done by bicycles in comparison to other modes?
2. How does the weather affect modal choice on the principal form of nondiscretionary travel, the work trip?
3. What modes do bicyclists use when they do not use their bicycles?

Considerable work is required on the relation between weather conditions and bicycle use before the demand for intraurban bicycle travel can be predicted.

PREDICTING DEMAND FOR BICYCLE FACILITIES

In an earlier paper, we pointed out the need for safe bicycle facilities in urban areas, the desirability of being able to measure the latent demand for such facilities, and the difficulty in measuring the demand given the current lack of information on bicycle use in comparison to other urban transportation modes (2). Others have also noted the problems associated with predicting future levels of bicycle travel and have undertaken studies to estimate current and future levels of bicycle use (3, 4). For example, Ohrn used origin-destination data from Minneapolis-St. Paul to estimate the number of trips that could be made by bicycle. His assumption was that a certain proportion of trips under 3.2 km (2 miles), currently made by other modes, would be transferred to bicycle trips, if safe bicycle facilities were installed (3).

In a similar vein, we have attempted to investigate the potential demand for bicycle travel by first examining the existing level of bicycle use in a city without any special provisions for bicycle travel. Then, by using the empirically established parameters of bicycle use, we found the proportion of travel currently done by automobile or bus that could be transferred to bicycles, if bicycling was made safer and more convenient by a system of bikeways and safe parking places (5). To calculate the volume of bicycle travel that could result from modal switching, we assumed that no trip will be transferred from automobile or bus to bicycle, if (a) the distance to be covered is too great, (b) the traveler has to transport other people or bulky packages, or (c) the weather is too unpleasant. By using the disaggregate data set described below, we found that 96 percent of all bicycle movements were under 3 km (1.86 miles) in length and that 96 percent of all bicycle movements were made by unaccompanied persons (5). We then found the proportion of automobile and bus movements that were both under 3 km (1.86 miles) and unaccompanied, and proposed that on the basis solely of distance and accompaniment, these movements could be transferred to bicycles.

This paper represents an effort to extend our previous work by investigating the impact of weather conditions on the demand for bicycle travel in our study area. When combined with our earlier findings, the results should help to provide a fuller picture of the extent to which the bicycle could be used for travel that is currently done by other modes. However, the intent here is not to provide results that are universally applicable, but rather to illustrate a method for assessing the impact of weather conditions on the demand for bicycle travel.

WEATHER AND BICYCLE USE

Although poor weather conditions are often cited as evidence against the viability of the bicycle as a real transportation mode, there has been, to our knowledge, no empirical investigation of modal use as a function of weather conditions. Only one study (6) has explicitly considered, from a normative viewpoint, the impact of weather on bicycle ridership. Based on the assumptions that a bicycle could be ridden on any day when (a) there was no snow or ice on the roads and (b) there was not more than 12.7 mm (0.5 in) of precipitation, Hirsch (6) concluded that bicycles could be used in Philadelphia for 310 days during a year (or 85 percent of the year). The Philadelphia study represents a start towards assessing the impact of weather on the demand for bicycle travel, and similar studies could easily be carried out for other cities that have different climates and weather conditions.

But before a rash of such studies is undertaken, it would seem useful to weigh the validity of the assumptions underlying the Philadelphia study and to establish empirically the weather conditions that a majority of bicyclists find intolerable. We need to know how sensitive bicycle use is to varying weather conditions and whether there are thresholds of temperature and precipitation that dramatically affect levels of bicycle ridership. Moreover, if unsuitable weather conditions are found to reduce bicycle use, then we need to know how the other components of the transportation system are affected; that is, we need to know what modes absorb the bicyclists who abandon use of their bicycles in bad weather. An additional consideration that should be explicitly recognized by any empirical investigation is the fact that weather conditions may well affect different types of bicycle use differentially.

