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Subject Areas

51 Highway Safety
52 Road User Characteristics

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FOREWORD

The papers in this RECORD cover a number of subject areas, ranging from pedestrian accident characteristics and bicycle transportation needs to a methodology for evaluating highway safety program countermeasures.

The first paper by Fruin discusses pedestrian accident characteristics in a one-way grid system. The paper reviews a limited investigation of 5 years of accident reports for 32 one-way intersections in New York City. Left-turn accidents were found to be more than two times as frequent as right-turn accidents. Visual obstruction by the vehicle's front roof support is suspected as the significant factor causing this difference. The results of the study suggest that backing into crosswalks should be discouraged by traffic design and law enforcement and that turning restrictions and exclusive pedestrian crossings are justifiable from a safety viewpoint.

Germano, Wright, Hicks, and Sanders present a review of bicycle transportation in the United States and an approach to planning bikeways. The review found that very little has been done at a comprehensive level in bikeway planning. Recommendations for a planning approach are made and supplemented by listings of data and information important to the planning process.

The paper by Salvatore examines the ability of elementary and secondary school children to sense oncoming car velocity. The study revealed that an older child is more likely to make correct slow and medium judgments of vehicle velocity. Results indicate considerable differences associated with age and sex. Vehicle-associated characteristics, such as size and noise, are also shown to influence velocity judgment.

CONTENTS

PEDESTRIAN ACCIDENT CHARACTERISTICS IN A ONE-WAY GRID

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The unique traffic configurations of one-way grid systems provide opportunities to statistically isolate and evaluate several aspects of pedestrian accident experience. One-way intersections have two conflict sides where the pedestrian must share the green with turning vehicles and two nonconflict sides where the pedestrian has an exclusive green crossing phase. Also, left- and right-turn movements represent a direct vehicle-to-pedestrian confrontation, independent of other vehicular distractions. A limited investigation of 5 years of pedestrian accident reports for 32 contiguous one-way intersections in New York City shows that, of 172 reported intersection accidents, 69.7 percent occurred on the conflict side, where pedestrians and vehicles compete for traffic priority. Results of the study show that exclusive pedestrian crosswalks independent of conflicts from turning vehicles have a lower pedestrian accident experience, justifying increased institution of turning restrictions for pedestrian safety; that backing into crosswalks should be discouraged through geometric design and stricter law enforcement; and that more detailed research is required to determine the human dynamics involved in turning a vehicle, particularly the effects that the visual impairment by the left front roof support has on the driver's judgment of pedestrian movement and position.

•EACH YEAR an estimated 350,000 pedestrians are struck by vehicles, resulting in about 10,000 deaths and many serious injuries. Not enough is being done to reduce this intolerable toll. This may be partially attributed to the complexities and limited understanding of the nature of the man-vehicle conflicts that cause these accidents, but it also is the result of the absence of a definitive national program of pedestrian accident prevention. The programs that do exist are almost universally directed at pedestrian responsibilities with limited emphasis on concomitant driver responsibilities. Because the driver wields the instrument of death and injury, he has the overriding obligation to use it safely with forbearance and deference to the pedestrian.

This study and some other recent research suggest that there is a need to promote more "pedestrian conscious" driving and to make the driver more aware of the human perceptual and judgmental limitations that exist within his vehicle and their potentially lethal implications. In addition, increased attention must be give to the pedestrian's right to safe and convenient use of the urban street rather than conceding complete preemptive traffic priority to the vehicle.

RATIONALE OF ONE-WAY GRID STUDY

Statistical investigations of pedestrian accident experience represent a troublesome area of research because the relatively low frequency of occurrence, combined with the wide range of potential contributory variables, tends to obscure meaningful analysis. Added to this are deficiencies in pedestrian accident reporting procedures that are typically designed for the more common vehicle-to-vehicle accident. Statistical research of pedestrian accidents therefore tends to concentrate on gross comparison

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techniques, which examine a broad base of accident statistics either in large systems or in numbers of comparable cities over long periods of time. For example, Snyder and Knoblauch (1) collected data on 2,157 pedestrian accidents in 13 major cities for the purpose of identifying causal factors. Hermes (2) investigated pedestrian accident experience at 400 unsignalized intersections in San Diego over a 5-year period for the purpose of evaluating the effectiveness of marked and unmarked crosswalks. Yaksich (3) noted pedestrian accident reductions in Baltimore after conversion of a two-way street system to one-way operation.

Because of their unique traffic configurations, one-way grid systems provide opportunities to statistically isolate several specific aspects of pedestrian-vehicle interaction. There are two distinctive types of pedestrian crossing conditions in one-way system intersections: a conflict-side crossing within which the pedestrian must compete with turning vehicles during the so-called walk cycle and a nonconflict crossing within which the pedestrian has exclusive crossing rights during the walk cycle, independent of vehicular conflict (Fig. 1). This contrasts with two-way intersections where the pedestrian never has exclusive crossing rights but must contend with both right- and left-turning vehicles during the walk cycle, unless specialized pedestrian signalization is provided. The one-way intersection also isolates turning movements, so there are single right-turning and left-turning sides, independent of any vehicle-to-vehicle conflicts with either oncoming or turning vehicles. The one-way intersection therefore provides direct comparisons of the relative pedestrian accident experience in crosswalks with and without turning conflicts and the relative pedestrian accident experience for left- and right-turning vehicles where there is a direct pedestrian-vehicle confrontation without distractions from other vehicles.

DESCRIPTION OF STUDY

The area selected for study is an eight-block long, four-avenue wide segment of the Manhattan, New York City, one-way street system. Located in the Chelsea section of west side Manhattan, it is bounded on the north by 21st Street, on the south by 15th Street, and on the east and west by 5th Avenue and 8th Avenue. Census tracts show that approximately 10,000 persons reside in the area, but daytime population on working days is at least five times that amount. The one-way system segment, which contains 32 intersections, is reasonably homogeneous in terms of land use and pedestrian and vehicular traffic activity. Two avenues run south, two run north, four streets run east, and four run west. The 32 intersections in the grid have 64 pedestrian conflict sides, consisting of 32 right-turning and 32 left-turning legs, and 64 nonconflict or exclusive pedestrian crossing sides.

The accident study consisted of a review of 5 years of accident records for the period 1967-71 and a classification of intersection accidents by type. A sample of the short-form accident record, which is filled out by the patrolman responding to an accident, is shown in Figure 2. This form is a dual-purpose one used for both vehicle-to-vehicle and vehicle-to-pedestrian accidents. To obtain data about individual accident characteristics required that the patrolman's written summary of the accident be referred to. There were naturally variations in the thoroughness of reporting accident detail. Also the form appears to be more applicable to the more frequent vehicle-to-vehicle accident. For example, the space allocated for the collision diagram is inadequate to portray detail at the point on the vehicle where the pedestrian was struck or to indicate the accurate location of the accident within the intersection. In spite of these deficiencies, sufficient information was obtained from patrolmen's reports to examine the specific areas of interest in the study.

Data were divided into intersection versus nonintersection accidents. An intersection accident was defined as one that occurred in or within 25 ft of an intersection. Intersection accidents were further classified by conflict versus nonconflict sides, with conflict-side accidents subdivided into straight, backing, right-turning, and left-turning. Additional classifications were made by time of day, day of week, weather conditions, and pedestrian age where determinable. Short counts of pedestrian and vehicular volume were also collected for half of the intersections in the study area.

Figure 1. Typical one-way intersection illustrating pedestrian conflicts.

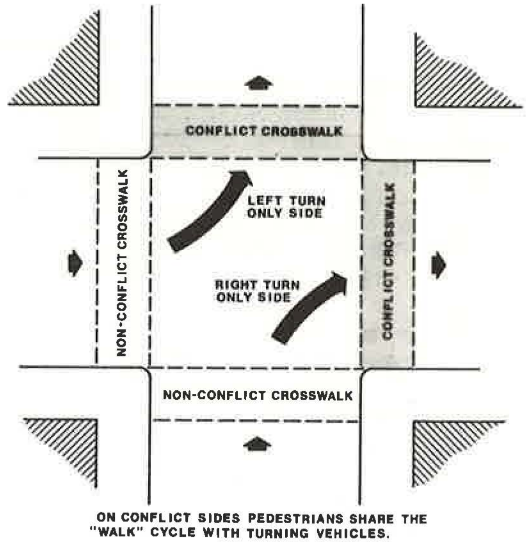


Figure 2. Sample short-form accident record.

POLICE DEPT. UF.6B

LOCATION

Date of Accident______ Day of Week______ Time______(A.M.)(P.M.) Borough______

Accident Occurred on______ Pct.______

St., Ave., Etc.

At Intersection With______ Acc. No.______

St., Ave., Etc.

Or If

Not at Intersection Indicate______ Of______

No. of Feet North, South, East or West — Nearest Intersecting St., Ave., Etc.

ACCIDENT INVOLVED
- ☐ Fatality
- ☐ Personal Injury
- ☐ Property Damage Only

TOTAL CASUALTIES
- No. Killed______
- No. Injured______

LIGHT CONDITION
- ☐ Daylight
- ☐ Dawn-Dusk
- ☐ Darkness

WEATHER
- ☐ Clear ☐ Snow
- ☐ Cloudy ☐ Sleet
- ☐ Rain ☐ Fog

COLLISION BETWEEN
- ☐ Vehicle—Vehicle
- ☐ Vehicle—Pedestrian
- ☐ Other

TRAFFIC CONTROL
- ☐ Police Officer
- ☐ S. C. Guard
- ☐ Signal Light
- ☐ Flashing Light
- ☐ Stop Sign
- ☐ Caution Sign
- ☐ Yield Sign
- ☐ Other
- ☐ None

PEDESTRIAN

A B C D
- ☐☐☐☐ With Signal } Crossing Intersection
- ☐☐☐☐ Against Signal } Crossing Intersection
- ☐☐☐☐ Diagonally } Crossing Intersection
- ☐☐☐☐ Crossing from Between Parked Cars

A B C D
- ☐☐☐☐ Playing in Roadway
- ☐☐☐☐ Other Acts in Roadway
- ☐☐☐☐ Not in Roadway
- ☐☐☐☐ Apparently Intox.

