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EFFECTS OF BICYCLE LANES
ON TRAFFIC FLOW

Robert J. Jilla

PURDUE UNIVERSITY
INDIANA STATE HIGHWAY COMMISSION

Final Report
EFFECTS OF BICYCLE LANES ON TRAFFIC FLOW

by

Robert J. Jilla
Graduate Assistant in Research

Joint Highway Research Project

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Final Report

EFFECTS OF BICYCLE LANES ON TRAFFIC FLOW

TO: J. F. McLaughlin, Director
Joint Highway Research Project

June 19, 1974

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

Project: C-36-17LL

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Attached is a Final Report on a JHRP Research Study titled "Effects of Bicycle Lanes on Traffic Flow". The research was performed and the report written by Mr. Robert J. Jilla, Graduate Assistant in Research on our staff. The research was directed by Professor H. L. Michael and R. C. Loutzenheiser.

The objectives of this research were to evaluate the effect of marked bicycle lanes on the traffic flow on an arterial street. The findings of the study indicate that bicycles and bicycle lanes result in a small decrease of speed of traffic and a slight shift away from the curb of the transverse placement of vehicles. Bicycle lanes when placed on streets without parking and of adequate width appear to have little detrimental effect on traffic flow and may serve the beneficial purpose of providing better separation between vehicles and bicycles.

The report includes suggested street characteristics desirable for bicycle lanes and suggested widths of such bicycle lanes on various width streets. These findings should be useful to the engineer in this developing area of much interest.

Respectfully submitted,

Harold L. Michael
Associate Director

HLM:ms

cc: W. L. Dolch
R. L. Eskew
G. D. Gibson
W. H. Goetz
M. J. Gutzwiller
G. K. Hallock

M. L. Hayes
C. W. Lovell
G. W. Marks
R. F. Marsh
R. D. Miles
G. T. Satterly

C. F. Scholer
M. B. Scott
J. A. Spooner
H. R. J. Walsh
E. J. Yoder
S. R. Yoder

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ABSTRACT

Jilla, Robert J. M.S.C.E., Purdue University, May 1974.
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In recent years, the bicycle has again become a convenient and useful form of transportation in the United States. Although incapable of traveling at fast speeds and still very much dependent on the environment, bicycles are now being purchased at a phenomenal rate. It is estimated that, by 1975, over 11 million bicycles will be sold annually. This rapid increase of bicycles requires a factual evaluation of the effects on traffic flow and safety. To date no research has been done on motor vehicle speed and displacement when both bicycles and motor vehicles share a common roadway. Research studies have concentrated on the bicycle and the cyclist. Some "standards" have been established for the construction of bikeways.

The objective of this study was to quantitatively measure vehicular speed and displacement on streets where bicycle lanes exist. Thus, four study sites were established in the community of West Lafayette. The research was conducted over a period of five months and was divided into 3 phases (light, medium, and heavy bicycle flow rates). The 20-pen event recorder was used to measure motor vehicle speeds, while displacements were visually observed with the aid of tape placed on the roadway.

It was found from the study that on narrow roads both a significant reduction of speed and displacement occurred when a motorist encountered a bicyclist in the traffic stream. For wide roads with higher speeds, the speed

reduction still was evident although displacements were not as significant since the motorist had some added "psychological comfort" of the wide road. It was also determined from the study that motor vehicles in the opposing traffic lane had less effect on the motorist than did a bicyclist. The research showed that a peak-hour does exist for bicycles. It was evident from the study that the bicycle is being used as an alternative mode of transportation by both students on the Purdue campus and residents of the community. It is recommended that similar studies be undertaken to establish some additional criteria for bicycle lane placement and to seek ways of providing additional protection to the bicyclist.

CHAPTER I. INTRODUCTION

Since the early 1950's the annual sale of bicycles has more than doubled in the United States. Over 80 million riders now travel on our streets and highways. In contrast to the children bicyclists of the past, this recent influx consists mostly of adults. Bicycle sales to adults have boomed during the past four years. In 1969, it was estimated that only 12 percent of the total bicycle sales in the United States were to adults; in 1971 this figure more than doubled to 25 percent (6)*. Heavy concentrations of bicycles are now found at universities, rest homes, and recreation areas. Some groups have found bicycles to be an inexpensive mode of travel.

Almost overnight our communities have been presented with the problems and benefits of the bicycle boom. Most of the existing bikeways are far from ideal. They lack adequate protective controls and often lack adequate sign controls.

Many motorists apparently do not recognize the bicycle as a desirable form of transportation. An estimated 5,300 bicycle riders will be killed and more than 40,000 injured in bicycle-automobile accidents this year alone in the United States. The American Automobile Association (22) counted 3600 urban deaths for bicyclists in 1971, a 71 percent increase over the average of the preceding three years. Three of every four killed were between the age of five and fourteen. For every traffic death there were 10 injuries.

*Numbers in parentheses refer to entries in the List of References.

It would appear that one way to decrease the number of bicycle accidents is to provide young cyclists with adequate bicycle safety training. Because various community groups frequently call upon police officers to give speeches or to develop programs about bicycle and traffic safety, the police officer has a major role in developing and presenting these training programs. Good safety programs of this type, however, are not easy to develop. Some authorities feel that elementary school is the proper place to provide children with bicycle safety training. The National Safety Council has developed a packaged, 8-hour program on bicycle safety instruction for children at the elementary school level. The "All About Bikes" program (6) emphasizes the child's decision making capacity as a cyclist rather than laying down static rules. Certain activities and projects relate bicycle safety theory to everyday cycling practice. A systematic bicycle safety program is basic to developing safe driving habits among future motorists. At the present time, for all practical purposes, efforts to develop safe automobile driving practices do not begin until a youth is old enough to become a licensed driver. Responsible attitudes toward risk taking and highway aggressiveness, however, can be effectively communicated to youngsters during early safety training. Attitudes toward highway rules, as well as specific skills in recognizing and responding to traffic situations, may be more deeply ingrained when they are developed during early training than when they are deferred until the high school years.

While safety is a primary concern of today's bicyclists, there is an additional important problem - security. The bicycle theft rate has sky-rocketed to phenomenal proportions. Bicycle theft is no longer a petty crime. The expensive metals used to reduce the weight of bicycles, the complex gearing mechanisms, and the numerous accessories that are

commonly used have greatly increased the average value of a bicycle. A light weight bicycle equipped with a ten-speed gear system can easily cost over \$120. Some models used for touring cost around \$300. Newly developed models are being sold for thousands of dollars. Stealing property of this value is considered a grand larceny offense. In San Francisco, California, approximately 2,400 bicycles were reported stolen during 1971, representing losses estimated at \$200,000 (23). Of these, 300 bicycles were recovered, but less than 50 percent could be traced to the original owner. In Chicago during 1970, approximately 12,800 thefts were reported. Recoveries amounted to 1,200 (8).

A study conducted by the Stanford Research Institute (14) revealed that the largest single application of energy is fuels for transportation (25 percent of total U.S. energy consumption). Other major energy consumption figures include: space heating in residences and commercial buildings (19 percent), industrial applications of energy in the form of process steam (17 percent), direct heat (11 percent), and electric drive (8 percent). The long-predicted energy crisis was suddenly painfully present during this winter all across America. Perhaps if the bicycle was used for short trips, less fuel would be used and depletion of the world's natural resources would slow down. In 1971, 10.1 million automobiles were sold in the United States (6). However, there were 10.8 million bicycles sold in that same year (6). This marked the first time bicycles outsold automobiles in recent history.

Objectives

The rapid increase of bicycle ridership in the cities and the increasing demands for marking separate lanes for bicycles in the street requires factual evaluation of the effects such action has on traffic flow and safety. This

report is a study and evaluation of the effects of the bicycle lane on the driver and his vehicle in the traffic stream. To date, research on bicycles has concentrated on the bicycle and the cyclist himself. Some "standards" have been established for construction of bicycle paths. Factors such as street capacity, signs and markings for bikeways, approach speed of vehicles, and maintenance of bikeways after installation have been neglected in bicycle studies. This report provides information on the effects of vehicular speeds and displacements on streets with existing bicycle lanes. The characteristics of bicycles and motor vehicles when in conflict with each other are evaluated, and the results provide criteria for bicycle lane design and bicycle lane placement in any city.

CHAPTER II. LITERATURE REVIEW

Definitions and Nomenclature

The boom in bicycling has been a recent development, and the associated nomenclature is recent enough to create communication difficulties. In an attempt to standardize some of the terminology, bikeways will be sub-divided into four categories. The emphasis of this report will fall on the second category of bikeways mentioned herein, namely the bicycle lane.

Bicycle

The word "bicycle" means every device propelled by human power upon which any person may ride, having two tandem wheels, either of which is more than fourteen inches in diameter. Those with wheel diameters of fourteen inches or less as well as the three wheeled non-motorized tricycle intended for use by young children are not included in the bicycle definition in this study.

Bikeway Network

A network of integrated bicycle and foot paths not necessarily contiguous, where demand for these facilities exists or is anticipated to exist in the future.

Bikeway

The term defines all facilities that explicitly provide for bicycle travel. Appendix B illustrates the bikeway facilities provided in each state. Bikeways include the following:

Bicycle Path

A completely separated right-of-way designed for the use of bicycles as illustrated in Figure 1. Crossflows by vehicular and pedestrian traffic are minimized. Pedestrian, but not vehicular, use of the path is normally allowed.

Bicycle Lane

A restricted right-of-way that utilizes city streets, secondary roads, and other existing facilities and is appropriately designated by signs, lane markings and/or physical barriers such as guard rails, special fencing, curbing, or parked vehicles (Figure 2).

Bicycle Route

A shared right-of-way (Figure 3) designated as such by signs placed on posts or stencilled on the roadway. No provisions are made for physical or marked separation from vehicular or pedestrian traffic.

Bicycle Corridor

A temporary measure that utilizes existing sidewalks, malls, plazas, or other areas where the right-of-way is shared with pedestrians (Figure 4).

Guidelines for Bikeway Design Selection

The decision to develop an "exclusive" bicycle path can cost well over ten times the cost of a lane or route. On the other hand, the availability of a physical resource such as an irrigation canal bank or an abandoned railroad bed might invite the construction of a separate and expensive bicycle path even though the path's course might not be coordinated to normal bicycle travel patterns. Safety to life and property is a key issue when determining bikeway

FIGURE 1. BICYCLE PATH

FIGURE 2. BICYCLE LANE

FIGURE 3. BICYCLE ROUTE

FIGURE 4. BICYCLE CORRIDOR

type, location and on-site design for accommodating bicyclists' freedom from potential conflict and their convenient accessibility.

The factors to be evaluated include motor traffic volume and speed, pavement width and right-of-way availability, abutting land use, and grade profile. Thorough analysis of all characteristics of specific road sections serves to rationally apply the optimum bikeway type where each would best serve.