There are at least two kinds of bicycle travel that could be expected to be affected by day to day seasonal fluctuations in the weather. One of these concerns discretionary travel. Discretionary travel is travel undertaken at the option of the individual and is inherently flexible in terms of the timing of trips as well as the choice of destination. In general, social, shopping, recreational, and personal business trips are all forms of discretionary travel. We could anticipate that the volume of discretionary travel might be responsive to weather conditions in that bad weather might reduce the number of discretionary trips made by all modes. We might also expect the proportion of discretionary travel made by bicycle to be particularly sensitive to weather conditions; if this is the case, bad weather would bring a reduction in discretionary bicycle trips and would mean that such trips would be either not made at all, postponed, or made by other modes.

The other aspect of bicycle use that is likely to be affected by weather conditions concerns nondiscretionary travel. Nondiscretionary travel is essentially travel that lacks flexibility in timing and choice of destination; trips to work and school are the principal forms of this type of movement. Since the work trip must be made at about the same time every weekday, the volume of nondiscretionary travel should remain invariant under different weather conditions. However, we could expect modal choice on the journey to work to be related to prevailing weather conditions. Since we have documented elsewhere the importance of the bicycle for the work trip (2, 5), it would seem particularly relevant to investigate how sensitive commuter bicycle use is to varying weather conditions and what alternative modes, if any, are used when the weather is poor.

The method that is proposed here for examining the impact of weather on levels of bicycle use involves the use of a travel diary. A travel diary is used by respondents to record, for some extended period of time, the details of all out-of-home travel. This method enables the researchers to distinguish between discretionary and nondiscretionary travel and also permits a comparison

of bicycle use with the use of other modes. If the travel data are to be compared, then daily weather records are also required that include information on temperature, precipitation, cloud coverage, and snow and ice accumulations. Ideally, these travel and weather data should be collected for 1-week periods at monthly intervals throughout the year. Unfortunately, no such ideal data set exists; therefore, the data that come closest to meeting the requirements set forth were gathered from the Uppsala survey in Sweden.

UPPSALA SURVEY

Carried out in the spring of 1971, the Uppsala household travel survey collected longitudinal, disaggregate travel data on the daily intraurban movements of some 300 households. Uppsala is a medium-sized city with a population of about 120 000 and is located 80 km (50 miles) northwest of Stockholm. At the time of the study, the city had no special facilities for bicycles, although about 75 percent of the households owned at least one adult bicycle and over 11 percent of all the person movements made within the city were made by bicycle (2). When only vehicular travel is considered, the bicycle accounts for 18 percent of all movements within the urbanized area.

The Uppsala study provides the best existing data source for evaluating intraurban bicycle use and comparing it to other modes. For a period of 35 consecutive days, the adult members (defined as those over 16 years of age) of the sample households recorded all movements made outside the residence. In this study, a trip was a series of movements that began and terminated at the residence; one or more locations could be visited in the course of a trip, and each interruption on the journey is referred to as a stop. For each stop on each trip, the panel members recorded the time of arrival and departure, the location of the destination, the purpose of the stop, and the mode of travel used for the trip. A detailed description of the design and methodology of the study can be found in Marble, Hanson, and Hanson (7).

In addition to the travel data, detailed weather records were kept during the study period. Readings on a number of variables that included temperature, precipitation, cloud coverage, pressure, and wind force were made daily at 7 a.m., 1 p.m., and 7 p.m. The amount of snow on the ground was recorded once a day; snow was present for only the first 6 days of the study. To ease the logistics of monitoring the 300 households in which travel diaries were being kept, the researchers divided the sample into 5 streams, each of which started keeping travel records on 5 different consecutive days. With this staggered start and staggered finish, the study extended over a 39-d period from March 29 to May 3. Since the study was conducted during this portion of the early spring, weather conditions varied considerably over the 39 days of observation. The temperatures ranged from -4°C to 18°C (25°F to 65°F). The precipitation recorded for a single day was up to 84 mm (3.2 in), and the snow coverage recorded for a given day was a maximum of 8.0 cm (3.2 in). In the following analysis, the travel data are compared to only the temperature, precipitation, and snow and cloud coverage weather variables.