Pedestrians' Ages

A ______
B ______
C ______
D ______

Drivers' Ages

1. ______
2. ______
3. ______
4. ______

Vehicle
1 2 3 4

DRIVER
- ☐☐☐☐ Exceeding Lawful Speed
- ☐☐☐☐ Disregarded Traffic Control
- ☐☐☐☐ Following Too Closely
- ☐☐☐☐ Improper Turn
- ☐☐☐☐ Other Improper Driving
- ☐☐☐☐ Inadequate Brakes
- ☐☐☐☐ Improper Lights
- ☐☐☐☐ Apparently Intox.
- ☐☐☐☐ Other

SKETCH OF ACCIDENT

USE SOLID LINE WITH ARROW TO SHOW PATH AND DIRECTION OF VEHICLE BEFORE IMPACT

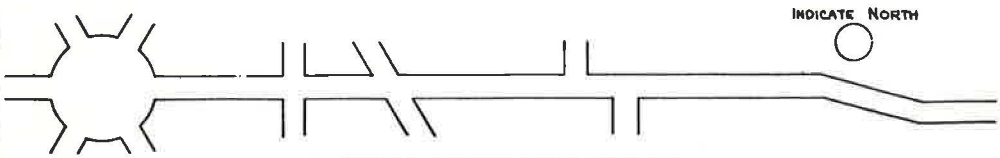
USE DOTTED LINE WITH ARROW TO SHOW PATH AND DIRECTION OF VEHICLE AFTER IMPACT

NUMBER EACH VEHICLE

INDICATE PEDESTRIAN BY ○

RAILROAD —I—I—I—I—

INDICATE NORTH



BRIEFLY DESCRIBE WHAT HAPPENED

____

____

____

____

____

MAJOR RESULTS OF STUDY

During the 5-year period encompassed by the records, 253 pedestrian accidents occurred within the one-way grid system, and 172 or 68 percent of the total was at intersections. There were five fatalities, but only one occurred at the intersection. The single intersection fatality was caused by a left-turning vehicle when both pedestrian and vehicle had the green light. Two fatalities were caused by midblock dart outs, another by a vehicle attempting to avoid one pedestrian and hitting another, and the last directly caused by alcohol involvement of the pedestrian. All fatalities were males over 60, which follows the classic accident severity pattern among the aged. A much younger age distribution was noted for all intersection accidents, which is not typical of the general accident experience in this country (Fig. 3). There is a significantly higher involvement of younger, more agile pedestrians in intersection accidents in this system; 54 percent was in the 20 to 50 age bracket. This can probably be attributed to the high working-age population in the study area during daylight hours.

The main focus of the study, the comparison of accident experience in conflict versus nonconflict sides of the intersection, illustrates the value of exclusive pedestrian crossing rights. Crossing on the conflict side of the intersection, where both pedestrians and vehicles share the green, accounted for 69.7 percent of the intersection accidents. This total was composed of 44.7 percent turning accidents, 17.5 percent straight accidents, and 7.5 percent back up (Fig. 4). This illustrates that a pedestrian has more than twice the probability of being struck by a vehicle when he is crossing on the conflict side.

Short traffic counts of both pedestrian and vehicular volumes at half of the intersections in the system showed that pedestrian activity was balanced between conflict and nonconflict crosswalks. As a point of interest, expansion of vehicle short count data into equivalent annual volumes shows that the approximate probability of a driver striking a pedestrian at an intersection in this system is about one in 9,000,000, demonstrating the inherent difficulties connected with pinpointing causal factors at specific accident sites. The short counts point up one other significant fact. Although vehicle turning movements averaged only 14 percent of the total recorded traffic moving through the intersections, turning accidents accounted for 45 percent of the accidents. Turning vehicles therefore are approximately six times more likely to strike a pedestrian than are through vehicles.

Backing movements manifest an even greater propensity for striking pedestrians, for, although the backing movement amounts to less than 1 percent of the observed traffic activity, it resulted in 11 percent of the accidents. An automobile backing into a crosswalk would therefore have more than 15 times the probability of striking a pedestrian that straight and turning movements combined have. This is attributed to the restricted visibility of the driver, combined with the pedestrian's lack of expectancy of a vehicle making this maneuver.

THE LEFT-TURN ENIGMA

An unusual characteristic of the intersection accident pattern is that left-turning accidents exceed right-turning by a ratio of 2 to 1 (31 percent versus 14 percent). Short count surveys showed that this imbalance was not attributable to differences in either pedestrian or vehicular volumes. Although this difference might be understandable in a two-way system where left-turning vehicles are subjected to attention conflicts from right-turning and/or straight through vehicles, it is a surprising pattern for a one-way system where right- and left-turn conditions are seemingly equal in every respect. This same predominance of left-turn pedestrian accidents has been noted in the national pedestrian accident survey conducted annually by the American Automobile Association (4). This survey involves reports of accident experience from about 2,000 cities in the United States and Canada. Interestingly, England with its left-side traffic system and right-side driver's seat has a predominance of right-turn accidents (Table 1).

These accident statistics strongly suggest that there are different factors operable in pedestrian accidents that occur during turns on the driver's side. Turning a vehicle itself is a complex human motor task, requiring continuous sensory feedback for velocity judgment and wheel adjustment through the turn. The turning driver has a much more complicated visual task and sensory feedback problem because he must observe and evaluate relative closing distances between his vehicle and a moving pedestrian from the constantly changing angular variations of a curved vehicle path. Controlled laboratory experiments (5) have shown that visual acuity is measurably reduced when the visual target is moved through a circular path.

To examine the premise that physical factors might vary between left and right turns, contributing to an accident differential, series of left and right turns were photographed by means of a slow-motion movie camera mounted in the approximate driver's position of a vehicle that was driven through the system. Subsequent review of the slow-motion film failed to reveal any apparent physical difference between the two types of turns, although the camera angle admittedly did not duplicate the full range of human vision. However, the films did show that even the small New York State motor vehicle inspection sticker affixed to the left front windshield could obscure pedestrians during part of the left turn. In addition, although not accurately represented in the camera's limited field of view, the vehicle's left front roof support post was found to occupy a considerable amount of the driver's field of vision during left turns.

IS IT THE FRONT LEFT ROOF SUPPORT?

The results of this limited accident investigation seem to suggest that the front left roof support could be a causative factor in a significant number of left-turn accidents in urban intersections. If true, the post may be responsible for other types of left-side pedestrian accidents as well. The predominance of left-turn pedestrian accidents noted in two-way systems might also be connected with visual impairments caused by this post rather than the attention conflicts from other vehicles as suggested by others. Vehicles represent massive visual targets in the driver's field of view, compared to pedestrians who may easily be obscured by the vertical post.

Allen (6) reported that a survey of 1960-62 automobiles showed that the front left roof support occupied 5 to 17 deg of the driver's field of view and was located between 10 and 26 deg left of straight ahead of the driver's eyes. Measurement of a late-model sedan in the company pool showed a 10-deg obstruction of the field of view. Figure 5 shows such a 10-deg visual impairment at the beginning of a left turn. At the point of initiating a turn, the driver turns his head away from center in the direction of the turn, gradually moving his head back to center as the turn is executed. It is at the point of turn initiation that the post causes the most obstruction, creating a blind zone that could encompass an area of more than 100 ft^2 with the more extreme post designs. As the driver turns, the blind zone is reduced, but it would be possible for the driver to assume that there were no pedestrians in the crosswalk based on his field of vision when initiating the turn, and therefore he would be unprepared to stop. At 10 mph a driver can execute a turn in less than 3 sec; during this same time a pedestrian on the blind side would move about 12 ft. This allows a very small margin of safety for the motorist to react and stop his vehicle to avoid a pedestrian he had not initially observed.

Accident reports were reviewed after this analysis of the visual impairment on the left side to determine whether a significant number of accident victims were also approaching from the left. Because of the nature of the reports this was not possible for all the accidents, but, where determinable, a relatively insignificant imbalance was noted for left-side accidents ($^{55}/_{45}$). On the basis of the available accident information, it is not possible to conclude the specific factor, or possible combination of factors, that is operable on left-turn accidents that causes their greater frequency of occurrence. But the human dynamics of turning, with the greater pedestrian accident potential, appear worthy of more detailed research.

POSSIBLE APPLICATIONS OF RESULTS

The extremely high probability of backing accidents as related to vehicular activity noted in this study indicates that backing into the crosswalk should be more strictly enforced as a moving traffic violation to focus the attention of both driver and pedestrian on the danger connected with this maneuver. Inasmuch as signal standards are located near crosswalks, signs on these standards noting that this is a violation might increase

Figure 3. Age of pedestrians involved in one-way intersection accidents in New York City.

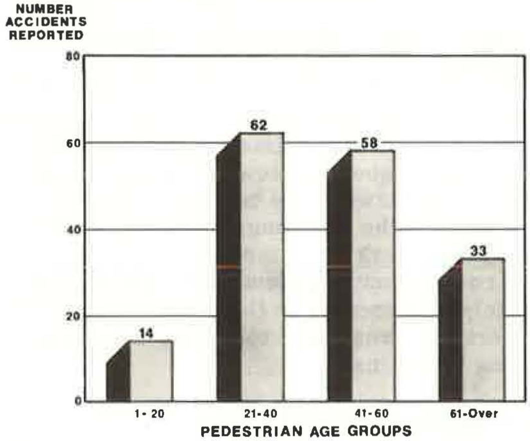


Table 1. Pedestrian accidents at roadway junctions in England.

Intersection Layout	Number of Accidents	
	Right Turn	Left Turn
T or Y		
Controlled	22	13
Uncontrolled	273	131
Crossroads		
Controlled	75	58
Uncontrolled	49	34
Total	419	236

Source: Correspondence from S. J. Older, Road Research Laboratory, reference TB/417/450/01.

Figure 4. Conflict-side versus non-conflict-side pedestrian accidents at 32 one-way intersections in study area.