Interrelated effects are so variable as to often alter bikeway design decisions, thus pre-empting any possibility of projecting a fixed standard of measure. Options available to more effectively shield bicyclists from potential motor vehicular danger should be thoroughly understood for appropriate and wise planning. Ultimate disposition of bikeway type and design should harmonize with individual site considerations and be responsive to localized conditions.

The bicycle lane is also believed by many to be a safe type of bikeway. Although not separating the bicyclist from motor vehicle traffic as completely as the bicycle path, the bicycle lane can afford some means of physical as well as "psychological" protection from the motorist. The education of the bicyclist as well as the motorist in regard to the use of the bicycle lane is necessary for its safe utilization. Developing a bicycle lane on a roadway requires consideration of many factors including motor vehicle traffic volume, parking density and turnover rate, traffic speed and anticipated bicycle volume.

Bicycle lanes can be designed to incorporate one lane (one way) on one or both sides of the roadway or two lanes (one or two ways) on one or both sides of the roadway. One lane serving one and two way traffic may be feasible in some instances where space is extremely limited. Although three and four lane bikeways exist in parts of Europe and Asia,

their application in the United States is questionable with present anticipated demand levels.

Separation of Bicycle Lane from Traffic Lane

Some authorities feel that the bicycle lane should be physically separated from the motor vehicle to the greatest extent practicable. Often, this will not prove feasible and a painted line on the roadway will provide the only means of "protection". Physical barriers for bicycle lanes more clearly define the bicycle lane in addition to minimizing vehicle encroachment. Many claim such barriers make bicycle lanes inherently safer where the right-of-way is being shared with a high volume of motor vehicle traffic.

Several methods are used to separate the bicycle lane from the traffic lane.

Painted Line

The painted line provides only psychological protection from the motorist, but hopefully serves as an admonishment to the motorist to stay clear of "bicyclist territory". The painted line can be used in combination with other methods.

Coloration of Bicycle Lane Pavement

Again, only a psychological barrier to encroachment by the motor vehicle, colored surfacing material can be used to clearly delineate the lane and in so doing provide a constant reminder to the motorist of the potential presence of bicycle traffic. The colored surfaced lane can also be used in conjunction with other methods.

Raised Pavement Markers

Raised pavement markers often referred to as "rumble bumps" or "dots" can be used to audibly identify the bicycle

lane boundary. Raised pavement markers can be used with a combination of other methods and can be reflectorized for visual discernment at night. However, problems occur when snow must be removed from the road.

Parked Vehicle

Parked motor vehicles can provide an excellent physical barrier between the bicycle lane and the outside traffic lane. The bicycle lane, however, should be wide enough to provide clearance for opening car doors.

Grade Separation

Grade separation provides the best separation from motor vehicles. The separation must be enough to significantly decrease the chance of motor vehicle encroachment onto the bikeway.

Bikeway Signing and Marking

Adequate signing is an important requirement of bikeway design. Signs as well as roadway markings must be used to ensure safe bikeway operation. Proper signing will help to (1) warn bicyclists of hazardous conditions, (2) establish the right-of-way, (3) exclude motor vehicles and/or pedestrians from the bikeway, and (4) warn motorists and pedestrians of the presence of bicycle traffic.

Bikeway signs should be standardized to provide universal comprehension and understanding by bicyclists and motorists alike. Newcomers to a given area should not be confused by an array of bikeway signs bearing strange and different symbols and messages. More specifically, all motorists and bicyclists should be informed directly as to bikeway type for thoroughly applying proper respect and use.

Sign readers are informed about what they are approaching and generally what may be expected, so as to enable prompt, adequate review of anticipated choices for maximum safety to life and property. As four types of bikeways are defined, with varying levels of safety attributed to them, it is incumbent upon bicyclists and motorists alike to be aware of each other.

Sign Types

The Manual on Uniform Traffic Control Devices recommends three major bikeway signs. These signs are shown in Figure 5.

Bike Route Sign - This sign measures 24 by 18 inches. The sign is green in color and contains a white message consisting of a bicycle symbol and the words "Bike Route" in 3 inch letters. The purpose of the sign is to guide bicyclists along the course of a bikeway. To indicate an impending change of course, a supplementary sign with a directional arrow may be placed below the Bike Route sign. This 24 by 6 inch rectangular sign contains a white arrow and border on a green background.

Bike Xing Sign - This sign consists of a black bicycle symbol on a yellow background. The sign is diamond shaped and measures 30 by 30 inches. Below the diamond shaped portion a 24 by 18 inch rectangular yellow sign bears the message "Bike Xing" in 6 inch black letters. The message is bordered in black and is reflectorized for effective night use. The purpose of the Bike Xing sign is to warn motorists that a bikeway will cross the roadway ahead.

No Bicycles Sign - The No Bicycles sign measuring 24 by 42 inches contains a black bicycle symbol encircled in red. A red diagonal line bisects both the circle and bicycle symbol to emphasize the prohibitive nature of the sign. Beneath this symbol are the words No Bicycles in black

FIGURE 5. BIKEWAY SIGNS

letters. Both signs have a black border on a white background.

Additional Signs

In addition to the three signs discussed above, the Manual on Uniform Traffic Control Devices recommends additional restrictive signs. These signs are designed to regulate traffic which may or may not enter a particular right-of-way. These signs carry a choice of the following messages:

1. Pedestrians and Bicycles Prohibited
2. Pedestrians Bicycles Motor-Driven Cycles Prohibited

There are several other standard roadway signs authorized in the Manual on Uniform Traffic Control Devices which may be relevant for particular situations. These signs carry the following messages:

1. Yield Ahead
2. Yield
3. Stop Ahead
4. Stop
5. Winding Road
6. Curve
7. Bump Ahead

Sign Location

Because of the absence of motor vehicles, signs may be placed closer to the edge of the bicycle path than to either the bicycle lane or bicycle route. This is advantageous as it is made more visible to the bicyclist. Lateral placement from the bicycle path should be approximately two feet. Vertical clearance from the ground to the base of the sign should be approximately seven feet to avoid pedestrian conflict with the sign.

Positioning of Warning Signs. For bicycle lanes and bicycle routes and for areas where bicycle paths are interrupted by cross traffic lanes, warning signs should be provided for both bicyclist and motorists. Warning signs for motorists should conform to standard roadway practices. Warning signs pertaining solely to the bicyclist should be positioned according to the existing requirements of the situation.

Intersection Signs. In urban areas it is recommended that the Bike Route sign be located at intersections involving bikeways. At a relatively minor intersection with no obstructions to vision present, the sign can be placed at the far side of the intersection. When bikeways enter major intersections or intersections with a restricted view, Bike Route signs are recommended at both the near and far sides of the intersections. The Bike Xing sign is mandatory at all intersections at which a bikeway crosses another right-of-way. In urban areas it is suggested that the Bike Xing sign be located one-half block prior to the intersection.

Sign Spacing. Recommended spacing between signs should be in accordance with the Manual on Uniform Traffic Control Devices. Sign spacing is normally determined in units of time depending upon expected vehicle approach speed. Since bicycle speeds are considerably less than motor vehicle speeds, bikeway sign spacing should be more frequent than the spacing for motor vehicle signs. It is suggested practice to place two Bike Route signs per block of bicycle lane. For bicycle paths, sign spacing can be less frequent.

Stencilled Pavement Messages

The use of symbolic pavement stencils for bicycle paths and bicycle lanes is highly recommended. The stencilled message used most frequently in this country is the standard Bike Route message. This stencil measures 24 by 18 inches.

Because of its relatively small size it is recommended for use only where it is not intended to warn motorists of the presence of bicyclists. If warning to the motorist is intended, the stencilled message should be as large as possible and contain a minimum number of characters. Pavement stencils bearing the message Bike Only may be used to caution motorists from entering the bicycle lane, particularly at locations where motorists might not be aware of the existence of the lane. A complete summary of bikeway signing and marking recommendations by one source for the bicycle path, bicycle lane, and bicycle route is given in Table 1.

Bikeway Design Criteria

Bikeway Design Speed

Although bicycles can be pedaled at speeds in excess of 30 mph, most bicyclists travel at significantly lower speeds. The average bicycle speed is around 10 mph. This figure is generally accepted as a conservative value for bikeway design purposes. Experimentation conducted in Davis, California showed average bicyclist velocity to be between 10-11 mph. In the event bicycle touring routes are developed apart from existing roads, a higher design speed should be used, perhaps as high as 25 mph. Similarly, downhill curves should be adjusted to reflect probable speeds that will be attained.

Bikeway Capacity

Bikeway capacity requirements, estimated in number of bicycles per hour, appear to be of relatively insignificant importance in the United States. Available literature indicates that even one lane bikeways will be sufficient to handle all but the most extreme future demands. For example, the estimated bikeway capacity reported from a German source

TABLE 1
SUMMARY OF BIKEWAY SIGNING RECOMMENDATIONS

	<u>Bike Path</u>	<u>Bike Lane</u>	<u>Bike Route</u>
Lateral Placement	1-3 ft. from edge	Roadway Criteria	Roadway Criteria
Vertical Placement	7 ft.	7 ft.	7 ft.
Positioning before hazards	50 ft.	not less than 50 ft.	not less than 50 ft.
Sign Message	Standard	Standard	Standard
Sign Illumination	if consid- erable night usage, must be illuminated	Roadway Criteria	Roadway Criteria
Sign Size:			
a. Route	Standard	Standard	Standard
b. Warning	May be less than standard	Standard	Standard
Overhead Signs:			
Clearance	8.2 ft.	8.2 ft.	Not recommended
Stencilled Warnings			
Size and Use:			
a. BIKE PATH	24" x 18"	Recommend-	Recommended
BIKE LANE		ed for side-	for sidewalk
BIKE ROUTE		walk use	use only
		only (24"	(24" x 18")
		x 18")	
b. Bicycle Sym- bol	Optional	3.5 x 7.0'	3.5 x 7.0'
c. BIKEWAY	Size to be determined	Size to be determined	Size to be determined
d. BIKE ONLY	6.0 x 31.0' (Total)	6.0 x 31.0' (Total)	-

Source: University of California at Los Angeles, Bikeway Planning Criteria and Guidelines, Institute of Transportation and Traffic Engineering. April, 1972.

allows for a total of 1,500 bicycles per hour on a two way, two lane bikeway. That amounts to one bike passing a given point every 2.4 seconds!

Bicycle and Bicyclist Dimensions

The following are considered average dimensions for the bicycle and bicyclist:

Handle Bar Width	1.96 ft.
Cycle Length	5.75 ft.
Pedal Clearance	0.50 ft.
Vertical Space Occupied by Bicycle and Bicyclist	7.40 ft.