IMPACT OF WEATHER ON VOLUME OF DISCRETIONARY TRAVEL

The 300 households included in the Uppsala sample represent a disproportionately stratified random sample, stratified on the basis of stage in the life cycle. The effects of weather on the volume of discretionary travel were examined by using a subset of 92 households that was representative of the population in Uppsala. Although a considerable amount of discretionary travel is undertaken in conjunction with the journey to work (8), the analysis in this section focuses on only the discretionary travel that is not associated with the work trip; in other words, discretionary stops that occur on trips in which there is a stop at the workplace are excluded. The volume of travel is measured by the number of stops per day (days 1 through 4 and 36 through 39 are appropriately weighted to correct for the fact that all sample households were not reporting on those days), and these travel data are compared to the temperature and cloud coverage data at 1 p.m. The weather conditions were noted and taken at that time because it represents the daily weather conditions. The precipitation data used throughout the analysis are the total daily precipitation.

The relations among the number of stops per day and the temperature, daily precipitation, and cloud coverage at 1 p.m. were examined to see if weather conditions had any effect on the volume of discretionary travel. The results clearly indicate that the number of discretionary stops made by all modes is insensitive to weather conditions; that is, the daily volume of discretionary travel is not related to temperature, precipitation, or cloud coverage. The correlation coefficients (r) show the lack of any significant relations among the number of discretionary stops per day and the temperature at 1 p.m. (-0.24), the daily precipitation (0.09), and the cloud coverage at 1 p.m. (0.01).

However, when the percentage of daily discretionary stops made by bicycle is examined, a significant relation (0.62) between bicycle use and temperature at 1 p.m. is evident (Figure 1). When the midday temperature rises, a larger proportion of daily discretionary travel is done by bicycle. The relation appears to be linear, and there are no threshold temperatures evident for bicycle use within the range of temperatures that prevailed during the study period. As shown in Figure 1, there is very little discretionary travel done by bicycle when the temperature is below 1° C (34° F).

In contrast to the relatively strong impact of temperature on bicycle ridership for nonwork travel, cloud coverage and precipitation were found to have no significant effect on the proportion of discretionary stops made by bicycle. A weak relation was found between the percentage of discretionary stops by bicycle and cloud coverage (-0.14). Unfortunately, there were only 7 days during the study when more than a trace of precipitation was recorded. Therefore, these results must be taken as entirely preliminary, but the correlation analysis shows only a weak relation between the percentage of discretionary stops made by bicycle and precipitation (-0.11). Since there were only 6 days with snow coverage, the effect of snow on the ground was also difficult to assess. However, on the days when there was snow on the ground, less than 5 percent of discretionary travel was done by bicycle. The conclusion must be that, within the range of early spring weather conditions observed, only temperature has a visible impact on the use of the bicycle for discretionary travel. Firmer conclusions must rest on data gathered at appropriate intervals throughout the year rather than on only one season.

Since we know that discretionary trip making as a whole is not affected by temperature, we must next ask what alternative means of travel are used when low temperatures bring reduced levels of bicycle use. This question is addressed by examining the relation between the daily proportion of bicycle travel and the daily proportion of travel by other modes. The results indicate that no single mode is exclusively used by bicyclists when bad weather prevails. As the daily proportion of

discretionary travel by bicycle riders decreases, the daily proportions of discretionary travel by bus rider, automobile driver, and automobile passenger all increase, as one would expect. The relations, although they are all significant, are not extraordinarily strong but are of approximately the same magnitude. The correlation coefficients are -0.27 for the relation between the percentage of discretionary stops for bicycle rider and bus rider, -0.23 for bicycle rider and automobile driver, and -0.33 for rider and automobile passenger. Evidently, in the city under study, the bicyclists use all three modes as a substitute for the bicycle.

IMPACT OF WEATHER ON MODAL CHOICE FOR JOURNEY TO WORK

Unlike discretionary travel that can be postponed or simply not undertaken, the journey to work must be made daily by those who work on a regular basis. Furthermore, there is generally little flexibility in the timing of the journey to and from work. As a result, if inclement weather greets the prospective morning commuter, the only travel decision he or she is really free to make (aside from the route to be taken) is the mode of travel to be used. We have established elsewhere (5) the importance of the bicycle in Uppsala as a transportation mode to work; over half (53.2 percent) of all bicycle stops were made at the workplace, and 20 percent of all stops at the workplace were made by bicycle. But how sensitive to weather conditions is the use of the bicycle for this purpose?