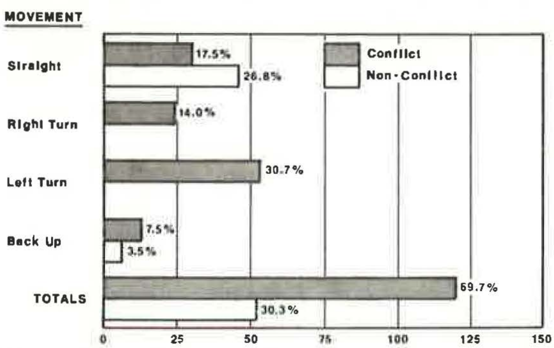
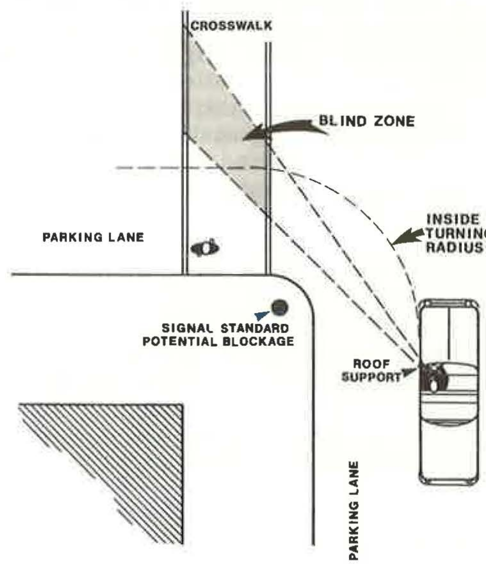


Figure 5. Impairment of driver's field of vision in left-turn movement by roof support.



compliance with the law. The higher pedestrian accident experience noted in the conflict crosswalk suggests that some differential markings between conflict and nonconflict crosswalks might be of value. The San Diego experience, where accidents were higher in marked crosswalks, is indicative that a new approach to crosswalk marking must be developed, not directed toward giving the pedestrian the impression that the crosswalk is his "territory" but toward alerting both driver and pedestrian that the crosswalk is at the critical point of man-vehicle interaction and that extreme caution is required from both. The higher accident probability of turning (in terms of vehicle volume) implies that restrictions on turns should be more generally applied in busy pedestrian areas. Also it suggests that there should be more investigation of the human dynamics of turning and more detailed study of the principles and warrants governing application of right turn on red.

ACKNOWLEDGMENTS

The author wishes to express his gratitude to the New York City Department of Traffic for assistance and cooperation in providing access to pedestrian accident records, to S. J. Older of the Road Research Laboratory for his prompt reply to an inquiry on the English experience, and to James Caffrey who extracted and summarized the accident data.

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THE EMERGING NEEDS OF BICYCLE TRANSPORTATION

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It is expected that bicycle sales will equal if not pass automobile sales in 1973. Adults are rediscovering the virtues of the bicycle: health, recreation, and ecology. The 50 million bicycles and estimated 73 million riders need safe, efficient, and enjoyable bike paths. Various levels of government are attempting to address this need by developing design criteria for bikeways. This paper will review some of the bicycling activities in the United States at various levels of government, summarize existing planning and design criteria, and recommend an approach for future planning efforts. It is hoped that this information will provide answers to some basic questions and point the way for additional research relating to the emerging needs for bikeways.

•DURING the last decade bicycle sales have tripled in the United States. This year it is estimated that they will even top the predicted 11 million sales of automobiles (1). Approximately 40 percent of these sales will be to adults compared to 35 percent in 1970 and 25 percent in 1969 (1).

Many dealers across the country are noting that adults of all ages are buying all the five- and ten-speed bikes they can supply, and manufacturers agree that the bicycle boom will continue for a long time. This has prompted some of the leading domestic bike companies to gear 85 percent of their production toward the manufacture of adult bikes (1).

The fact that many people have rediscovered the virtues of the bicycle, including health, recreation, and ecology, is probably the single most important reason for its rebirth. All of these virtues contribute to the growing belief that bicycles are here to stay, as demonstrated by the dramatic increase in bicycle users (Fig. 1) that has occurred during the past decade (2).

Although there are over 50 million bicycles and an estimated 73 million riders (3), planners and engineers in the United States have only begun to provide safe, efficient, and enjoyable mobility for the cyclist. The bicycle mode of transportation can and should be adequately served, but the cost of providing bikeways must be justified. (For the purpose of this paper, the term "bikeways" will be used to describe any road, path, or trail used for bicycle transportation.) Unfortunately, the determination of demand for bicycle facilities and the planning and design of a system of bikeways to satisfy this demand are not an easy task.

BICYCLE HISTORY

The current boom in bicycles is not the first such phenomenon in two-wheeled travel. Since its beginning with the invention of the "hobby horse" in 1819, the bicycle has experienced periodic surges of popularity. The hobby horse, first patented in the United States by W. K. Clarkson of New York City, maintained its popularity for only a few short years because of its high cost and clumsy design. Other names attached to the vehicle were velocipede (swift foot), the patent accelerator, the bivector, the bicipede, and the dandy horse. The last name humorously characterizes the high cost of the machine and type of well-to-do male who could afford to buy it (4).

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In 1840, interest in bicycling was revived by Kirkpatrick McMillan, a Scottish blacksmith, who added cranks, pedals, and driving rods to the hobby horse and also equipped it with a comfortable seat, a padded armrest, and a handlebar. Further improvements were made by the Michaux Company in France, and by 1867 bicycling had become the sensation of Paris.

Despite the still cumbersome design of the machine, the new craze continued to spread, first to England and soon after to the United States. The following quote was taken from the Brooklyn Eagle in 1869: "Whole streets will no doubt in due time be modified to meet the requirements of the coming vehicle." Henry Ward Beecher, a celebrated New England clergyman, predicted that "he would not be surprised to see, in short time hence, a thousand velocipedists wheeling their machines to Plymouth Church" (4). Unfortunately the financial panic of 1870 ensued, and the velocipede craze in America collapsed as quickly as it began.

The term bicycle was first used when the "ordinary bicycle" was patented in 1872. It was characterized by solid rubber tires that reduced vibration and a large front wheel that reached a maximum diameter of 64 in. The ordinary bicycle was not destined to be around long, though, because of several major shortcomings. Because its center of gravity was very close to the center of the front wheel, the bike was unstable, particularly on rough surfaces. Mounting and dismounting caused a great deal of difficulty, restricting its use mainly to young, agile males.

At a time when the unsafe ordinary bicycle was flourishing in America, the "safety bicycle," which resembled today's bicycle, was introduced in Europe. After it arrived in the United States, the safety bicycle had such an impact that, in 1892, newspapers and periodicals were describing the "bicycle craze" it created.

During this period, the League of American Wheelmen, a federation of local "ordinary" bicycle clubs was lobbying for good roads and bicycle side paths much the same as that organization and many others are doing today. Their efforts were rewarded when states began to enact local road-aid laws, led by New Jersey in 1891 (4).

In the late 1890s, there was a dramatic decline in bicycle popularity. This was probably due in part to the fact that the older generation found cycling too strenuous because of the bicycle's primitive design. Regardless of the reasons for the decline of bicycle popularity, the bicycle was relegated to the position of being a child's toy. This is evidenced by the fact that, of the 18 million bicycles in use in 1949, 85 percent were designed for children (4).

After the 1890 bicycle craze declined, it was not until the mid-1960s, nearly 65 years later, that the new bicycle boom began to materialize. Because of the large number of adults responsible for the boom, the bicycle can no longer be considered a toy.

THE CURRENT BICYCLE BOOM

In New York City recently, the Parks Department decided to close Central Park to automobiles on weekends and weeknights to accommodate the more than 10,000 cyclists that have frequented the park in a single day. Wisconsin has instituted a 320-mile bikeway statewide, over which 728,000 cyclists rode in 1970 alone (5). All across the country there is talk of providing bikeways and bike trails, and most authorities agree that the sheer numbers of bicyclists in the country are enough to warrant such consideration. Before funds are committed for costly bicycle facilities, though, it would be useful to examine the reasons for the demand.

Renewed interest in the bicycle is an obvious by-product of the environmental movement in the United States. It is the only mode of vehicular transportation that creates no noise or air pollution. Ecology-conscious individuals therefore feel they are doing their share to help the environment when they pedal instead of drive.

Conservation is another reason for the bicycle boom. The bicycle consumes no fuel and uses about $\frac{1}{16}$ the space of an automobile. Acceptance of the bicycle as a means of commuting to work would result in a reduced need for acres of high-cost parking facilities in many urban areas and might also relieve traffic congestion.

The bicycle has long been accepted as a means of transportation by children, and, with the advent of lightweight multispeed bikes, it is now becoming more widely accepted by adults. The bicycle offers reliable, convenient transportation with minimum cost and low upkeep. It costs little or nothing to park. It can even result in time savings for the commuter in some urban areas, inasmuch as the average speed of motor vehicles in many cities has been reported to be as low as 10 mph during the peak hours (2). For the cyclist there are no buses to catch, no cars to start, and no bothersome traffic jams. For example, in a recent race conducted in Boston between 10 automobiles and 10 bicycles over a specific route during rush hour, bicycles finished first seven times out of 10 (1). The same test was conducted by students at the Georgia Institute of Technology in Atlanta. Bicycles and cars raced to five different points approximately 2 to 3 miles from a downtown location during the afternoon rush hour. The bicycles won in every case.

Bicycling as a means of exercise is becoming more and more popular. For one thing, it is a pleasant way to acquire and maintain physical fitness as compared to jogging, running in place, isometrics, and other types of exercises that tend to become monotonous. Physical fitness experts contend that cycling ranks third behind running and swimming as the best means of exercise.

Cycling is also an excellent recreational activity. The Bureau of Outdoor Recreation, for example, has reported cycling as the fastest growing recreational activity in a country that has become increasingly more oriented to outdoor recreation (2). It is also a relatively inexpensive activity (when compared to others such as golf, boating, and camping), requiring only a small initial expenditure and very little maintenance.

Perhaps the bicycle boom stems from the increasing adult desire to escape from the monotony and pace of urban life. Perhaps concern for the environment has created a desire to engage in nonconsumptive activities, or perhaps there is a growing discontent associated with the frustration of automotive commuting. Whatever the reasons for the current trend in bicycling, it should be clearly evident that provisions must be made to deal with the growing demands and numbers of cyclists.

GOVERNMENTAL ACTIVITY IN BICYCLING

The federal government has taken the first steps toward gearing national policy in the direction of creating bikeways and bike trails.

Because bicycles can be used for both recreation and transportation, the U. S. Department of Transportation has teamed up with the Department of the Interior to promote bikeways and bike trails. The joint decision to promote bicycles at the federal level was made in early 1971 by Secretary of the Interior Rogers Morton and former Secretary of Transportation John Volpe. According to Volpe, "It must be our plan to restore some sense of humanism to our downtown streets.... The city must be a gathering place for people, not vehicles" (2). The use of the bicycle serves to achieve this objective.

At present, there is federal money available for constructing bikeways. Federal highway funds may be used for this purpose when bikeways are built in conjunction with a federal-aid highway project. A letter from Volpe urging promotion of bikeways by state highway officials along with a Federal Highway Administration notice entitled "Trails in Highway Rights-of-Way" established the policy of the Department of Transportation toward such facilities. The notice stated, "There are times when in the planning of a highway it is possible to include in the highway right-of-way a walking or bicycle trail that would be of significant benefit to the community.... In all cases where we have a 3-C (continuous, coordinated, comprehensive) planning operation in progress, consideration should be given to including trails as part of the areawide transportation plan" (6). However, this money must be requested from and administered by the state highway department.