Bikeway Width and Clearance

Since the cost of providing bikeways varies with the width, it is important to determine the minimum width necessary to accommodate the bicyclist. The proper lateral clearance to obstructions and other hazards must be provided. The recommended minimum width for a one-lane bikeway is 3.2 ft. This figure is based upon a 10 mph design speed. It should be kept in mind that the 3.2 foot width cited above is a minimum effective width. Choice as to what width specification is to be used depends on many factors. For example, if available space is no factor, a more liberal standard should be adopted. On the other hand, if available space is a problem and the anticipated use of the bikeway is not excessive, the conservative minimum standard might be in order.

Should a bicycle lane be located adjacent to a parking lane, additional clearance should be allowed for dynamic obstructions such as open car doors. Two feet is recommended as sufficient additional clearance. Moreover, if the bicycle lane is in close proximity to the motor vehicle traffic lane, additional clearance may be required if a physical barrier is not provided.

Grade

Although acceptable bikeway grades and the length of such grades depend to a great measure on the characteristics of the individual bicyclist and his equipment, the wind velocity, air density, bikeway surface and other factors, most literature recommends that bikeway gradients exceed no more than 5% except for very short distances. For the modern bicycle equipped with gear changing mechanisms, more severe grades can be negotiated. The bicyclist merely continues pedaling at a given rate of revolutions per minute and down shifts until he reaches a gear which enables him to easily climb the grade. However, for the middle-weight bicycle without gear shifting capabilities or with only two or three gear ratios to select from, long uphill grades should be held to a minimum.

Radius of Curvature

In planning for bicycle paths, radii of curvature consistent with the design speed of the path must be established. Radius of curvature is generally of no concern in regard to bikeways developed on existing road alignments since the existing road design should be more than adequate for bicycles traveling at reasonable speeds. Care must be taken, however, to avoid sharp angles and short radius curves when constructing bicycle paths, particularly at the bottom of a long negative grade where the velocity of a descending bicycle can be quite high. Radius of curvature, therefore, should be directly related to the anticipated operating speed.

Drainage

Bikeway drainage facilities should be designed to prevent washouts and to avoid ponding. It is recommended that a $1/4$ to $3/8$ inch per foot slope be provided along the bikeway to

insure proper drainage. Overflow of surface water should not be allowed as the resultant deposit creates a dangerous hazard to the modern thin tired bicycle.

While existing drainage systems incorporated into road rights-of-way are normally sufficient for both bicycle lanes and bicycle routes, exposed drainage grates can be hazardous. The danger lies in the possibility of the bicycle wheel becoming entrapped in the exposed grate. Side-opening storm drains are recommended, where feasible. When surface grates only are feasible, their design should be zig-zag and perpendicular to bicycle movement. Cross strips may be attached to existing unsuitable grates. However, care must be taken when modifying drainage grates since their original design was probably based on hydrodynamic principles.

Bikeway Barriers

Barriers for bicycle lanes are considered by many to be important for the safety of bicyclists and they do more clearly delineate the restricted usage of street or other rights-of-way. Concrete median barriers appear to be ideal for new construction but may not be logical for existing streets due to their high cost. The Dowelled Curb (parking bumper) can be used as a bicycle lane barrier because it is easily installed and is comparatively inexpensive. The cost to construct this type of physical barrier for bicycle lanes, including signing, stencilling, and grate modification is estimated to be \$3,760 per mile.

Bikeway Lighting

Because bicycle headlights are for the most part a "to be seen" and not a "to see with" accessory, bikeways for night operations must be adequately lighted. Bikeways utilizing community roads and streets to be used at night should be located on well lighted roadways. Bicyclists

should be discouraged from operating at night on poorly illuminated bikeways. Specific illumination requirements research for bikeways is exceedingly rare. However, in most cases existing roadway lighting will be sufficient for bicycle lanes and routes. The lighting of bicycle paths must obviously be done on a selective basis, primarily in public parks and recreation areas. In these cases the lighting of bicycle paths will most probably be only part of a more extensive park facility lighting scheme.

Bicycle Parking Facilities

With the increased popularity of bicycling, the need for more and safer parking facilities has likewise increased. It is estimated that nearly one-half million bicycles are reported stolen annually. The conventional bicycle rack by itself has questionable value unless care is exercised in locating it. On occasion entire racks laden with locked bicycles have been taken by thieves. Among the several types of bicycle racks are the radial, V-bar, tree guard, concrete block, concrete depression and the cable. Costs of these apparatus range from \$15 to \$350 per unit, depending on type, material and capacity.

Equally important as the parking facility itself is its location. For obvious reasons bicycle parking facilities should be located where the possibility of theft is minimized. For example, automobile parking garages and lots normally contain some residual space that can be used to safely accommodate bicycles. Bicycle parking facilities in parks, playgrounds, shopping centers, universities, employment places and other civic areas should be located in open areas where people are moving about continually.

Bicycle Safety

The tremendous increase in bicycling in our country has brought greater attention to problems of bicycle safety and the need for more attention to cyclists. Many adults use bicycles today for transportation to and from work. Others use bicycles as a means of exercise. The great interest in ecology has led many adults as well as youngsters to ride bicycles to get closer to nature and enjoy the benefits of the natural environment.

Unfortunately, little information has been available regarding the full extent of bicycle accidents and trends of accidents in this country. A recent survey was conducted by the American Automobile Association (AAA) concerning the bicycle accident problem. A total of 1,723 cities responded, and most replies were fairly complete. The following is a summary of the AAA findings. It is to be emphasized that this report is for urban areas only. Many communities have failed to develop programs to control and facilitate bicycle traffic. Lack of bicycle programs, enforcement, bicycle lanes or routes represents a serious shortcoming in most urban areas.

The annual death toll from bicycle accidents is about 570 for all urban areas in the United States. It is estimated that about 43,000 bicyclists are injured annually.

Bicycle deaths are increasing rapidly. Comparing the year of 1971 with the average for the three previous years, bicycle deaths increased 54 percent and injuries were up 27 percent during the same period (Figure 6). Bicycle riders often precipitate accidents by unsafe actions such as failing to yield on entering a roadway and riding against the traffic stream.

Three out of every five cyclists killed in traffic were between the ages of 5 and 14. Bicyclists killed during the day are younger than those killed at night. Of those killed

FIGURE 6. TRENDS IN BICYCLE DEATHS AND INJURIES

during the day, 43.1 percent are under 10 years of age, while only 12.7 percent of those killed at night are in this age group (Figure 7).

The age distribution of bicyclists injured is somewhat similar to the age distribution for those killed. Seven out of ten are under 15 years of age. The age group of 10 to 14 accounts for 39.2 percent of those injured. Only 6.2 percent are 25 years of age and older (Figure 8).

Types of Bicycle Accidents

Colliding with a car accounted for 97.1 percent of all bicycle accidents. In 1.2 percent of the cases, the bicyclist collided with a fixed object; 0.5 percent collided with a pedestrian; and 0.4 percent collided with another bicycle. Other bicycle accidents involved 0.1 percent colliding with a train and 0.1 percent colliding with an animal.

"Failing to yield upon entering the roadway" was the most common action of bicyclists at the time of involvement in accidents. This action accounted for 30.0 percent of the accidents. Driving with traffic (18.5 percent) and driving against traffic (10.7 percent) were the next most common actions. Figure 9 shows additional actions of the bicyclist at the time of the accident.

Bicycle Registration and Licensing

"Registration" and "Licensing" are often used interchangeably when talking about permit or control systems. A license is a permission granted by a competent authority to engage in an activity otherwise unlawful. "Licensing" is the act of granting this permission. A register is a written record containing regular entries of items or details. "Registration" is the act or the fact of registering.

FIGURE 7. BICYCLISTS KILLED BY AGE GROUPS - DAY AND NIGHT - 1971

FIGURE 8. BICYCLISTS INJURED BY AGE GROUPS - 1971

FIGURE 9. ACTION OF THE BICYCLIST

In regard to bicycling, those interested in regulations of the bicycle for safety and other purposes are mainly concerned with the licensing aspect of the system. This is also true for those that are interested in utilizing the licensing system as a means of raising revenue. Those that are interested in reducing bicycle thefts are primarily concerned with the registration aspect. The registration and/or licensing of bicycles is not new to the nation. Many large cities and small towns have established ordinances and procedures for bicycle registration/licensing.

Registration and Licensing

The main purposes for the registration of bicycles are two-fold: to assist in their recovery if they are stolen, and to discourage bicycle thieves. The major purposes for the licensing of bicycles are to provide:

1. An opportunity for the inspection of bicycles for proper and safe condition.
2. A ready means of identification of the bicycle and/or owner. This can be especially important in the case of a severely injured child who in most cases has no other means of identification.
3. A source of revenue to operate the registration/licensing system.
4. A possible supplementary source of funds for bikeway system improvement.

At one time, individual community licensing/registration systems were practical. This is not true today. The high degree of mobility in our society and the increased interest in the bicycle as a source of easy dollars by the criminal makes community systems impractical. For example, bicycles stolen in one community that has such a system are simply disposed of in areas that have no system.

To illustrate the diversity of thought concerning bicycle licensing/registration systems throughout the country, some existing and proposed systems are briefly discussed below.

Chicago, Illinois

The City of Chicago employs a free but compulsory bicycle registration system. The registration may be accomplished by filing the registration form in the office of the commander of the respective police district in which the bicycle owner resides. In lieu of this procedure, the registration may be accomplished by sending the completed form through the mail.

The registration record contains the date of registration, the make, serial number, model and description of the bicycle, the name and residence address of the owner, the owner's age, the name and address of the person from whom purchased, and the date of purchase. The Chicago registration system, computerized for maximum efficiency, is administered by the Department of Streets and Sanitation. The system is also designed to provide a means for dispersal of bicycle safety information, traffic regulations and news about the latest developments in the Chicago Bikeway system to the City's estimated one million bicyclists.

Denver, Colorado

The Denver Police Department Bicycle Bureau has the responsibility for bicycle registration although the fire department has the inspection responsibility. After having the bicycle inspected at the fire station, the bicycle owner mails the completed inspection form with a \$1.00 registration fee to the Bicycle Bureau. A metal registration placard is sent to the owner by return mail. The registration is valid for one year. It has been estimated

that in Denver the estimated cost of issuing a bicycle license, including salaries, materials, postage, inspection, and equipment is approximately \$1.18 per bicycle. The Denver Bikeway Plan recommends the adoption of a Statewide registration system to promote better service, greater efficiency, registration compliance and benefits for the bicyclist.

Washington, D.C.

The bicycle licensing and registration system in Washington is essentially a voluntary one, although existing City statutes limit the operation of bicycles to only those operators that possess a valid bicycle registration card for that bicycle.

All persons engaged in the business of buying or selling new or used bicycles are required to make a weekly report to the Chief of Police listing: all sales or purchases for the week; the description of each bike sold or purchased; the serial number and registration number (if applicable), and the name and address of each person to or from whom a bicycle was sold or purchased.