This question was answered by examining the travel records of all full-time employed persons in the original sample and by examining their modal choice for journey to work in light of the weather data. Only work trips made on regular weekdays were included (weekends and holidays were excluded), and only the first daily arrival at the workplace was considered. This data base was used to compute the percentage of stops made by each mode for each of 27 d and to compare the weather data taken at 7 a.m. and 7 p.m. Generally speaking, if a person is going to decide to ride a bicycle to work, the decision will be made in the early morning and will be based on the observable morning weather conditions as well as the reported weather prognosis for the rest of the day. Since we did not have the daily morning weather forecasts, we used the actual weather data taken at 7 p.m. as the best available surrogate for the expected early evening weather conditions.

As expected, the correlation coefficient for the number of stops at the workplace is totally unrelated to either the temperature at 7 a.m. (-0.001) or the cloud coverage at 7 a.m. (-0.06). The use of the bicycle for the work trip, however, is sensitive to both of these weather variables. The percentage of daily journeys to work by bicycle increases as a function of increasing temperature at 7 a.m. (0.45) and decreases as a function of greater morning cloud coverage (-0.42). The relation, shown in Figure 2, between commuter bicycle use and early morning temperature is interesting to compare with the relation portrayed in Figure 1 between discretionary bicycle use and midday temperature. The most striking difference is that there is a markedly higher average daily proportion of bicycle travel for the journey to work than for discretionary travel. On the average, only 4.3 percent of daily discretionary travel is done by bicycle, while the average daily percentage of work journeys made by bicycle is 26.7! Also, a visual comparison of the regression lines in Figures 1 and 2 shows a steeper slope in Figure 1, which indicates that the percentage of discretionary travel made by bicycle increases more rapidly as a function of rising temperatures than that of travel to work. Thus, bicycle use for the journey to work is less sensitive to temperature than bicycle use for nonwork purposes is. It is also evident from Figure 2 that even when the temperature hovers around the freezing point, a substantial portion (between 20 and 25 percent) of all travel to work is made by bicycle. Furthermore, commuter bicycle use is affected little by snow on the ground; on those 5 workdays when there was snow, the bicycle accounted for between 16 and 29 percent of the daily work trips.

The fact that the proportion of daily commuter travel by bicycle is related to cloud coverage at 7 a.m. is another departure from the findings described earlier that concern the impact of weather on discretionary travel by bicycle. Although bicycle use for nonwork travel was found to be unrelated to cloud coverage, a moderately strong inverse relation exists between bicycle use for journey to work and early morning cloud coverage. A possible explanation lies in the fact, previously mentioned, that, although the work-trip modal-choice decision is made in the early morning, estimates of early evening weather conditions are also taken into consideration, and the heavier the morning clouds, the greater the estimated probability of poor weather later in the day. Since discretionary trips are usually of a much shorter duration than work trips, the prospective traveler has only to make relatively short-term weather predictions. Thus, people are willing to embark on a discretionary bicycle trip in cloudy weather when it seems apparent that no marked weather change will occur within the estimated time span of the trip. But selecting a mode for the work trip involves longer range amateur weather forecasting, and therefore people are reluctant to ride a bicycle to work when morning clouds seem to portend afternoon or evening rain. In fact, the appearance of clouds seldom actually produced precipitation.

Since rain was recorded for only a few nonholiday weekdays (only three) during the study period, the impact of precipitation on commuter bicycle use unfortunately cannot be evaluated. However, the argument that estimated evening weather conditions play a role in the morning modal-choice process is supported by the correlations found between the percentage of daily work trips by bicycle and the temperature at 7 p.m. (0.48) and the cloud coverage at 7 p.m. (-0.32). These relations could be expected, at least in part, on the basis of the positive correlations between morning and evening temperature and morning and evening cloud coverage. Table 1 gives a summary of these relations. But, the fact that commuter bicycle use is more strongly related to morning cloud coverage than to evening cloud coverage seems to indicate that the decision to ride a bicycle to work is dependent on the individual's (often erroneous) appraisal of daily weather and its development.