Federal money is also available through other governmental agencies. The Department of the Interior, through the Bureau of Outdoor Recreation (BOR), administers Land and Water Conservation Fund grants under the President's Legacy of Parks Program. These grants provide funds to state and local governments for acquisition and development of outdoor recreation areas and facilities, including bike trails. Other federal assistance is available through grant programs under Community Development, Department of Housing and Urban Development, Urban Renewal, and Open Space Land Programs.

Currently, attempts are being made to pass federal legislation to aid in the planning and construction of bikeways. For example, Edward I. Koch, congressman from New York, has introduced the Bicycle Transportation Bill. If passed, the bill would permit state and local governments to use Highway Trust Fund moneys for the development of bikeways, including construction of bicycle shelters and installation of bicycle traffic control equipment.

On the state level, the example set by Oregon is one that many states are beginning to follow. Oregon passed an act, the first major breakthrough for bikeway financing, that states, "Footpaths and bicycle trails should be established wherever a highway, road or street is being constructed, reconstructed or relocated. Funds received from the State Highway Trust Fund may also be expended to maintain such footpaths and trails; to establish footpaths and trails along other highways, roads and streets and in parks and recreation areas.... The amount expended by the commission or by a city or county as required or permitted by this section shall never in any one fiscal year be less than one percent of the total amount of the funds received from the highway fund" (7).

New York, Maryland, and Washington have also passed laws allocating use of Highway Trust Fund money for the construction of bikeways. Many other states such as California are investigating similar bills that are pending in their state legislatures.

Other states have enacted legislation relating to the provision of bikeways. Arizona recently passed a bicycle study bill on a statewide basis from which $50,000 was appropriated from the general fund for the highway department to administer. Arkansas conducted a study in which it was concluded that the state highway department had the legal authority to construct and maintain bikeways within the state highway system. Iowa received a $10,000 appropriation to determine the need for bikeways in that state. Minnesota's 1971 legislature appropriated $30,000 to its state Department of Natural Resources to build a bikeway from Lake Phalen to St. Paul. Other states have also appropriated funds to plan, study, or build bicycle facilities, while many county and city governments have independently initiated programs for planning and construction of bikeways.

STATUS OF BIKEWAYS IN THE UNITED STATES

To determine the status of bikeways in the United States, the authors conducted an extensive survey. Included in the survey were state highway departments, organizations and interest groups, overseas cycling clubs, federal agencies, individuals, manufacturers, cities, and counties. The letter sent to these groups was an information request in which the following four major areas of consideration were outlined:

1. Planning criteria,
2. Design criteria,
3. Need for bikeways, and
4. Accident experience and safety aspects.

Over 60 percent of the recipients replied to the request. The greatest response, however, came from the state highway departments where 47 out of 50 responded. Table 1 gives some of the information obtained from state and local governments.

PLANNING OF BIKEWAYS

From the evidence that has been presented, it is clear that millions of dollars will be spent for the construction of bikeways during the next decade. If waste of public funds is to be avoided, plans for bikeways must be developed on the basis of a well-conceived planning process. A suggested approach to planning for bikeways is given in the following paragraphs. It should be remembered that bicycle planning is an integral part of the overall transportation planning process, and planning for bikeways should be comprehensive rather than piecemeal. Bikeways should complement other transportation facilities and contribute to the integrity and efficiency of the total transportation system.

Figure 1. Recent increase in bicyclists (3).

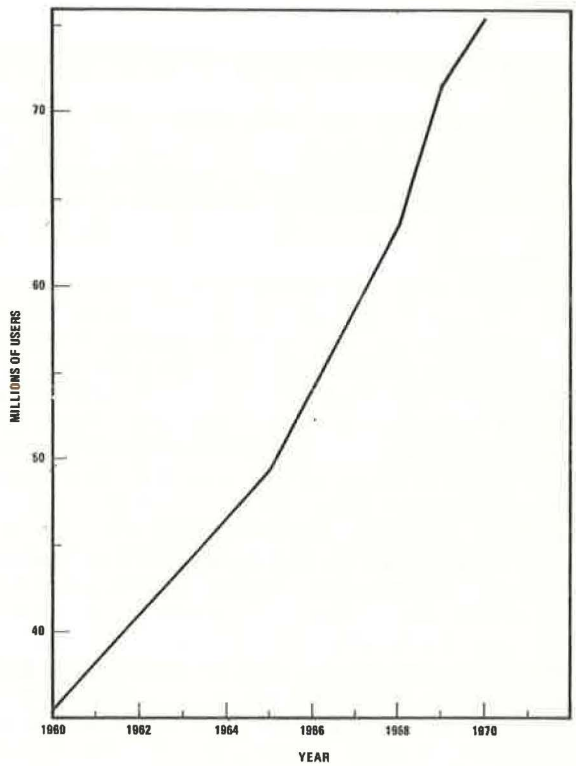


Table 1. State activities in bikeway development.

State	Conducting Research	Legislation Pending	Legislation Passed	Developed Planning Criteria	Developed Design Criteria
Alabama					
Alaska					
Arizona	X	X			
Arkansas	X				
California	X	X		X	X
Colorado	X	X		X	X
Connecticut		X			
Dist. of Columbia	X			X	
Delaware					
Florida	X	X		X	
Georgia	X	X			
Hawaii	X			X	
Idaho	X			X	
Illinois	X	X			
Indiana					
Iowa	X				
Kansas					
Kentucky				X	
Louisiana					
Maine	X				
Maryland	X		X		
Massachusetts		X			
Michigan					
Minnesota	X				
Mississippi					
Missouri					
Montana	X				
Nebraska					
Nevada					
New Hampshire	X				
New Jersey	X	X			
New Mexico	X				
New York	X		X	X	
North Carolina					
North Dakota					
Ohio	X	X			
Oklahoma					
Oregon	X		X	X	X
Pennsylvania	X				
Rhode Island					
South Carolina					
South Dakota					
Tennessee	X				
Texas					
Utah					
Vermont					
Virginia	X				X
Washington	X		X		
West Virginia					
Wisconsin	X				
Wyoming					

Figure 2 shows a suggested approach to bikeway planning that resembles many of the systems used in transportation planning. Local governments involved in planning and construction of bicycle facilities might find these planning guidelines useful.

Organize for the Job

The initial step in the process is to organize for the job. A regional or municipal planning agency would probably best serve as the coordinating organization. However, many other interest and government groups must provide input for the agency involved in organization. Following is a list of groups that would provide invaluable data:

1. Federal government (BOR, DOT, etc.),
2. State government (departments of natural resources, highways, or transportation),
3. School representatives,
4. Ad hoc citizen groups,
5. Bicycle manufacturers,
6. Municipal government (department of public safety, local traffic engineering, etc.),
7. Cycling clubs,
8. Bikeway promotional organizations (e.g., Bicycle Institute of America, League of American Wheelmen, etc.), and
9. Local and regional governments.

Inventories

A great deal of information is required as a prerequisite to planning bikeways. Inventories must be made of travel and user characteristics, land use, available principal facilities, and accident experience. Information on travel and user characteristics can be obtained as a part of a general origin-destination study or by means of a special telephone or mail survey. Such an inventory would seek information on bicycle ownership, social and economic data pertaining to bicycle users, and information on trip origins, destinations, lengths, purposes, and travel patterns relating to time. Land use surveys and forecasts would provide information on future travel patterns and focus attention on those areas that can best be served by bikeways. Special surveys would be required to identify specific available principal facilities for bikeway use. Such facilities would include little-used roads, abandoned railroad beds, power easements, sidewalks, towpaths, bridle trails, flood plains, parks, school grounds, campuses, golf courses and country clubs, airports, and even cemeteries. Accident statistics could be obtained from police files and would provide valuable input for planning safe bicycle facilities.

Information gathered from the inventories must be analyzed to predict future demand as closely as possible and to aid in planning. Important components of the analysis are summarized later.

Trip Generation—The generation of bicycle trips depends on many factors including the following:

1. Bicycle ownership,
2. Type of community,
3. Availability of facilities,
4. Social and economic characteristics of users,
5. Weather and climatic conditions, and
6. Local terrain.

The purpose of determining the number of trips generated is to provide data to assist in forecasting the demand and choosing locations for bikeways. The best method available for obtaining this information, as previously mentioned, is surveying the neighborhood. Such a survey should obtain information concerning user characteristics, preferences, attitudes of bicycle users with respect to roadways, types of trips, reasons for using bicycles, perceived evaluation of risk, socioeconomic data, and personal opinions. Although open-ended questionnaires are difficult to analyze, they can often provide useful answers to difficult questions.

Figure 2. Systems analysis approach to bikeway planning.