Exemplary Bikeways

Both bicycle paths and lanes have been well utilized in Davis, California, a community bubbling with bicycle enthusiasm. This city of 24,000 has more than 18,000 bicycles, of which over 10,000 are on the University of California campus. In 1963 the townspeople realized that Davis had not only a large number of bicycles, but also all of the problems which might be expected from their unplanned usage. Along with this realization was an awareness that nearly all segments of the Davis community wanted to preserve the bicycle as a means of transportation. A combined effort by both the citizens of Davis and its city officials has

resulted in the construction of a network of bikeways. When completed in 1974, it will include twelve miles of bicycle corridors, five miles of which will be physically separated bicycle paths. The main impetus of this movement is concern for the safety of the bicyclists.

While the Davis bicycle system has been designed to augment the community's transportation system, other areas have expanded the recreational facilities for bicycle riders. Dade County, Florida, has established over 100 miles of bicycle routes which include some asphaltic recreational bicycle paths. Milwaukee, Wisconsin, has incorporated two recreational bicycle paths into its 64-mile circular bicycle route. Boulder, Colorado, constructed an asphalt bicycle path on the urban flood plain of a local creek. This one and one-half mile corridor provides the town's business district with both recreation and transportation. The Boulder bicycle path, with its paralleling green belt, is an excellent example of good flood plain management. Similar arterial urban paths can be established in communities where abandoned rights-of-way are strategically located.

CHAPTER III. WORK PLAN AND METHOD OF ANALYSIS

Description of Study Roadways

To analyze the interaction and effects of bicycles on motor vehicle traffic, four study sites were selected in the community of West Lafayette, Indiana (Figure 10). Each site had a designated right-of-way for bicycles by providing a bicycle lane adjacent to the through traffic lane as illustrated in Figure 11. Factors considered in the site selection process were roadway geometrics, average daily motor vehicle traffic, generated bicycle traffic, and speed of motor vehicle traffic. A description of each site follows.

Located adjacent to the Purdue University campus, Third Street serves as a collector and distributor road to both bicycle and motor vehicle traffic. The street (about 29 feet wide) is used to link the residence halls of the University with the main sector of the campus. A bicycle lane is located for each direction of flow and measures 3.67 feet in width. A motor vehicle traffic lane is 11 feet wide for each direction.

University Street is located on the campus of Purdue University. The street (about 35 feet wide) provides for one-way travel in the northbound direction. It serves as a distributor road for students to and from residence halls and other parts of the community. Bicyclists are provided with a 3.50 feet wide bicycle lane located on the right side of the roadway. Two twelve foot lanes are provided for motor vehicles, and parallel parking is permitted on the left side of the roadway.

FIGURE 10. CITY OF WEST LAFAYETTE

FIGURE II. TYPICAL BICYCLE LANE FOR STUDY

Grant Street is an arterial that serves both the campus and community. The morning peak-hour traffic consists mainly of the work trip to greater Lafayette and the student commuter to Purdue University. Bicycle traffic is generated on Grant Street (about 35 feet wide) because of commuter bicycling to work, college, or to West Lafayette High School which is located there. Bicycle lanes are provided in both directions. They are 3.83 feet wide. Lanes for through motor vehicle traffic measure 14 feet for each direction.

Salisbury Street is an arterial that serves as a major connecting road to the U.S. 52 by-pass located around Lafayette. An elementary school and a junior high school are located on Salisbury Street (about 40 feet wide). These schools with their activities create the need for bicycle lanes. Bicycle lanes measuring 4.33 feet in width are provided for each direction. Traffic lanes for motor vehicles are 15 feet in width with special turning lanes marked where needed.

Time Period

The study was conducted over a period of five months and was divided into three distinct phases. Phase I which extended from May 10, 1973 to June 26, 1973 was considered "before" data as 1972 bicycle pavement markings had worn off and bicycle traffic was minimal as the period was between the Spring and Summer Sessions at the University. Phase II lasted from June 27, 1973 until August 10, 1973. The pavement markings were repainted and University classes were in session. The final observation period, Phase III, was from late August, 1973 until October 1, 1973 while the Fall semester of the University was in session and public schools were open. Each of the four study sites was studied during each of the three phases. As motor vehicle

traffic during any hour of daytime was sufficient for study purposes, the volume of bicycle traffic was a major factor in the selection of the time periods for each phase of the study. In the design of the experiment each phase was to be characterized by progressively higher volumes of bicycles. Factors, such as the University being in session and activities of the public schools near the bicycle lanes, served as some criteria for establishing when significant numbers of bicycles would be present on the roadway for the purpose of this study.

Data Desired

To properly analyze the effects of bicyclists on motor vehicle traffic, three variables were chosen to be measured. They were motor vehicle speed, the lateral displacement of the motor vehicle, and the flow rates for bicycles and motor vehicles. To minimize interactions and the several possibilities of different occurrences relative to bicycles and motor vehicles, four cases or conditions were established. Case 1 consisted of a single motor vehicle using the street under normal operating conditions. Case 2 was defined to exist when two motor vehicles were traveling in opposing directions on a given section of roadway. Case 3 constituted a bicycle and a motor vehicle traveling in the same direction over a section of roadway under study. Case 4 consisted of a bicycle and motor vehicle traveling in the same direction and another motor vehicle traveling in an opposing direction. Two measures were obtained for each case - motor vehicle speed and displacement.

Equipment Available

Two types of equipment were available for the measurement of motor vehicle speed for this study. They were the radar meter and the 20-pen event recorder. Since information

on variables other than speed were desired, the 20-pen recorder was chosen for all speed measurements.

Two methods were also available to measure the displacement of motor vehicles. One method was that of using photography while the other method involved a visual observation of displacement with the aid of segmented tape applied at various cross-section intervals on the roadway. As the experiment was designed with displacement measurements to be recorded only to the nearest foot, the second method was chosen for this study.

Method of Data Collection

The 20-pen recorder records detailed event information on a moving chart which travels at a fixed speed. This chart then provides the time base from which to measure recorded events. Pens are actuated by impulses which can be created by motor vehicles traveling over pneumatic tubes. The events of a time period are then graphically recorded on a chart in the form of a continuous time diagram.

For this study, the equipment was set up in the following manner (Figure 12). Two pneumatic tubes were placed in the roadway 132 feet apart. After a gap of 100 feet, another set of pneumatic tubes was placed, again with 132 feet between tubes. It was in these two zones or "traps" that both motor vehicles and bicycles were isolated and measurements recorded. The pneumatic tubes were each connected to a terminal which received the impulses from motor vehicles passing over the tubes and transmitted them to the 20-pen recorder. Such an assembly was repeated for each pneumatic tube on the roadway. The 20-pen recorder obtained energy from a 12-volt battery and actuations were recorded on the continuously moving chart whenever a motor vehicle passed over a pneumatic tube.

FIGURE 12. TYPICAL SETUP OF EQUIPMENT

Displacement of the motor vehicle was the second variable measured. Strips of tape approximately one foot in length were placed on the roadway near each set of pneumatic tubes. The marking for the bicycle lane was used as the reference line from which all measurements were made. Strips of tape were placed at 2, 4, and 6 foot intervals from this line. It was possible to interpolate between tape strips and observe displacements to the nearest foot. When a motor vehicle passed through the zone under study, the distance of the right front tire of the vehicle from the bicycle lane marking was observed. It was this displacement that was recorded for each set of pneumatic tubes.

By manually connecting two control boxes with various combinations of buttons to the 20-pen recorder, the observed displacements of motor vehicles were recorded on the continuously moving chart. The combinations of buttons also allowed for other visual observations to be recorded and stored on the chart. These included bicycles (to obtain a volume count), motor vehicles in the opposing lane for case 2 analysis, and cancellations, if an unusual occurrence took place. During the study, a pneumatic tube was connected to a visual register counter to obtain hourly volumes of motor vehicles in the opposite direction of travel. Manually recorded data included bicycle wrong-way movements and pedestrians walking in the bicycle lane.

The chart of the 20-pen event recorder ran at 12 inches per minute. The normal length of one chart ran for 110 minutes.

Trial Run

Prior to any collection of data, a trial run was held at the University Street site. The equipment was set up and several speeds and displacements were recorded. The

chart was taken back to the laboratory and the speeds calculated and events noted. After briefly analyzing both the speed and displacement data, it was agreed that the data could logically be collected in this manner. Thus, the experiment proceeded and data was collected at all four sites at least once during each phase of the study.

Statistical Analysis

Prior to collecting data, it was determined approximately how many observations would be needed to provide the desired degree of accuracy. From the review of the literature, it was noted that $\alpha = 0.10$ was a common value for many motor vehicle speed and displacement studies. Therefore, a minimum sample size, n , to provide an estimate of $\bar{X}$ differing from μ by at most 1 mph was calculated from the following formula:

$$n = \left(\frac{z_{\alpha/2} \sigma}{e} \right)^2 \quad (1)$$

where:

$$z_{\alpha/2} = 1.645 \quad (\alpha = 0.10)$$

σ = estimated standard deviation

e = estimated error

Assuming $\sigma = 5$ mph and $e = 1$ mph, the minimum sample size for statistical significance was about 68.

After the data for each phase had been collected, it was then necessary to classify each motor vehicle speed and displacement into one of the four cases. Each case was analyzed separately as was each speed zone or "trap" of each case. Once the samples were obtained, the mean motor vehicle speeds and the mean displacements were calculated.

The degree of dispersion of the motor vehicle speeds and displacements was measured in terms of a standard value. This standard value, known as the standard deviation, was computed for each sample of size n for all cases.

Confidence intervals for μ were established ($\alpha = 0.10$) for all cases using the formula

$$\bar{X} - t_{\alpha/2} \frac{S}{\sqrt{n}} < \mu < \bar{X} + t_{\alpha/2} \frac{S}{\sqrt{n}} \quad (2)$$

where $\bar{X}$ and S are the mean and standard deviation, respectively, of a sample of size $n < 30$ from an approximate normal population, and $t_{\alpha/2}$ is the value of the t -distribution, with $v = n-1$ degrees of freedom, leaving an area of $\alpha/2$ to the right.

The final step in the analysis involved the testing of the means between the various cases. For this test, the null hypothesis was that there was no significant difference between the means of any two cases that were being compared. The alternative hypothesis was that there was a significant difference between the means. A two-tailed test was chosen with $\alpha/2 = 0.05$. If the calculated test statistic fell within the critical region, the hypothesis was rejected and the test concluded there was a significant difference between the means.