Since bicycle use for the journey to work does vary considerably from day to day (Figure 2), even though the number of work trips remains relatively stable over time, the question arises concerning what other modes are used on the days when the proportion of commuter trips made by bicycle is low. As was done for discretionary travel, the daily proportion of work trips made by each mode was calculated and compared to the percentage of daily work trips made by bicycle. The results indicate that the strongest inverse relation exists between the percentage of daily commuter travel by bicycle and the percentage of commuter travel by bus (-0.52). However, significant correlations were also found between bicycle use and the other modes: automobile passenger (-0.36), walking (-0.36), and automobile driver (-0.25). Thus, again, a variety of alternatives is used by bicyclists when bicycles are not used, but the results indicate that a reduction in bicycle use is more strongly re-

Figure 1. Bicycle use for discretionary travel as a function of midday temperature.

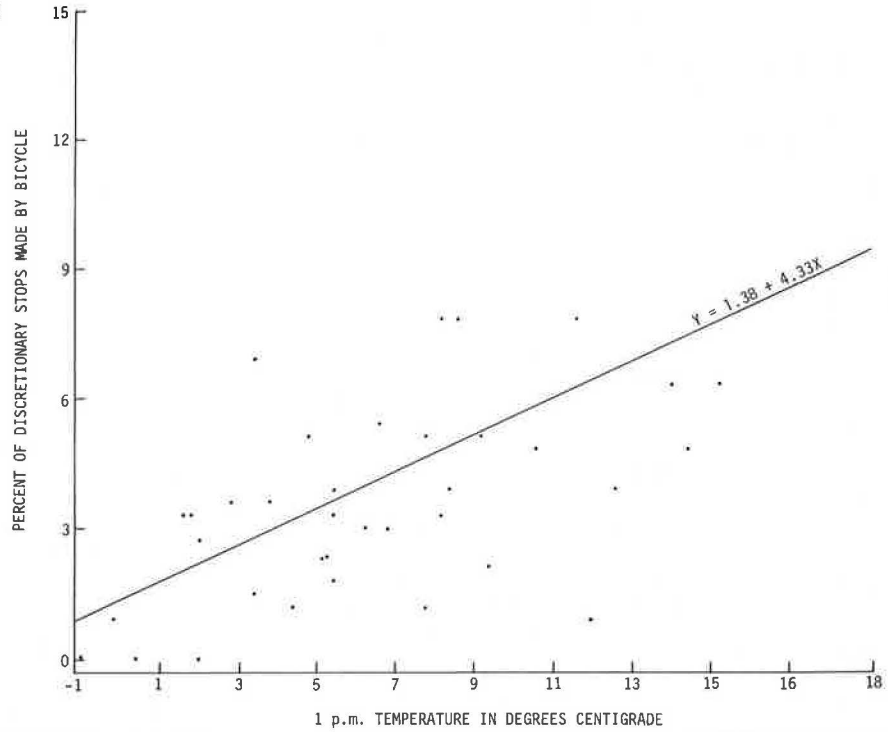

Figure 2. Bicycle use for journey to work as a function of early morning temperature.