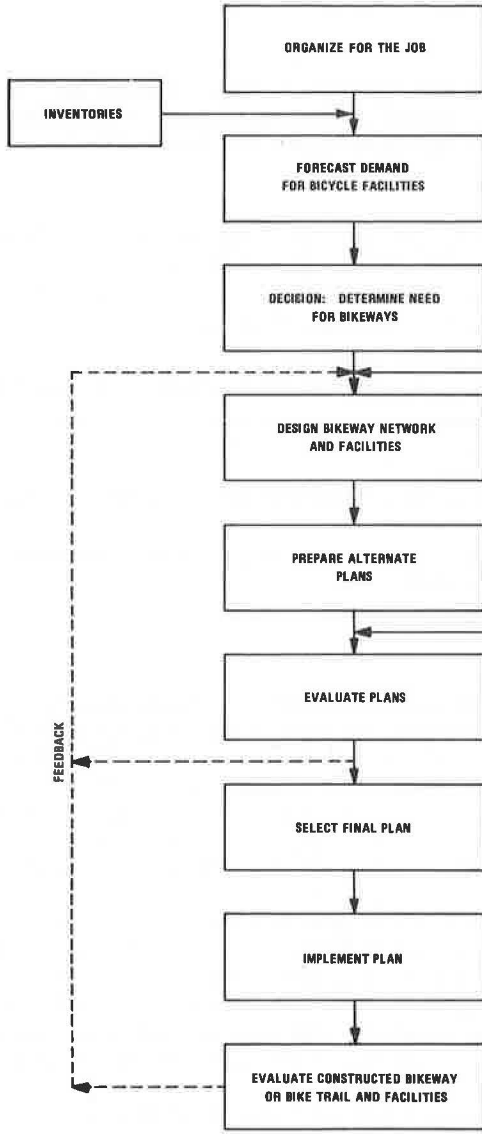
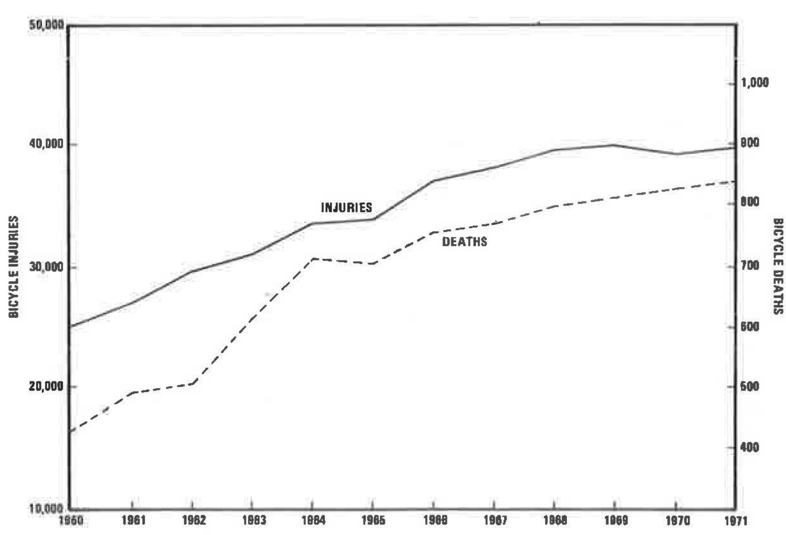


Figure 3. Bicycle injuries and deaths in the United States (11).



Other information required from a study area would include a list of traffic generators and possible changes in the population or demographic characteristics of the population. Major generators of bicycle trips are schools, colleges and universities, shopping districts, employment centers, scenic areas, parks, and recreational facilities. Changes in population or demographic characteristics are often not easy to detect but are necessary to predict accurate demand and to provide adequate facilities.

Trip Lengths and Times—These data pertain to the average bicycle trip length and time and the time of day in which the trip is made. Because of its flexibility and maneuverability, the bicycle has many advantages on short trips in congested areas. This is exemplified in both Europe and the United States. In Rotterdam, where 43 percent of all trips are by bicycle, average bicycle travel time is about 10 min. As population density decreases and trips lengthen, bicycle trips decrease as demonstrated in many U. S. suburban developments (8).

Because the bicycle is primarily used for recreational purposes in the United States, most riding takes place during nonwork hours. It remains to be seen what effect the provision of bikeways would have on nonrecreational bicycle travel.

Safety Consideration—Another major concern is the collection of accident statistics that can provide planners with information to develop both planning and design criteria as well as warrants for establishing bikeways. While the number of people riding bicycles has increased dramatically, so has the number of bicycle accidents and fatalities. Baldwin (9) recently reported at a safety seminar that bicycle deaths were up 78 percent from 1960 to 1970 (nationwide), and the trend is getting worse. According to the National Safety Council, more than 820 persons lose their lives and an additional 40,000 to 50,000 others suffer disabling injuries in bicycling accidents each year (10). The death toll has been climbing steadily since 1960, going from 2.8 deaths per million population to 3.8 in 1967 (10). These increasing losses are attributed primarily to the greater accident exposure brought about by the ever-increasing number of bicyclists traveling on inadequate facilities. Figure 3 shows the increase in bicycle accident injuries and fatalities from 1960 to 1970.

There are generally two types of bicycle accidents: collisions and falls. Although falls are more common, they are less serious. Collisions usually result in serious injury or death. Reports (2) have shown that

1. One out of three accidents involved an automobile,
2. One out of four bicycles involved in an accident is mechanically defective, and
3. Two of every three riders killed or injured in collisions with automobiles have violated a law or safety rule.

Frequent causes of cyclist fatalities and injuries are as follows:

1. Making improper turns,
2. Disregarding traffic signs, signals, and markers,
3. Riding double,
4. Running into an open door of a parked vehicle, and
5. Failing to yield right-of-way.

Of particular danger to the cyclist are fixed objects, curbs and gratings, wet streets, cracks in pavement and potholes, and loose dirt and gravel. Inexperience of the cyclist is also a factor that often contributes to accidents.

To separate bicycles from motor vehicles is an obvious measure that would no doubt go far toward reducing the present high incidence of accidents. Many authorities feel that separating the two modes on exclusive rights-of-way is the direction to be taken (2). Little research has been done in the United States to determine what effect this would have on the number of accidents; however, several European researchers have sought the answer to this question. Studies (12, 5) conducted in the Netherlands, Denmark, and France have concluded that there was a significant reduction in bicycle-automobile accidents when separate bike paths were provided for cyclists. The French study reported a reduction of up to 45 percent in certain areas.

Figure 4. Percentage of total trips made by bicycle (8).

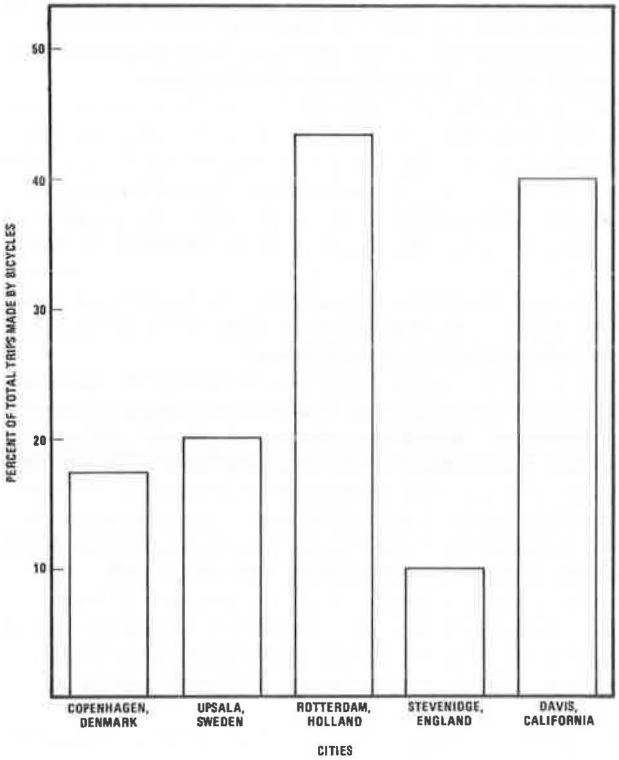


Table 2. Summary of existing design criteria.

Design Element	Guideline
Speed, mph	10
Bicycle and cyclist dimensions, ft	
Handle bar width	1.96
Cycle length	5.75
Pedal clearance	0.5
Vertical space	7.4
Horizontal bikeway clearance, ft	
Min	0.8
Max	1.6
Vertical bikeway clearance, ft	8.2
Bikeway width (for two-way traffic), ft	
Min	5.25
Recommended	8.00
Grade, percent	
Max for short runs	10
Recommended	5
Radius of curvature, ft	
Min	6
Max	50
Recommended	20

Note: Drainage must be included to prevent washouts, avoid ground saturation beneath trail, and prevent frost action with resulting heaving. Table 3 gives advantages and disadvantages of various surface materials (5).

Table 3. Advantages and disadvantages of currently used bike path materials.

Material	Advantages	Disadvantages
Portland cement concrete	Long service life, supports heavy loads if reinforced, all weather surface	High construction costs, difficult and costly to maintain
Asphalt concrete	Long service life, easy to maintain, all weather surface	Moderately high construction cost, requires skilled technicians for good quality
Compacted aggregate	Easy to maintain, low cost	Short life expectancy, not an all weather surface, poor riding quality
Soil-aggregate mixture	Low cost, easy to maintain	Not an all weather surface, cannot support heavy loads, poor riding quality
Soil-cement	Smooth riding surface, easy to maintain	Susceptible to erosion, erodes easily under traffic

Forecasting

After the completion of an inventory analysis, a forecast of demand can be made. At present, however, there are no recognized methods and little experience in forecasting such a demand and almost no experience in forecasting latent demand. For this reason, much of the forecasting that has been done has been of a subjective nature.

Experience in cities that have provided new bikeway facilities suggests that substantial latent demand may exist. Figure 4 shows the percentage of total trips made by bicycles in several cities where special provisions have been made for bicycle transportation (8).

A pressing need exists for a demonstration project consisting of controlled experiments designed to aid in the formulation of an accurate forecasting method for existing as well as latent demand.

Developing a Plan

If preliminary analysis indicates the need for bikeways, a plan would be developed. This plan would be based on both the objectives and planning and design criteria.

Objectives—Defining objectives and obtaining required information to be used in design must be accomplished after the needs have been outlined. The task of formulating objectives is probably one of the more difficult ones in the planning process. Bikeways must be planned to serve people and fulfill their desires. User objectives in the planning process consist of safety, convenience, reduced cost, pleasure, and access to certain areas. Planning objectives include flexibility, consideration of other modes, creation of a desirable environment, and optimization of the return on investment.

Planning and Design Criteria—As a part of the overall planning process, maintenance problems, construction costs, development of priorities, and terrain features are all important factors to receive consideration by planners.

Engineering design for bikeways should be based on rational, up-to-date design criteria. Because the bicycle is a unique vehicle, it has special needs and problems. In comparison to motor vehicles, bicycle speeds are lower, but for comparable speeds braking distances are longer than those for motor vehicles. The bicycle also affords the cyclist minimum physical protection.

Design criteria that need to be considered are design speed, bicycle and cyclist dimensions, minimum width and clearances, grade, radius of curvature, bikeway surface, and drainage. Table 2 gives much of the information being used as guidelines today. Table 3 gives the advantages and disadvantages of materials used for the construction of bikeways. It appears that some of the accepted standards are based on subjective judgment and should be applied with that in mind. A quick review of these tables will point out the need for research to develop objective and rational design standards.

Evaluation, Selection, and Implementation of Plans

As the next step in the planning process several alternative bikeway plans can be developed and evaluated. One method of evaluating such plans is to establish a location team. A suggested list of the type of people to have on this team is given in the following:

1. Chairman,
2. Technical advisors,
3. Representatives of the decision-making bodies,
4. Representatives from local cycling groups,
5. Community representatives, and
6. Impartial consultant to evaluate alternatives.

The location team will make recommendations for the selection of final plans or request that new alternatives be submitted. If a final plan is recommended, implementation can take place.