CHAPTER IV. DATA ANALYSIS

Because the four study sites exhibited different roadway geometrics and different bicycle and motor vehicle volumes, the analysis of data was performed separately for each site. Comparisons of speeds and then displacements were made between cases for each site, but not between sites. The analysis consisted of calculating parameters (mean and standard deviation), intervals ($\alpha = 0.10$) and paired tests between the different cases. In most cases, the actual sample sizes were less than the desired minimum of 68. The small samples were attributed to the rarity of occurrences of some of the cases that were defined. During Phases I and II, bicycle volumes were low and cases 3 and 4 were difficult to obtain. It was found that samples of case 1 were the easiest to obtain while case 4 was the most difficult, occurring on the average of about 1 per hour. Thus, the amount of time and labor necessary to obtain a minimum sample size was not feasible in some instances during the study. As 68 was calculated to be a minimum sample size, statistical tests that have been performed with samples less than the minimum have limited validity.

Detailed diagrams for each site layout and details of data collection are included in Appendix A.

Third Street

Speed Analysis

A summary of data for the speed study at Third Street (a two-way, 29 foot roadway) appears in Table 2. Speed

Table 2
Summary of Third Street Speed Data

Phase I Trap 1	$\bar{X}$	σ	n	Phase I Trap 2	$\bar{X}$	σ	n
Case 1	28.87	5.22	113	Case 1	26.04	4.94	117
2	29.11	6.62	13	2	26.89	2.99	7
3	25.71	5.23	9	3	24.41	4.88	13
4	33.01	8.11	2	4	27.98	7.55	2
Phase II Trap 1				Phase II Trap 2			
Case 1	25.84	3.89	104	Case 1	24.72	4.29	104
2	23.90	4.63	41	2	23.52	4.32	29
3	23.32	3.80	44	3	21.97	3.87	43
4	23.16	5.43	7	4	19.84	4.57	2
Phase III Trap 1				Phase III Trap 2			
Case 1	27.47	4.34	82	Case 1	25.06	4.10	87
2	27.24	5.55	12	2	24.69	4.11	6
3	26.59	4.81	40	3	23.36	4.90	49
4	19.94	10.08	3	4	--	--	--

Case 1 - Single Motor Vehicle
Case 2 - Motor Vehicles in Opposing Directions
Case 3 - Bicycle and Motor Vehicle
Case 4 - Bicycle and Motor Vehicles in Opposing Directions

intervals are graphically shown in Figures 13 and 14. Nearly all case 4 intervals are not shown due to the small sample sizes. The results of the paired tests are shown in Table 3.

By examining the mean speeds for case 1 and case 3, it can be seen that a reduction of speed took place when the motorist came adjacent to a bicyclist on Third Street. Similarly, by comparing case 2 with case 3 it was found that case 3 speeds were slower when a motorist traveled near a bicyclist on the roadway than when he came adjacent with another vehicle in the opposing traffic lane (case 2). However, the paired statistical tests show that cases 1 and 3 were significantly different for all three phases. For Phase II, cases 1 and 2 and cases 2 and 3 were also significantly different.

Volumes for all three phases are presented in Figure 15. Motor vehicle volumes for Phase II were more than 30 percent higher than for Phase I and Phase III, which may account for some of the difference in speeds between cases 1 and 2 and cases 2 and 3. Nevertheless, the significance involving case 3 suggests that bicycles do in fact reduce motor vehicle speeds. Because the study site was located adjacent to the campus, the volume counts for bicycles rapidly increased when the University was in session (Phase III had more than 10 times as many bicycles as Phase I).

Displacement Analysis

A summary of the displacement data is shown in Table 4. A brief examination of the mean displacements for each phase showed that the smallest displacements occurred during the case 2 conditions. The results appear logical for traffic lanes only 11 feet in width. The presence of a bicyclist (case 3) produced the largest mean displacements (between 3 and 5 feet). Displacement intervals are shown in Figures 16 and 17. Results of the statistical tests of

FIGURE 13. CONFIDENCE INTERVALS FOR SPEED DATA
($\alpha = 0.10$)

FIGURE 14. CONFIDENCE INTERVALS FOR SPEED DATA ($\alpha = 0.10$)

Table 3
Statistical Comparisons of Mean Speeds

Comparison	$\bar{X}_1$	$\bar{X}_2$	n_1	n_2	$t_{\text{calc.}}$	Significant $\alpha=0.10$
Phase I						
Case 1-Case 2	28.87	26.89	113	7	1.60	No
1-3	28.87	24.41	113	13	3.09	Yes
1-4	28.87	27.98	113	2	0.16	No
2-3	26.89	24.41	7	13	1.40	No
2-4	26.89	27.98	7	2	-0.19	No
3-4	24.41	27.98	13	2	-0.64	No
Phase II						
Case 1-Case 2	25.84	23.90	104	41	2.39	Yes
1-3	25.84	21.97	104	43	5.52	Yes
1-4	25.84	23.16	104	7	1.28	No
2-3	23.90	21.97	41	43	2.07	Yes
2-4	23.90	23.16	41	7	0.34	No
3-4	21.97	23.16	43	7	-0.55	No
Phase III						
Case 1-Case 2	27.47	24.69	82	6	1.59	No
1-3	27.47	23.36	82	49	4.89	Yes
1-4	27.47	19.94	82	3	1.28	No
2-3	24.69	23.36	6	49	0.73	No
2-4	24.69	19.94	6	3	0.78	No
3-4	23.36	19.94	49	3	0.58	No

Null Hypothesis: $\mu_1 - \mu_2 = \mu = 0$

FIGURE 15. VOLUME COUNTS OF BICYCLES AND MOTOR VEHICLES
(THIRD STREET)

Table 4
Summary of Third Street Displacement Data

Phase I Trap Case	1 1 2 3 4	$\bar{X}$ (ft)	σ	n	Phase I Trap Case	1 1 2 3 4	$\bar{X}$ (ft)	σ	n
		2.30	1.50	112			2.14	1.58	117
		1.07	1.55	13			1.14	2.03	7
		3.91	1.97	12			3.38	1.93	13
		--	--	--			--	--	--
Phase II Trap Case	1 1 2 3 4	3.07 1.65 4.86 3.00	1.46 1.32 1.73 1.82	102 40 44 7	Phase II Trap Case	1 1 2 3 4	1.78 1.16 3.04 --	1.32 1.22 1.75 --	104 30 45 --
Phase III Trap Case	1 1 2 3 4	3.11 2.00 4.89 2.66	1.64 1.71 1.50 1.14	82 12 39 3	Phase III Trap Case	1 1 2 3 4	2.44 1.67 4.30 --	1.51 1.03 1.63 --	87 6 49 --

- Case 1 - Single Motor Vehicle
- Case 2 - Motor Vehicles in Opposing Directions
- Case 3 - Bicycle and Motor Vehicle
- Case 4 - Bicycle and Motor Vehicles in Opposing Directions

FIGURE 16. CONFIDENCE INTERVALS FOR DISPLACEMENT DATA ($\alpha = 0.10$)

FIGURE 17. CONFIDENCE INTERVALS FOR
DISPLACEMENT DATA ($\alpha = 0.10$)

the means are found in Table 5. A significant difference in mean displacements occurred when case 2 and case 3 conditions were compared for each phase of the study. This is logical as in case 2 a car would be closer to the curb while passing another car and in case 3 a car would be closer to the centerline while passing a bicycle, thus creating the maximum difference in displacements. In Phases I and III, case 1 and case 3 were significantly different; while in Phase II no significance occurred, probably because of the heavier motor vehicle volumes. During the heavier volume phase (Phase II), significance occurred between cases 1 and 2, probably due to reasons similar to those noted above for cases 2 and 3. The other significant comparisons noted had a sample size too small to assume validity in one case.

University Street

Speed Analysis

During the Phase I study, minimum sample sizes could not be obtained for case 3 and case 4 conditions (Table 6). Since the University was not in session during Phase I, few bicyclists traveled on University Street (a one-way, 35 foot wide roadway). As a result, it was not possible to make valid statistical calculations. A comparison of volume counts given in Figure 18 showed a definite increase in bicycle and motor vehicle traffic for each phase of the study. The graphs in Figures 19 and 20 represent a 90 percent confidence interval for all speed data that was obtained. Statistical comparisons are presented in Table 7. It is worthy to note that significant differences in the mean speeds were obtained during the Phase III conditions for three of the comparisons made. The increased bicycle volumes did have some effect on a single motorist in the

Table 5
Statistical Comparisons of Mean Displacements

Third Street

Comparison	$\bar{x}_1$	$\bar{x}_2$	n_1	n_2	$t_{\text{calc.}}$	Significant $\alpha=0.10$
Phase I						
Case 1-Case 2	2.30	1.14	112	7	1.48	No
1-3	2.30	3.38	112	13	-1.96	Yes
1-4	2.30	1.50	112	2	0.32	No
2-3	1.14	3.38	7	13	-2.40	Yes
2-4	1.14	1.50	7	2	-0.13	No
3-4	3.38	1.50	13	2	0.73	No

Comparison

Phase II

Case 1-Case 2	3.07	1.65	102	40	5.68	Yes
1-3	3.07	3.04	102	45	0.10	No
1-4	3.07	3.00	102	7	0.10	No
2-3	1.65	3.04	40	45	-4.21	Yes
2-4	1.65	3.00	40	7	-1.87	Yes
3-4	3.04	3.00	45	7	0.05	No

Comparison

Phase III

Case 1-Case 2	3.11	1.67	82	6	3.20	Yes
1-3	3.11	4.30	82	49	-4.10	Yes
1-4	3.11	2.66	82	3	0.66	No
2-3	1.67	4.30	6	49	-5.47	Yes
2-4	1.67	2.66	6	3	-1.26	No
3-4	4.30	2.66	49	3	2.34	Yes

Null Hypothesis: $\mu_1 - \mu_2 = \mu = 0$

Table 6
Summary of University Street Speed Data

Phase I Trap 1 Case 1 2 3 4	$\bar{X}$ (MPH) 27.11 26.39 -- --	σ 4.34 2.98 -- --	n 87 5 -- --	Phase I Trap 2 Case 1 2 3 4	$\bar{X}$ (MPH) 27.33 31.97 25.99 --	σ 5.06 4.05 3.38 --	n 87 4 7 --
Phase II Trap 1 Case 1 2 3 4	27.62 27.60 26.21 --	4.83 3.46 4.32 --	93 46 43 --	Phase II Trap 2 Case 1 2 3 4	27.03 26.41 24.15 --	4.76 4.79 4.81 --	93 77 34 --
Phase III Trap 1 Case 1 2 3 4	25.67 23.44 24.26 25.86	4.34 3.61 3.82 10.45	78 21 62 3	Phase III Trap 2 Case 1 2 3 4	25.96 23.91 23.99 23.86	3.93 2.55 3.00 1.87	76 9 30 4

Case 1 - Single Motor Vehicle
Case 2 - Motor Vehicles in Opposing Directions
Case 3 - Bicycle and Motor Vehicle
Case 4 - Bicycle and Motor Vehicles in Opposing Directions

FIGURE 18. VOLUME COUNTS OF BICYCLES AND MOTOR VEHICLES
(UNIVERSITY STREET, ONE-WAY)