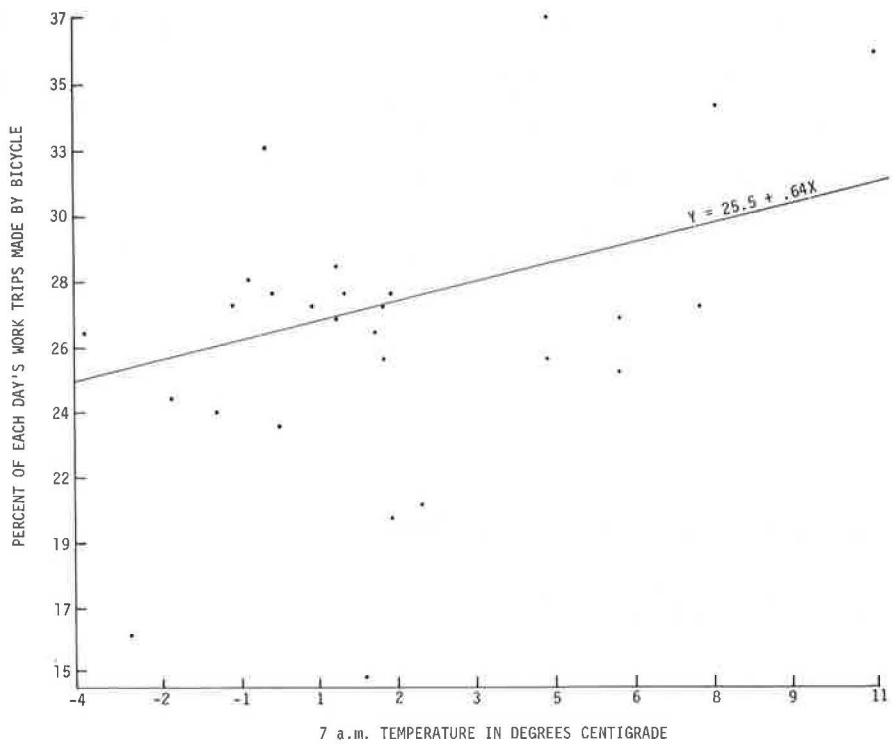

Table 1. Correlation coefficients for selected weather variables and bicycle use on the journey to work, March 29 to May 3, 1971.

Item	Temperature		Cloud Coverage		Percentage of Daily Work Trips by Bicycle
	7 a.m.	7 p.m.	7 a.m.	7 p.m.	
Temperature					
7 a.m.	1.00	–	–	–	–
7 p.m.	0.78	1.00	–	–	–
Cloud coverage					
7.a.m.	0.01	-0.12	1.00	–	–
7 p.m.	0.06	0.13	0.45	1.00	–
Percentage of daily work trips by bicycle	0.45	0.48	-0.42	-0.32	1.00

lated to an increase in the bus, walking, and automobile passenger modes than to an increase in the automobile driver mode. While it is unlikely that this is due to the individual's lack of access to an automobile (5), it may reflect the person's desire or need to leave the automobile at home for use by another household member.

CONCLUSIONS

The results of this study indicate that further empirical investigations of this nature should prove fruitful. If appropriate data were available for time periods throughout the year, we could gain considerable insight into the way in which daily weather conditions impact the demand for bicycle travel. Although the data on which this exploratory study was based were limited, they did afford a glimpse of the kinds of processes that can and should be uncovered, if we are to understand the relation between weather and bicycle use.

The expectation at the outset was that weather conditions would have some impact on the use of the bicycle as an urban transportation mode. Although the dearth of rainy days during the study period precluded any meaningful insight into the impact of precipitation on bicycle use, this paper has shown that both temperature and cloud coverage are related to the proportion of daily travel done by bicycle in the study area. Perhaps more important is the finding that weather affects bicycle ridership differentially in accordance with the type of travel in question; discretionary travel by bicycle is more sensitive to temperature changes and less sensitive to cloud coverage than bicycle use for the journey to work is. This paper has also shown that several different modes of transportation are used as alternatives to the bicycle on days when bicycle ridership is low. Finally, although bicycle use does decline with falling temperatures, a substantial portion of travel to work is done by bicycle even when temperatures are below freezing. It is apparent that for the work trip, in particular, people can and will use bicycle facilities (if they are provided) under variable weather conditions. It appears that attitudes constitute a more formidable deterrent to bicycle use than the weather does.

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Abridgment

Development of a Bicycle Accident Rate in Arizona

Richard G. Perreault, Judson S. Matthias, and Mary R. Anderson, Arizona State University

The climate in Arizona allows bicycling to be a year-round activity in the most populous areas of the state. The number of accidents in the state has increased from 383 in 1967 to 1124 in 1975. More than 90 percent of these accidents occurred in urban areas. In the last few years, the growing concern and previous lack of planning have motivated state and local authorities to conduct extensive surveys and to finance research for recommendations and solutions to this problem. Data are now categorically collected and stored at state and local levels for analyzing the location, probable cause, time of day, and conditions at the time of the accident. Extensive surveys have yielded data such as predicted ownership, location, and usage of bicycles. Projected bicycle usage and projected accidents indicate that solutions to the growing accident problem must be found.

STATEMENT OF PROBLEM

Statistics frequently used to measure effectiveness are the number of accidents or injuries occurring in a defined area during a specified time. These statistics are compared with previous results or with results from other areas. This method does not account for changes in