The final stage in the planning process concerns evaluation of the results. Project administrators evaluate in retrospect the problems encountered in planning and identify the impacts of the completed system. These data can be used in the future development of bicycle facilities to establish new and better planning and design criteria.

SUMMARY

In all probability, the bicycle boom will continue for a long time. Bicycle use is so widespread in many parts of the United States that bicycle traffic volumes may soon become comparable to those of automobiles.

State highway departments and municipal traffic engineering departments have had little experience in coping with the problem of bicycle traffic, especially where automobiles and bicycles must share the existing roadway. Accident experience regarding automobile-bicycle conflicts will continue to worsen until provisions are made for bicycles. Cyclists will undoubtedly continue to increase in number and consequently overburden many existing streets and worsen the traffic safety problem.

Engineers and planners should accept the bicycle boom as a challenge. That challenge will invite that test of new and innovative ideas that can be used in the planning and design of bikeways. Demonstration projects, research projects, and financial commitments to the bicycle mode of transportation must take place to ensure that bikeways are properly planned and constructed.

ACKNOWLEDGMENT

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THE ABILITY OF ELEMENTARY AND SECONDARY SCHOOL CHILDREN TO SENSE ONCOMING CAR VELOCITY

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Forty children, aged 5 to 14, were asked to classify the velocity of vehicles approaching them on a two-lane rural road in a residential setting as slow, medium, or fast. Developmental aspects are definitely present. The older the child is, the more likely he is to make correct slow and medium judgments of the vehicle's velocity. However, the correct judgments of fast are inversely related to age. This puts the older child at greater risk. Sex is also a significant variable. The females in the sample were much more conservative and, therefore, much more likely to correctly classify the dangerous fast vehicles. By contrast, the males in the sample made more correct judgments over the whole speed range. Results indicate considerable differences associated with age and sex. Vehicle-associated characteristics, such as size and noise, are also shown to influence the velocity judgment.

•THE Injury Control Research Laboratory has a general interest in the factors that affect the development of a person's ability to use his distance senses for the appreciation of environmental hazards. The purpose of this study is to investigate the developmental characteristics that enable children of elementary and secondary school age to utilize their distance senses in this manner. Its purpose also is to determine how maturational aspects interact with sensory impressions produced by vehicle noise, size, and color and other factors such as traffic volume and roadway curvature in controlling velocity judgments.

It is inherent in the social structure that children of school age interact with vehicular traffic in their daily activities. Because the child's role in this interaction is primarily that of pedestrian and because in the elementary school age range between one-half and three-fourths of the pedestrian accidents occur at midblock, between intersections (1), it is desirable to determine how this ability to sense the velocity of oncoming vehicles develops with age. Also, it is important to know how visual and auditory cues emanating from the approaching vehicle affect velocity judgments.

Among the few studies dealing with pedestrian behavior (2, 3, 4), only one (5) is specifically concerned with children pedestrians.

THE FIELD AND THE EXPERIMENT

The field site was a two-lane rural road in the town of North Kingstown, Rhode Island. The subject and experimenters were situated by the side of the road at the location shown in Figure 1. Personnel and equipment were screened from the approaching traffic by trees and shrubbery. The subject had a sight distance of approximately 1,100 ft. The asphalt road, 24 ft wide and without shoulders, in a residential, rustic community composed the naturalistic setting for the experiment. The road has a maximum grade of 4 percent and a maximum curvature of 2 percent. The subject was asked to judge the speed of approaching cars. Only cars moving in the direction indicated in the figure were evaluated.

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The equipment consisted of radar and a decibel meter. The radar and associated meter indicating miles per hour were used as an index of the true speed of the approaching vehicle. The decibel meter was used to provide an index of ambient noise present during the experiment and sound level of the vehicle as it passed by the observer. The audibility of the approaching vehicle at the observation distance was also recorded. The traffic in the lane of interest ranged from 15 to 64 cars per hour. On the average, it was recorded, one observation was made every 2 minutes.

SUBJECTS

The subjects, 40 children aged 5 to 14, were divided by sex as given in Table 1. Local neighborhood children, familiar with the traffic in the immediate vicinity, were enlisted as subjects. Children outside the neighborhood and unfamiliar with the traffic situation were also used. Each child was paid $1 for participating in the experiment, which lasted from 4 to 8 hours. Subjects found the task interesting and challenging and were well motivated to participate in the experiment.

SOURCES OF VARIATION

The experimental design called for the control of age and sex differences by the selection procedure already defined. In addition, the effect of a third variable, observation distance, was included for experimental manipulation inasmuch as the sensory cues associated with any given vehicular speed vary considerably with the distance between the subject and the vehicle. Two distances, 250 and 500 ft, were chosen as reference points at which estimates of the oncoming car were to be made.

Age, sex, and observation distance were the variables chosen for experimental control. It is recognized in this naturalistic setting that other factors, not under control of the experimenter, influence judgment. Sensory characteristics associated with the approaching vehicles were thus recorded with each judgment. These characteristics were vehicle speed, type, size, color, and noise.

EXPERIMENTAL PROCEDURE

The experimental group consisted of three experimenters and a subject. After the subject was familiarized with the equipment and surroundings, the purpose of the experiment was explained. The subject's attention was directed toward the approaching traffic, and he was told to observe the vehicle until it crossed the black pneumatic tube across the road. At the point he was to judge the velocity as slow, medium, or fast. The distance of pneumatic tube was varied so that half of the subjects experienced the 500-ft observation distance first and half experienced the 250-ft observation distance first. A pilot study indicated that, although a velocity judgment rendered in miles per hour was stimulating to the older male subject, it made the older female subjects uncomfortable and was not understood by the younger subjects. It was therefore decided to convert all judgments to slow, medium, and fast. These were well understood by all age groups.

For each observation, the first experimenter recorded the velocity judgment and the true velocity of the approaching vehicle as indicated by radar. The second experimenter recorded the decibel level at the time the observation was made and at the time the vehicle crossed the observation point. He also recorded the ambient noise level at the outset of the experiment and the presence of masking noise at the time an observation was made. Masking noises were most likely those of other vehicles in the vicinity but were also due to airplanes overhead, other people, and farm machinery. The third experimenter recorded the size, type, and color of the vehicle observed. A sample recording sheet and the descriptors with the associated codes are given in the Appendix of the original report (14).

During the course of the experiment, the first experimenter requested information from the subject pertinent to his familiarity with the present traffic situation, his ability to cross the street independent of adult assistance, and the cues he utilized in judging velocity. Candy and other entertainment were allowed the younger children.

Sixty observations per subject—30 at each distance—resulted in 2,400 observations for the experiment.

RESULTS AND DISCUSSION

The velocity distribution of the 2,400 vehicles observed in the experiment is shown in Figure 2. The road has a posted speed limit of 30 mph. Over 65 percent of the vehicles were traveling at velocities faster than the posted limit.

During the data collection phase, a definite tendency was noted for the subjects familiar with the traffic to categorize as slow vehicular velocities less than 31 mph, as medium velocities between 31 and 40 mph, and as fast velocities greater than 40 mph. Bivariate distributions—radar or actual velocity versus estimated velocity—shown in Figure 3 display graphically developmental, distance, and sex differences.

The main effects associated with the variables controlled by the experimenter (sex and distance) and two variables determined by the traffic mix (audibility and vehicular noise and vehicle size) are shown graphically in Figure 4. The z-scores for testing significance of differences between two non-independent proportions (6) along with a significance table for interpreting the score differences are given in Tables 2 and 3. In Table 2, the line marked fast gives the percentage of vehicles that were traveling over 40 mph correctly classified as fast by the subject, i. e., the correct responses in that interval divided by the number of events in that interval and multiplied by 100.

Obviously, females categorize fast vehicles correctly more often than do males (Fig. 4c). The difference here is rather large, 19 percent. On the other hand, the females categorized slow vehicles less correctly than the males. This difference, however, is on the order of 9 percent.

From Figure 4a it can be seen that the audibility of the vehicles makes a difference in terms of categorizing fast and slow vehicles. The audible or louder vehicles are more likely to be classified fast than are the inaudible or less noisy vehicles. Conversely, the inaudible vehicle is more likely to be classified as slow than the audible or noisier vehicle. The convergence of the fast, medium, and slow judgments toward a common point indicates that lack of auditory cues impairs discrimination.

Observation distance (Fig. 4b) also influences the velocity judgment. As would be expected, discrimination becomes more difficult the farther away the vehicle is from the observer. The percentage of both fast and slow vehicles correctly classified decreases as the observation distance increases. It should be noted that the percentage of medium-velocity vehicles correctly classified increases with observation distance. The reason for this is that, as the observation distance increases, the number of fast and slow judgments decreases; therefore, the frequency of correct medium responses in passing from audible to inaudible conditions (Fig. 4a) has to increase.

The size of the car also appears to exert an effect on the velocity judgment of the observer. Small and compact cars are more likely to be correctly classified as fast than are medium- and large-sized vehicles. Vehicular size does not seem to influence the medium and slow judgments significantly.

The developmental aspects of correct velocity classification of approaching vehicles are graphically shown in Figure 5. The surprising finding is that the percentage of fast vehicles correctly classified declines with age, contrary to what is expected. However, in support of the developmental hypothesis, the percentage of medium and slow vehicles correctly classified increases with age. When Figure 5 is examined, it should be noted that variations in percentage of correct responses about the straight lines are very marked, particularly for the fast category, thus indicating some capricious effects. Additionally, it should be kept in mind during the discussion and interpretation that, though the mean velocity of the vehicles was the same across all ages ($r = 0.01$), the standard deviation varied inversely with age ($\alpha > 0.005$). This indicates that the actual velocity range of the vehicles was smaller for the older subject, thus making the task more difficult for the older subject.

Given above are the minimum results associated with the three experimentally controlled variables and two factors determined by the traffic mix. Further analysis of traffic mix factors such as vehicle color and type plus the important interactions within and across the two types of factors will be reported in a separate paper.

Figure 1. Field site.