FIGURE 19. CONFIDENCE INTERVALS FOR SPEED
DATA ($\alpha = 0.10$)

FIGURE 20. CONFIDENCE INTERVALS FOR
SPEED DATA ($\alpha=0.10$)

Table 7
Statistical Comparisons of Mean Speeds
University Street

	$\bar{x}_1$	$\bar{x}_2$	n_1	n_2	$t_{\text{calc.}}$	Significant $\alpha=0.10$
Comparison						
Phase I						
Case 1-Case 2	27.33	26.39	87	5	0.65	No
1-3	27.33	25.99	87	7	0.96	No
1-4	--	--	--	--	--	--
2-3	26.39	25.99	5	7	0.21	No
2-4	--	--	--	--	--	--
3-4	--	--	--	--	--	--
Comparison						
Phase II						
Case 1-Case 2	27.62	26.41	93	77	1.63	No
1-3	27.62	24.15	93	34	3.61	Yes
1-4	--	--	--	--	--	--
2-3	26.41	24.15	77	34	2.28	Yes
2-4	--	--	--	--	--	--
3-4	--	--	--	--	--	--
Comparison						
Phase III						
Case 1-Case 2	25.96	23.44	76	21	2.80	Yes
1-3	25.96	23.99	76	30	2.77	Yes
1-4	25.96	23.86	76	4	2.03	Yes
2-3	23.44	23.99	21	30	-0.57	No
2-4	23.44	23.86	21	4	-0.34	No
3-4	23.99	23.86	30	4	0.12	No

Null Hypothesis: $\mu_1 - \mu_2 = \mu = 0$

traffic stream. In Phase II, a single vehicle's speed was reduced when passing a bicycle (cases 1 and 3 and cases 2 and 3 were significant).

Displacement Analysis

The examination of case 2 conditions for each phase of the University Street study showed that two motor vehicles traveling adjacent to each other on this one-way street did have some effect on displacement. This resulted in small displacements of the vehicle from the bicycle lane marking. The computations for each phase are presented in summary form in Table 8. The largest mean displacements that were recorded again took place when the motorist came into conflict with a bicyclist under case 3 conditions. When confidence intervals were obtained for the displacement study, some negative values appeared in the computations. Since a displacement of zero feet was assumed to be at the marking of the bicycle lane, negative displacements meant that the motor vehicle was actually traveling on the bicycle lane stripe or in the bicycle lane. Confidence limits with a 10 percent level of significance are presented in Figures 21 and 22. The statistical test of the means showed all comparisons that were made significant for the Phase II study (Table 9). Limited data prevented comparisons to be made between all cases, especially in Phase I. As expected, cases 2 and 3 were significantly different since these should be the normal "closest to curb" and "closest to centerline" conditions, respectively. Also the significance for cases 1 and 2 implies that motor vehicles leave extra space between each other as they pass. When a motor vehicle passed a bicycle (cases 1 and 3), there was a significant change in displacement.

Table 8
Summary of University Street Displacement Data

Phase I	$\bar{X}$ (ft)	σ	n	Phase I Trap 2 Case 1 2 3 4	$\bar{X}$ (ft)	σ	n
Trap 1							
Case 1	1.88	1.71	85		2.58	1.59	85
2	1.60	2.07	5		2.00	2.00	4
3	--	--	--		1.85	1.34	7
4	--	--	--		--	--	--
Phase II							
Trap 1							
Case 1	2.49	1.45	92	Phase II Trap 2 Case 1 2 3 4	2.69	1.39	93
2	1.89	1.22	46		1.85	1.03	77
3	3.55	1.79	45		3.67	1.39	31
4	--	--	--		--	--	--
Phase III							
Trap 1							
Case 1	2.14	1.59	78	Phase III Trap 2 Case 1 2 3 4	2.56	1.17	73
2	1.09	1.13	21		2.22	1.14	9
3	3.79	1.72	63		4.39	1.55	31
4	--	--	--		3.25	1.50	4

Case 1 - Single Motor Vehicle
Case 2 - Motor Vehicles in Opposing Directions
Case 3 - Bicycle and Motor Vehicle
Case 4 - Bicycle and Motor Vehicles in Opposing Directions

FIGURE 21. CONFIDENCE INTERVALS FOR
DISPLACEMENT DATA ($\alpha=0.10$)

FIGURE 22. CONFIDENCE INTERVALS FOR
DISPLACEMENT DATA ($\alpha = 0.10$)

Table 9
Statistical Comparisons of Mean Displacements

University Street

	X_1	X_2	n_1	n_2	$t_{\text{calc.}}$	Significant $\alpha=0.10$
Comparison						
Phase I						
Case 1-Case 2	2.58	1.60	85	5	1.04	No
1-3	2.58	1.85	85	7	1.37	No
1-4	--	--	--	--	--	--
2-3	1.60	1.85	5	7	-0.23	No
2-4	--	--	--	--	--	--
3-4	--	--	--	--	--	--

Comparison

Phase II						
Case 1-Case 2	2.49	1.85	92	77	3.36	Yes
1-3	2.49	3.67	92	31	-4.06	Yes
1-4	--	--	--	--	--	--
2-3	1.85	3.67	77	31	-6.74	Yes
2-4	--	--	--	--	--	--
3-4	--	--	--	--	--	--

Comparison

Phase III						
Case 1-Case 2	2.56	1.09	73	21	5.25	Yes
1-3	2.56	4.39	73	31	-5.90	Yes
1-4	2.56	3.25	73	4	-0.90	No
2-3	1.09	4.39	21	31	-8.91	Yes
2-4	1.09	3.25	21	4	-2.76	Yes
3-4	4.39	3.25	31	4	1.42	No

Null Hypothesis: $\mu_1 - \mu_2 = \mu = 0$

Grant Street

Speed Analysis

A study of the speed data obtained for Grant Street showed that a reduction of motor vehicle speeds took place when a bicyclist was present on the roadway. By examining Table 10 it can be seen that for the Phase I study the average speed reduction between cases 1 and 3 was 8.17 miles per hour. A motor vehicle traveling in the opposing traffic lane seemed to have very little effect on the overall mean speed. This can be verified by comparing the normal conditions of case 1 with that of case 2. Volume counts of bicycles and motor vehicles are graphically represented in Figure 23. The counts for the Phase III study were taken during the morning peak hour so that a high bicycle count would be possible. The imbalance shown in the directional split was due to commuter bicycling and motor vehicle travel to West Lafayette High School, Purdue University, and other parts of the community. Confidence intervals for the speed data are graphically presented in Figures 24 and 25. A comparison of mean speeds between case 1 and case 3 at a 10 percent level of significance showed that there was a significant difference in speeds for all 3 phases of the study (Table 11). A single vehicle (case 1) and opposing vehicles (case 2) also resulted in a significant difference in speed for Phases II and III.

Displacement Analysis

Average displacements of at least 4.85 feet were recorded for all cases of the 3 phase study (Table 12). Roadway geometrics showed that through traffic lanes measured 14 feet in width. This provided the motorist with some extra "psychological driving comfort" when traveling on a roadway with bicycle lanes. Case 3 conditions had the

Table 10
Summary of Grant Street Speed Data

Phase I Trap 1 Case 1 2 3 4	$\bar{X}$	σ	n	Phase I Trap 2 Case 1 2 3 4	$\bar{X}$	σ	n
	35.55	3.84	92		34.39	4.53	90
	35.21	4.96	68		25.23	4.81	66
	27.38	7.98	16		29.59	7.66	20
	--	--	--		--	--	--
Phase II Trap 1 Case 1 2 3 4	34.81 33.98 32.81 28.94	3.98 3.86 3.69 7.43	84 76 16 3	Phase II Trap 2 Case 1 2 3 4	33.36 33.50 33.50 27.48	4.55 4.84 4.17 4.80	90 78 20 3
Phase III Trap 1 Case 1 2 3 4	34.31 33.78 31.79 31.14	3.57 3.45 3.14 2.15	72 41 56 4	Phase III Trap 2 Case 1 2 3 4	31.92 31.13 29.84 29.31	3.87 3.69 2.86 3.50	75 41 49 7

Case 1 - Single Motor Vehicle
Case 2 - Motor Vehicles in Opposing Directions
Case 3 - Bicycle and Motor Vehicle
Case 4 - Bicycle and Motor Vehicles in Opposing Directions

FIGURE 23. VOLUME COUNTS OF BICYCLES AND MOTOR VEHICLES
(GRANT STREET)

FIGURE 24. CONFIDENCE INTERVALS FOR
SPEED DATA ($\alpha = 0.10$)

FIGURE 25. CONFIDENCE INTERVALS FOR
SPEED DATA ($\alpha = 0.10$)

Table 11
Statistical Comparisons of Mean Speeds

Grant Street

	X_1	X_2	n_1	n_2	$t_{\text{calc.}}$	Significant $\alpha=0.10$
Comparison						
Phase I						
Case 1-Case 2	35.55	35.21	92	68	0.47	No
1-3	35.55	29.59	92	20	3.38	Yes
1-4	--	--	--	--	--	--
2-3	35.21	29.59	68	20	3.10	Yes
2-4	--	--	--	--	--	--
3-4	--	--	--	--	--	--

Comparison

Phase II						
Case 1-Case 2	34.81	33.50	84	78	1.87	Yes
1-3	34.81	32.81	84	16	1.96	Yes
1-4	34.81	27.48	84	3	2.61	Yes
2-3	33.50	32.81	78	16	0.64	No
2-4	33.50	27.48	78	3	2.13	Yes
3-4	32.81	27.48	16	3	1.82	Yes

Comparison

Phase III						
Case 1-Case 2	34.31	31.13	72	41	4.47	Yes
1-3	34.31	29.84	72	49	7.70	Yes
1-4	34.31	29.31	72	7	3.62	Yes
2-3	31.13	29.84	41	49	1.84	Yes
2-4	31.13	29.31	41	7	1.26	No
3-4	29.84	29.31	49	7	0.38	No

Null Hypothesis: $\mu_1 - \mu_2 = \mu = 0$

Table 12
Summary of Grant Street Displacement Data

Phase I Trap 1	$\bar{X}$	σ	n	Phase I Trap 2	$\bar{X}$	σ	n
Case 1	5.72	0.87	92	Case 1	5.21	1.18	90
2	5.36	0.82	68	2	5.42	0.90	64
3	5.90	1.19	10	3	5.71	0.82	14
4	--	--	--	4	--	--	--
Phase II Trap 1				Phase II Trap 2			
Case 1	5.86	0.98	84	Case 1	5.46	1.01	90
2	5.36	1.04	75	2	5.03	0.95	78
3	6.31	0.59	16	3	5.55	1.39	20
4	5.66	0.57	3	4	--	--	--
Phase III Trap 1				Phase III Trap 2			
Case 1	5.64	0.81	72	Case 1	5.61	1.01	75
2	5.36	0.82	41	2	5.43	0.97	41
3	6.01	0.65	55	3	6.16	0.79	49
4	6.25	0.49	4	4	4.85	1.34	7

Case 1 - Single Motor Vehicle
Case 2 - Motor Vehicles in Opposing Directions
Case 3 - Bicycle and Motor Vehicle
Case 4 - Bicycle and Motor Vehicles in Opposing Directions

largest displacements for each phase, except in Phase III (case 4). Thus, the bicyclist did effect the motorist despite the wide traffic lanes. Confidence intervals for the mean displacements are shown graphically in Figures 26 and 27. Statistical comparisons between cases (Table 13) proved that most of the Phase I comparisons were either insignificant or could not be compared because of limited data. Significance of the means between cases 1 and 3 was found in the Phase II and III studies.

Salisbury Street

Speed Analysis

Motorists reduced speed when coming into conflict with a bicyclist on Salisbury Street (a two-way, 40 foot wide roadway). The reduction of mean speed ranged from 1.35 to 6.16 miles per hour (Table 14). When a bicyclist, motorist, and another motor vehicle in the opposing traffic lane came into conflict (case 4), a definite reduction in speed took place in the Phase III study. However, the sample size was small. The average reduction was 8.24 miles per hour less than the normal speed of a single vehicle on the roadway. Volume counts are shown in Figure 28. Phase III is worthy of examination. Most of the 126 bicycles counted in the hour represented students bicycling to the junior high school located on Salisbury Street. From this study it should be evident that a peak-hour demand does exist for bicycles. Confidence intervals for the speed data are graphically presented in Figures 29 and 30. A comparison of mean speeds between case 1 and case 3 yielded significant results for each of the 3 phases (Table 15). Case 2 and case 3 were compared at a 10 percent level of significance and each result was found to be significant. A comparison

FIGURE 26. CONFIDENCE INTERVALS FOR
DISPLACEMENT DATA ($\alpha = 0.10$)

FIGURE 27. CONFIDENCE INTERVALS FOR
DISPLACEMENT DATA ($\alpha = 0.10$)

Table 13
Statistical Comparisons of Mean Displacements

Grant Street

	$\bar{x}_1$	$\bar{x}_2$	n_1	n_2	$t_{\text{calc.}}$	Significant $\alpha=0.10$
Comparison						
Phase I						
Case 1-Case 2	5.72	5.36	92	68	2.76	Yes
1-3	5.72	5.71	92	14	0.04	No
1-4	--	--	--	--	--	--
2-3	5.36	5.71	68	14	-1.45	No
2-4	--	--	--	--	--	--
3-4	--	--	--	--	--	--

Comparison

Phase II						
Case 1-Case 2	5.86	5.03	84	78	5.53	Yes
1-3	5.86	6.31	84	16	-2.50	Yes
1-4	5.86	6.00	84	3	-1.40	No
2-3	5.03	6.31	78	16	-7.11	Yes
2-4	5.03	6.00	78	3	-9.70	Yes
3-4	6.31	6.00	16	3	2.21	Yes

Comparison

Phase III						
Case 1-Case 2	5.64	5.43	72	41	1.23	No
1-3	5.64	6.16	72	49	-3.71	Yes
1-4	5.64	4.85	72	7	1.54	No
2-3	5.43	6.16	41	49	-4.05	Yes
2-4	5.43	4.85	41	7	1.11	No
3-4	6.16	4.85	49	7	2.56	Yes

Null Hypothesis: $\mu_1 - \mu_2 = \mu = 0$

Table 14
Summary of Salisbury Street Speed Data

Phase I Trap 1 Case 1 2 3 4	$\bar{X}$	σ	n	Phase I Trap 2 Case 1 2 3 4	$\bar{X}$	σ	n
	33.11	4.00	84		32.24	3.73	84
	33.13	3.51	51		29.30	4.00	2
	30.09	3.16	10		29.58	2.80	16
	28.09	1.69	4		--	--	--
Phase II Trap 1 Case 1 2 3 4				Phase II Trap 2 Case 1 2 3 4			
	34.63	3.36	78		32.91	3.65	70
	33.63	4.30	63		33.94	4.18	61
	31.84	3.43	14		31.56	3.93	21
	22.12	3.42	4		--	--	--
Phase III Trap 1 Case 1 2 3 4				Phase III Trap 2 Case 1 2 3 4			
	33.08	3.86	62		31.18	4.15	70
	31.66	4.67	19		29.15	5.25	7
	26.92	3.98	39		26.48	3.47	51
	24.84	4.68	5		--	--	--

Case 1 - Single Motor vehicle
Case 2 - Motor Vehicles in Opposing Directions
Case 3 - Bicycle and Motor Vehicle
Case 4 - Bicycle and Motor Vehicles in Opposing Directions

FIGURE 28. VOLUME COUNTS OF BICYCLES AND MOTOR VEHICLES
(SALISBURY STREET)

FIGURE 29. CONFIDENCE INTERVALS FOR
SPEED DATA ($\alpha = 0.10$)

FIGURE 30. CONFIDENCE INTERVALS FOR
SPEED DATA ($\alpha = 0.10$)

Table 15
Statistical Comparisons of Mean Speeds

Salisbury Street

	X_1	X_2	n_1	n_2	$t_{\text{calc.}}$	Significant $\alpha=0.10$
Comparison						
Phase I						
Case 1-Case 2	33.11	33.13	84	51	-0.03	No
1-3	33.11	29.58	84	16	3.39	Yes
1-4	33.11	28.09	84	4	5.28	Yes
2-3	33.13	29.58	51	16	3.31	Yes
2-4	33.13	28.09	51	4	5.14	Yes
3-4	29.58	28.09	16	4	1.17	No

Comparison

Phase II						
Case 1-Case 2	34.63	33.63	78	63	1.51	No
1-3	34.63	31.56	78	21	3.30	Yes
1-4	34.63	32.12	78	4	1.43	No
2-3	33.63	31.56	63	21	2.04	Yes
2-4	33.63	32.12	63	4	0.84	No
3-4	31.56	32.12	21	4	-0.29	No

Comparison

Phase III						
Case 1-Case 2	33.08	31.66	62	19	1.21	No
1-3	33.08	26.48	62	51	9.56	Yes
1-4	33.08	24.84	62	5	3.83	Yes
2-3	31.66	26.48	19	51	4.42	Yes
2-4	31.66	24.84	19	5	2.90	Yes
3-4	26.48	24.84	51	5	0.76	No

Null Hypothesis: $\mu_1 - \mu_2 = \mu = 0$

of cases 3 and 4 produced no significant results due to the small sample size of case 4.

Displacement Analysis

A study of displacement data showed that the largest displacements for the case 3 conditions occurred during the Phase III study (Table 16). Bicycle volume counts were checked for this phase. Again, the presence of heavy bicycle volumes caused the motorist to be influenced from his normal driving location. The mean displacements for case 2 conditions showed that a motor vehicle in the opposing traffic lane had little effect on the motorist under study. Graphically pictured in Figures 31 and 32 are 90 percent confidence intervals for the displacement data. Statistical tests of mean displacements (Table 17) found case 1 and case 3 comparisons to be significant for each phase of the study. Cases 3 and 4 proved to be significant for all phases at the 10 percent level of significance. However, these results have limited validity since sample sizes for case 4 were small.

Other Observations

When data were being collected at each site, manual counts were also made of wrong-way movements by bicyclists (bicycles moving in an opposing direction to vehicles) and pedestrians walking in bicycle lanes. These data are shown in Table 18 and summarized in Table 19.

Wrong-way movements were larger on the near-campus sites and where motor vehicle counts were low. However, the wrong-way rate had no definite trend. During Phase III at Grant and Salisbury Streets, motor vehicle counts were unusually high and almost no wrong-way movements occurred. Part of this was due to the large volumes. However, the study took place during the morning peak when most persons

Table 16
Summary of Salisbury Street Displacement Data

Phase I Trap 1 Case 1 2 3 4	$\bar{X}$	σ	n	Phase I Trap 1 Case 1 2 3 4	$\bar{X}$	σ	n
	3.08	1.48	83		4.56	1.38	81
	2.86	1.42	51		--	--	--
	4.00	1.49	10		4.66	1.54	15
	3.25	0.95	4		--	--	--
Phase II Trap 1 Case 1 2 3 4	3.70 3.73 4.07 3.50	1.17 1.38 1.26 1.00	78 63 14 4	Phase II Trap 2 Case 1 2 3 4	4.65 4.35 4.71 --	1.42 1.47 1.22 --	70 60 21 --
Phase III Trap 1 Case 1 2 3 4	4.24 4.15 5.69 4.00	1.23 1.67 1.05 1.41	62 19 39 5	Phase III Trap 2 Case 1 2 3 4	5.22 4.71 6.33 --	1.41 1.79 1.04 --	70 7 51 --

Case 1 - Single Motor Vehicle
Case 2 - Motor Vehicles in Opposing Directions
Case 3 - Bicycle and Motor Vehicle
Case 4 - Bicycle and Motor Vehicles in Opposing Directions

FIGURE 31. CONFIDENCE INTERVALS FOR
DISPLACEMENT DATA ($\alpha = 0.10$)

FIGURE 32. CONFIDENCE INTERVALS FOR
DISPLACEMENT DATA ($\alpha = 0.10$)

Table 17
Statistical Comparisons of Mean Displacements
Salisbury Street

	$\bar{x}_1$	$\bar{x}_2$	n_1	n_2	$t_{\text{calc.}}$	Significant $\alpha=0.10$
Comparison						
Phase I						
Case 1-Case 2	3.08	2.86	83	51	0.88	No
1-3	3.08	4.66	83	15	-3.76	Yes
1-4	3.08	3.25	83	4	-0.34	No
2-3	2.86	4.66	51	15	-4.09	Yes
2-4	2.86	3.25	51	4	-0.76	No
3-4	4.66	3.25	15	4	2.27	Yes

Comparison

Phase II						
Case 1-Case 2	3.70	3.73	78	63	-0.14	No
1-3	3.70	4.71	78	21	-3.48	Yes
1-4	3.70	3.50	78	4	0.39	No
2-3	3.73	4.71	63	21	-3.16	Yes
2-4	3.73	3.50	63	4	0.44	No
3-4	4.71	3.50	21	4	2.16	Yes

Comparison

Phase III						
Case 1-Case 2	4.24	4.15	62	19	0.21	No
1-3	4.24	6.33	62	51	-9.95	Yes
1-4	4.24	4.00	62	5	0.36	No
2-3	4.15	6.33	19	51	-5.31	Yes
2-4	4.15	4.00	19	5	0.20	No
3-4	6.33	4.00	51	5	3.64	Yes