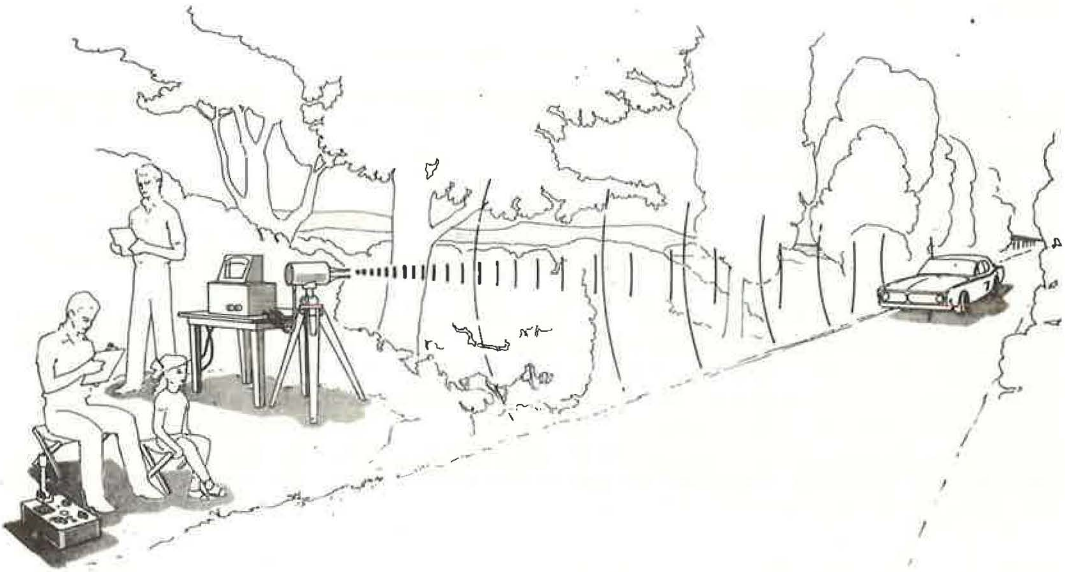


Table 1. Distribution of subjects by sex and age.

Sex	Age 5	6	7	8	9	10	11	12	13	14	Total
Male	2	2	2	2	2	2	2	2	2	2	20
Female	2	2	2	2	2	2	2	2	2	2	20
Total	4	4	4	4	4	4	4	4	4	4	40

Table 2. Percentage of correct velocity judgments.

Judgment	Male Versus Female	Audible Versus Inaudible	500 Versus 250 Ft	Small and Compact Versus Medium and Large
Fast	5.74	2.23	1.76	6.17
Medium	0.96	1.52	2.57	1.53
Slow	4.39	1.74	4.23	1.69

Table 3. z-scores at various levels of significance.

Test	Significance Level 0.10	0.05	0.01	0.001
One tail	1.25	1.64	2.33	3.09
Two tail	1.64	1.96	2.58	3.29

Figure 2. Velocity distribution of vehicles in sample.

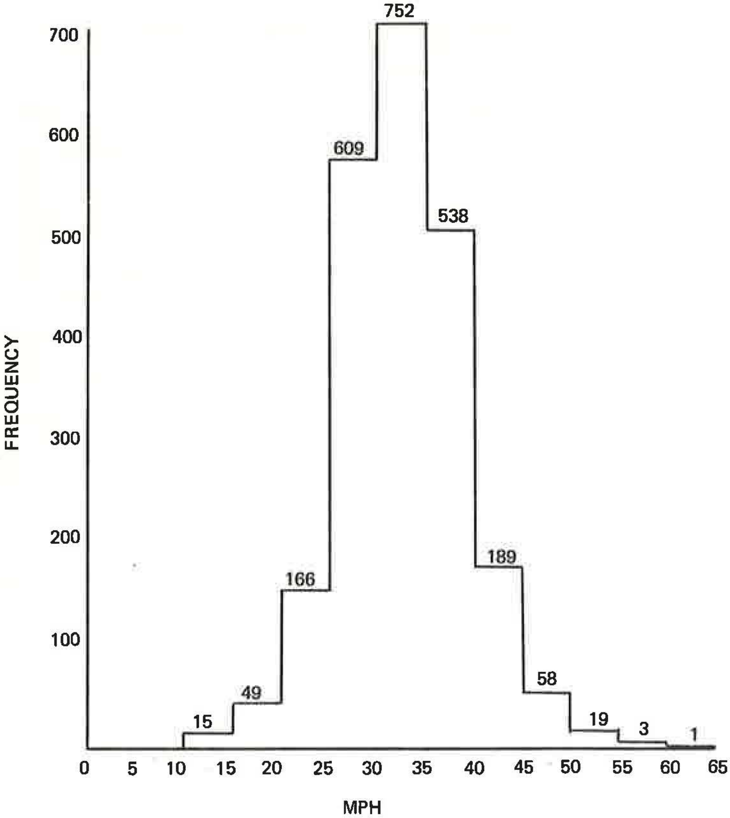


Figure 3. Sample bivariate distributions of radar velocity versus estimated velocity: (a) 5-year-old male at 250 ft; (b) 12-year-old male at 250 ft; (c) 9-year-old male at 500 ft; and (d) 14-year-old female at 500 ft.

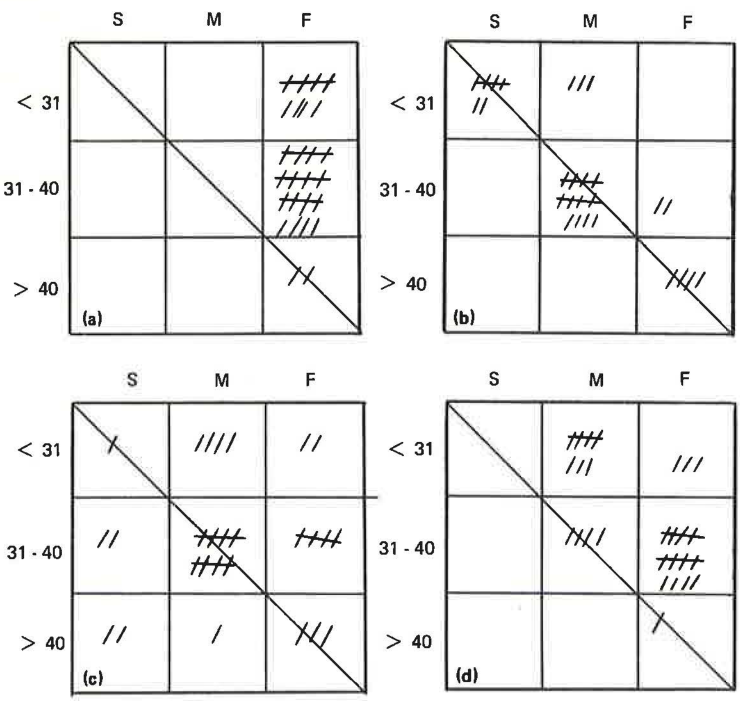


Figure 4. Percentage of correct velocity judgments versus (a) vehicular noise, (b) observation distance, (c) sex, and (d) vehicle size (S = small, C = compact, M = medium, L = large).

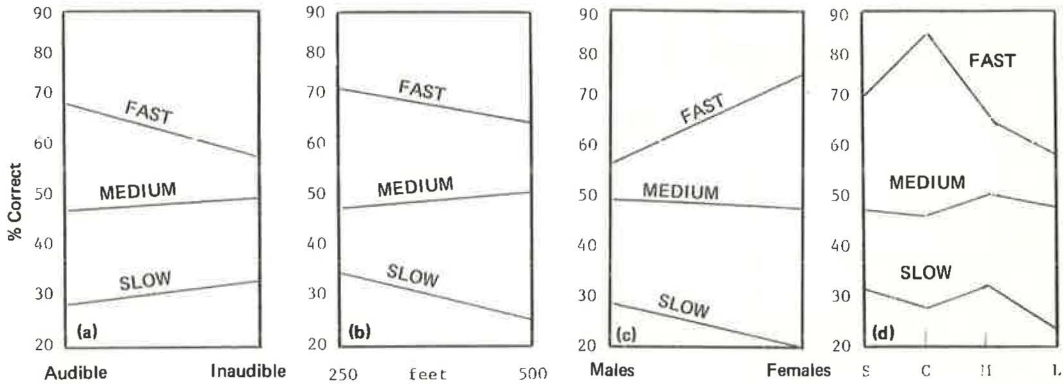
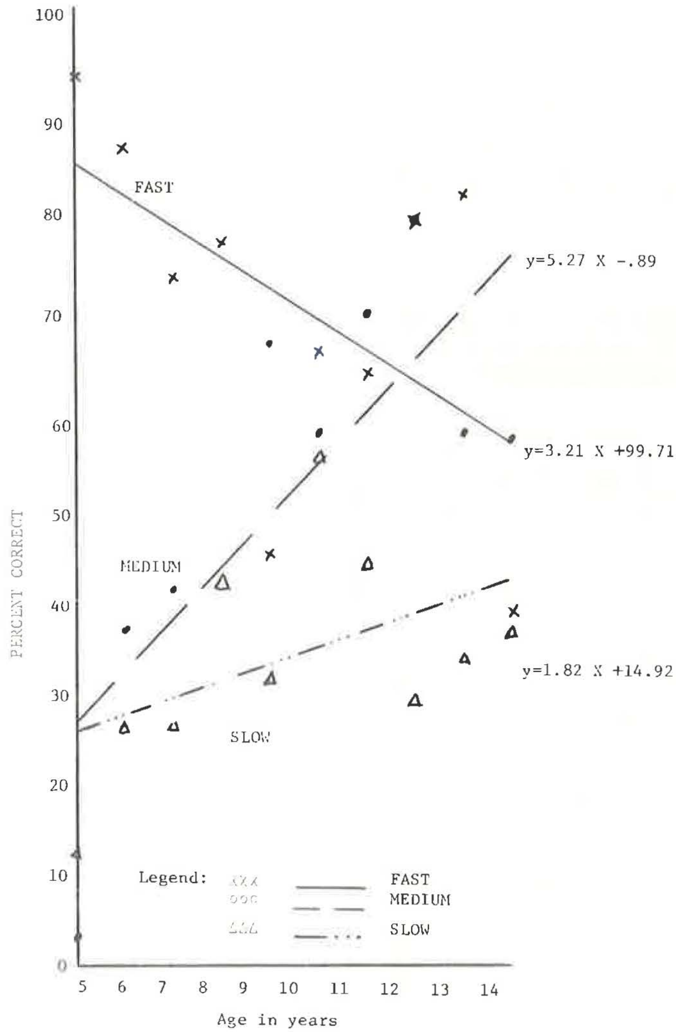


Figure 5. Percentage of vehicles correctly classified versus age of subject.



It is evident from Figure 4 that fast vehicles are more likely to be correctly identified than medium vehicles, and, in turn, more medium vehicles are correctly classified than slow vehicles. Data given in Table 4 point to the conclusion that this state of affairs is due not to the ease of classifying the faster vehicles but to the frequency with which slow and fast judgments are rendered. Relative to the actual velocity as measured by radar, slow judgments are made much less often than fast judgments. Therefore, it is to be expected on the basis of chance that fast vehicles will be more correctly classified than slow vehicles. Our method of categorizing actual car velocities thus results in the characterization of the sample as conservative or tending to overestimation.

The tendency toward overestimation and caution was quite pronounced with the older girls in the group. Comparison of 11- to 14-year olds across the sex dichotomy shows that the females rendered twice as many fast judgments as males but one-fourth as many slow judgments as the males. It is suggested then that the older females were more conservative and less likely to base the velocity judgment on actual sensory cues emanating from the vehicle. (Compare Figures 3c and 3d.) All errors of the 14-year-old female are on the side of conservatism, whereas the judgments of the 9-year-old male would as often as not lead to risky action. This sex-linked characteristic was also found in a velocity-sensing task in children by Uruno and Yoshibe (5). Working with 5- and 6-year-old kindergartners, they found the females to be more conservative. Our sample did not show this sex-associated characteristic at this early age. This may be due to cultural or procedural differences.

The ability to sense oncoming car velocity is definitely a developmental characteristic (Fig. 5). The correlations represented by the curves shown in Figure 5 are as follows: medium, significant beyond the 0.005 level; and fast and slow, significant beyond the 0.1 level. The percentage of both slow and medium vehicles correctly classified increases with age, the latter slowly and the former rapidly. However, the percentage of fast vehicles correctly classified is inversely related to age.

Although there is a great deal of variation, the linear trend is clear. The basis for this dangerous inversion is to be found in age and sex differences. Apparently the younger subjects were not responding to sensory cues present in the experiment. An overwhelming number of the judgments rendered by the 5-year olds were fast. The speculation is that these younger children were responding to parental dicta concerning the dangers of the road and that actual sensory cues were ignored. Instead, the youngest subjects found pleasure in finding cues, such as vehicle noise, corroborating the fast judgments. The frequency of slow, medium, and fast judgments are given in the Appendix of the original report (14) as are the percentages of slow, medium, and fast vehicles that were correctly classified. The younger children of both sexes and the older females by their more conservative judgment maximize the percentage of fast vehicles correctly classified and minimize the percentage of slow vehicles correctly classified. The older boys, on the other hand, attempting to utilize the visual and auditory cues to velocity, do not maximize any one judgment category and are more susceptible to miscues that may be associated with the stimulation emanating from the vehicle. (Whether this is associated with the overrepresentation of boys in the accident statistics is not known.) Furthermore, it stands to reason that though more of the judgments of the very young of both sexes and the older female will be wrong they will, in fact, be safer.

It is quite possible that the conservatism of the female is not semantic but perceptual. A study by DiPietro and King (4) on pedestrian gap acceptance found that females accept longer gaps in seconds than males but show no difference for the gaps accepted in feet. It seems, therefore, that the females judged the vehicles to be moving faster. It would be of interest to bring the question into the laboratory to determine whether the conservatism stems from perceptual rather than risk-taking factors.

The approaching vehicle emits physical signals that impinge as visual and auditory stimuli on the observer. The situation is quite similar to the judgment that a driver passing another car must make of a car approaching him in the opposite direction. Vertical judgments of velocity in this situation are difficult because the conditions of stimulation are unfavorable to the human. Mashhour (7) has calculated the stimulus

Table 4. Frequency and percentage of occurrence of velocity judgment versus actual velocity.

Radar Velocity (mph)	Estimated Velocity S	M	F	Total	Percentage of Grand Total
<31	248	398	165	811	34
31 to 40	106	646	503	1,255	52
>40	9	101	224	334	14
Total	363	1,145	892	2,400	
Percentage of grand total	15	48	37		100

Figure 6. Estimated velocity as a function of vehicle noise.

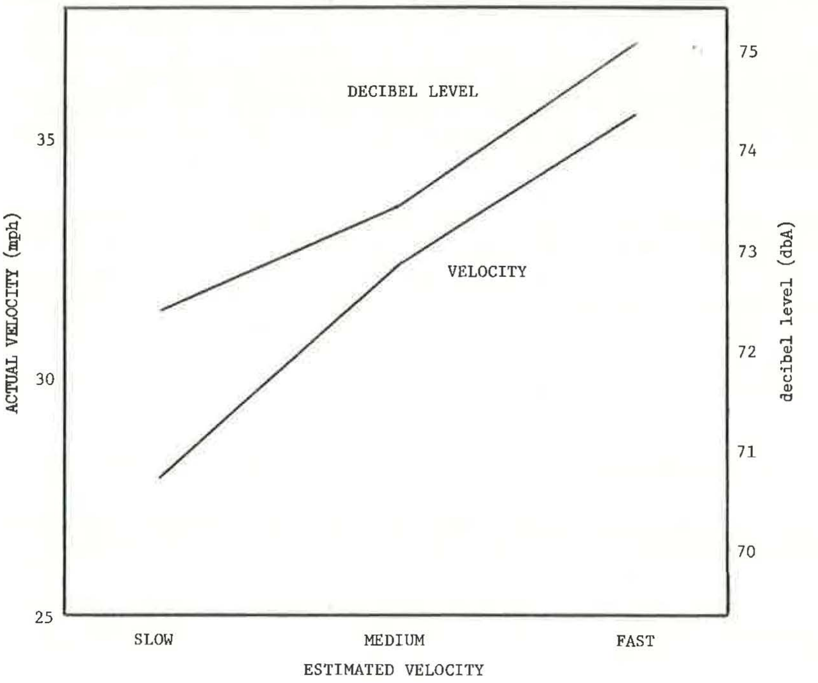


Table 5. Time gaps, in seconds, for two crossing distances.

Crossing Distance (ft)	Velocity (mph) 10	20	30	40	50	60
250	17.0	8.5	5.7	4.3	3.4	2.8
500	34.1	17.0	11.4	8.5	6.8	5.7

correlate (the angular velocity of the vehicle's image on the retina) of an oncoming car running at 60 km/hr (37 mph) at a 500-m distance to be about 1 min of arc per second, which lies below the absolute threshold of the adult. On the other hand, the same vehicle will have an angular velocity of 77 deg of arc per second when it is 10 m from the observation point (an increase of approximately 4,800 times). This type of visual velocity judgment, though difficult to make, is, in fact, made. For example, Crawford (8) has shown that the threshold interval accepted by a passing driver is modulated by oncoming car speed.

In the passing situation only visual cues are available for observation, whereas in the pedestrian case both visual and auditory cues may be available. In any case, two studies of adult pedestrian behavior (2, 3) indicate that the pedestrian demands not a distance gap but a time gap, so that the velocity of the approaching vehicle is evaluated in making the decision to cross or not to cross the street. Specifically, Moore (3) computes the equation $s = 45 + 2.9v$ as the distance allowed to the approaching vehicle. In this equation v is velocity of the approaching vehicle and indicates that the pedestrian requires a clearance of 45 ft plus the distance the approaching vehicle travels in 2.9 sec. Moore interprets the 2.9 sec as approximately the time necessary to reach a point on the road that is beyond the predicted track of the oncoming vehicle.

The above interpretation of adult pedestrians' gap acceptance clearly implies the ability to sense velocity. The children in this sample clearly demonstrated an ability to evaluate approaching vehicle velocity. However, it was also demonstrated that the validity of the perception is dependent not only on the organismic factors such as age and sex but also on such environmental conditions as distance to the vehicle and its size and noisiness.

In judging the velocity of one's own vehicle, it has been found that auditory cues result in faster judgments than visual cues (9). Figure 6 intends to show that, although the velocity judgment is influenced by actual velocity, it also is influenced by factors that are only casually correlated with actual velocity. The figure indicates that the noisiness of the vehicle is associated with its classification.

A correlational analysis has shown a strong association between the actual recorded velocity and the estimated velocity, as should be expected. In addition, there is a strong association between the estimated velocity and the decibel level of the approaching vehicle. Logic suggests, then, that when the decibel level is not associated with the real velocity the estimated velocity will be in error. The addition of an auditory cue that may or may not be indicative of true speed is, then, an additional hazard present for the pedestrian but not present for the passing driver. A dangerous vehicle in terms of this analysis, then, is a fast vehicle that is not generating noise to warn the pedestrian.

Table 5 gives the time gaps for distances of 250 and 500 ft, not unreasonable distance gaps, for car speeds ranging from 10 to 60 mph. As can be seen, the time available to cross the street shrinks considerably as velocity increases.

Judgment errors can arise from several sources. As has been pointed out, vehicle noise may be actually inversely related to the actual velocity, whereas the subject tends to consistently rate louder vehicles as faster. Furthermore, the visual cue of size, though apparently unrelated to vehicle speed, is related to estimated speed. It is expected that, of two objects moving at the same velocity, the smaller one will appear to be moving faster (10). This refinement of the data plus the effect of vehicle type and vehicle color awaits further computer analysis. It is hoped not only that the dimensions of the stimulus, other than actual velocity, that influence velocity judgment will be demonstrated but that particularly dangerous combinations will be pinpointed by the regression analysis. From this the countermeasures will be evident. For those interested in this approach, it is mentioned that a technique for calculating pedestrian injuries and deaths and, therefore, the benefit of countermeasures is available (11).

It should be noted that other factors, such as environmental overcrowding and family instability (12), play a role in the road accidents of children. A problem for research to attack would be to attempt to determine whether other factors operate by producing impulsive, maladaptive behavior and inattentiveness or by adversely affecting the velocity judgment, which, in turn, adversely affects the decision to act or refrain from acting.

From a practical point of view, it would be desirable to determine whether children's approach to traffic can be improved by training in judging the speed and distance of approaching cars.

Review of the gap-acceptance literature (13) shows consensus in the underestimation of high-speed gap times. In one study, Moore (3) asked subjects to indicate, by pushing a button, the last instant at which they would cross the street with a vehicle approaching. The computed number of collisions under these circumstances, which assumed a constant rate of walking, is very high and at odds with the fact that pedestrians are injured roughly 1 in 1 million times while crossing the road. However, these computations do not allow for vehicle-pedestrian interactions that initiate evasive maneuvers by adjusting course and velocity.

CONCLUSION

The role of several organismic and environmental variables on the perception of approaching car velocity by elementary school age children was examined. In particular it was shown that age and sex as well as size, noisiness, and speed of the oncoming vehicle influence the judgment of velocity. It is hoped that the information presented in this paper may serve as a base for implementing appropriate countermeasures.

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