Null Hypothesis: $\mu_1 - \mu_2 = \mu = 0$

Table 18
Violation Data

Site	Phase	Time of Study	Wrong-Way Movements By Bicycles	Pedestrians Walking In Bicycle Lane
Third Street	I	10:10 A.M.-1:04 P.M.	1	0
	II	10:40 A.M.-2:20 P.M.	7	0
	III	9:40 A.M.-11:40 A.M.	11	0
University Street	I	10:00 A.M.-12:05 P.M.	0	0
	II	10:23 A.M.-4:10 P.M.	11	0
	III	8:15 A.M.-10:48 A.M.	15	0
Grant Street	I	10:22 A.M.-2:07 P.M.	5	2
	II	11:00 A.M.-2:30 P.M.	5	6
	III	7:35 A.M.-8:35 A.M.	1	1
Salisbury Street	I	10:25 A.M.-1:35 P.M.	3	7
	II	9:20 A.M.-12:30 P.M.	3	2
	III	7:30 A.M.-8:30 A.M.	0	1

Table 19
Violation Analysis

Site	Wrong-Way Movements By Bicyclists (per hour)	Bicycle Flow Rate (BPH)	Wrong-Way Rate (#/10 Bicycles)	Pedestrians Walking In Bicycle Lane (per hour)
Third Street Phase I	0.3	9	0.3	0
Phase II	1.9	32	0.6	0
Phase III	5.5	118	0.5	0
University Street Phase I	0	6	0	0
Phase II	1.9	15	1.3	0
Phase III	5.8	91	0.6	0
Grant Street Phase I	1.3	8	1.6	0.5
Phase II	1.4	13	1.1	1.7
Phase III	0.8	115	0.1	0.8
Salisbury Street Phase I	0.9	9	1.0	2.2
Phase II	0.9	16	0.6	0.6
Phase III	0	126	0	0.8

using motor vehicles and bicycles were either traveling to school or to work.

The near-campus sites had no pedestrian violations while several occurred at the other two sites. One might suspect otherwise, as pedestrian violations might be low on Grant and Salisbury Streets where the roadways are wide and motor vehicle volumes are high. However, most pedestrians near the University campus were college students, while on Grant and Salisbury Streets most pedestrians were younger children. Age of pedestrian may be a major factor in pedestrian violations.

Summary

A summary of motor vehicle and bicycle flow rates is shown in Table 20. As expected bicycle flow rates increased between Phases I and III. Flow rates of over 100 bicycles per hour were observed on the bicycle lanes which varied between 3.50 feet and 4.33 feet. However, when schools were not in session the flow rates were very low (usually less than 20 bicycles per hour).

The results of the statistical paired tests for speeds and displacements are shown in Tables 21 and 22. In all but one of the twelve studies (four sites and three phases each), a single motor vehicle had a lower speed when passing a bicycle than when traveling by itself (case 3 and case 1). A reduction of 6.17 mph on Grant Street (35 feet wide) was the largest mean value computed. Reductions in mean speed for the other three sites were as follows:

Third Street (29 feet wide)	2.28 mph
University Street (35 feet wide)	1.54 mph
Salisbury Street (40 feet wide)	4.81 mph

When a single motor vehicle passed a bicycle (case 3), a significant displacement toward the center of the roadway took place as compared to when a motor vehicle traveled by

Table 20

Summary Table of Volumes

Site	Posted Speed Limit (MPH)	Vehicle Lane Width (ft.)	Bicycle Lane Width (ft.)	Vehicle Flow Rate ¹ (Vph)	Bicycle Flow Rate ² (Bph)
Third Street	30	11	3.67	56	9
Phase I				84	32
Phase II				69	118
Phase III					
University Street	30	12	3.50	53	6
Phase I				108	15
Phase II				142	91
Phase III					
Grant Street	35	14	3.83	162	8
Phase I				183	13
Phase II				503	115
Phase III					
Salisbury Street	35	15	4.33	192	9
Phase I				210	16
Phase II				203	126
Phase III					

¹in direction of major flow and lane next to bicycle lane²in direction of major flow

Table 21
Summary Table of Significantly Different Speed Cases ($\alpha=0.10$)

Cases	1-2	1-3	1-4	2-3	2-4	3-4
Third Street Phase I		4.46				
II	1.94	3.87		1.93		
III		4.11				
University Street Phase I			NA		NA	NA
II		3.47	NA	2.26	NA	NA
III	2.52	1.97	2.10*			
Grant Street Phase I		5.96	NA	5.62	NA	NA
II	1.31	2.00	7.33*		6.02*	5.33*
III	3.18	4.47	5.00*	1.29		
Salisbury Street Phase I		3.53	5.02*	3.55	5.04*	
II		3.07		2.07		
III		6.60	8.24*	5.18	6.82*	

Numbers indicate change in speed (mph) if statistically significant.

* at least one case had a sample size less than 10.

NA - test was not made due to insufficient volumes.

Table 22

Summary Table of Significantly Different Displacement Cases ($\alpha=0.10$)

Cases	1-2	1-3	1-4	2-3	2-4	3-4
Third Street						
Phase I		1.08		2.24*		
II	1.42			1.39	1.35*	
III	1.44*	1.19		2.63*		1.64*
University Street						
Phase I			NA		NA	NA
II	0.64	1.18	NA	1.82	NA	NA
III	1.47	1.83		3.30	2.16*	
Grant Street						
Phase I	0.36		NA		NA	NA
II	0.83	0.45		1.28	0.97*	0.31*
III		0.52		0.73		1.31*
Salisbury Street						
Phase I		1.58		1.80		1.41*
II		1.01		0.98		1.21*
III		2.09		2.18		2.33*

Numbers indicate change in displacement (ft.) if statistically significant.

* at least one case had a sample size less than 10.

NA - test was not made due to insufficient volumes.

itself on the roadway (case 1). Motorists on Salisbury Street (40 feet wide) increased displacement on the average of 1.39 feet due to the presence of a bicyclist on that roadway. Increases in displacement when cases 1 and 3 were compared for the other three sites are noted below.

Third Street (29 feet wide)	0.62 ft.
University Street (35 feet wide)	0.85 ft.
Grant Street (35 feet wide)	0.46 ft.

A comparison of cases 2 and 3 was found to be significant in over half of the studies.

CHAPTER V. APPLICATION OF ANALYSIS

Although a limited amount of data was collected for each site, the results can still be used to provide some guidelines for the placement of bicycle lanes in a community. Important factors for the establishment of bicycle lanes are motor vehicle volumes, motor vehicle speed, bicycle volumes, and roadway geometrics. By plotting motor vehicle speed data from each of the four sites against width of roadway, it was noted that a linear relationship existed as shown in Figure 33. This figure should be recognized as illustrative only, developed from the available data at the sites utilized in this study. The widths and speeds involved, however, are typical of city streets with 2-way traffic without parking in many cities.

Lane design widths for bicycles and motor vehicles were developed from this study and are shown in Figure 34. When traffic lanes are increased in width, the width of the bicycle lane also is increased. This provides the bicyclist with some extra "psychological comfort" when traveling in the bicycle lane and for equitable sharing of extra street width.

Bicycle lane placement, however, is not only a function of two variables (motor vehicle speed and width of roadway). The prohibition of vehicle parking, average daily motor vehicle traffic volume, bicycle demand, roadway geometrics, and the bicycle lane system in the community are additional factors that should be carefully examined before a bicycle lane is established on a particular street.

FIGURE 33. ILLUSTRATIVE RELATIONSHIP OF AVERAGE MOTOR VEHICLE SPEED TO ROADWAY WIDTH

FIGURE 34. RECOMMENDATIONS FOR BICYCLE AND MOTOR VEHICLE
LANE WIDTHS

CHAPTER VI. FINDINGS AND RECOMMENDATIONS

Summary of Research

The objective of this study was to determine the effects of the operation of bicycles on the operation of motor vehicles when the two modes of transport share a common roadway. Four study sites were selected in the community of West Lafayette, Indiana. The period of study lasted for five months and was divided into 3 distinct phases - no school, summer school, and a regular academic session. Each site was studied at least once during each phase.

Three primary variables were measured; motor vehicle speed, motor vehicle displacement, and flow rates of bicycles and motor vehicles. Four conditions or cases of traffic on the roadway were defined (single motor vehicle, motor vehicles in opposing directions, bicycle and motor vehicle in same direction, and bicycle with motor vehicles in opposing directions) and each speed and displacement measured was classified into one of these cases.

Minimum desirable sample sizes were established for each case. However, these were not always obtained in the study because of very infrequent occurrences of several case conditions. Sample means, variances, and standard deviations were computed and analyzed. Using a confidence level of 90 percent, statistical tests of mean speeds and displacements were performed on the data to establish which conditions were of significance.

Findings

1. A reduction of vehicular speed occurred when a motorist was adjacent to a bicyclist in the bicycle lane. The range of mean speed reductions is shown below:

Street	Width of Roadway (ft.)	Reduction of Mean Speed (mph)	
		Minimum	Maximum
Third	29	0.88	3.16
University	35*	1.34	2.88
Grant	35	2.00	8.17
Salisbury	40	1.35	6.16

*One-way street with parking on left side and bicycle lane on right side. All others are two-way streets without parking.

2. The reduction of motor vehicle speed was greater when large volumes of bicycles were present on the roadway; such as during the morning peak-hour when going to school traffic existed.

3. Bicycles exhibited peak-hour characteristics with some flow rates exceeding 100 bicycles per hour. The morning peak for bicycles in West Lafayette is from 7:30-8:30 A.M. The evening peak is from 3:30-4:30 P.M. Bicycle flow at the Third Street and University Street sites (which were near a large midwestern university) increased rapidly for short increments of time (usually 10-20 minutes) when students were traveling to and from hourly classes at the University when it was in session. However, a fairly uniform and lower bicycle flow rate occurred throughout many hours of the day even when the University was not in session at these same two sites. At the Grant and Salisbury Street sites (which were near community public schools), bicycle volumes were minimal except during the morning and evening peak hours.

4. The presence of a bicyclist (case 3) caused an increase in the displacement of the motor vehicle. Shown below is the range of mean additional displacements of the vehicle from the bicycle lane when adjacent to a bicycle as compared to that of a vehicle traveling alone on the street.

Street	Width of Roadway (ft.)	Width of Bicycle Lane (ft.)	Increased Displacement due to the Presence of a Bicyclist (ft.)	
			Minimum	Maximum
Third	29	3.67	1.24	1.86
University	35*	3.50	0.98	1.83
Grant	35	3.83	0.09	0.55
Salisbury	40	4.33	0.06	1.45

*One-way street with parking on left side and bicycle lane on right side. All other streets are two-way traffic with no parking.

5. The mean speeds that were measured for case 1 (a single motor vehicle) were similar to the posted speed limits.

6. On roadways with traffic lanes of 14 feet or more in width, the presence of a motor vehicle in the opposing lane (case 2 conditions) had a small effect on the speed and displacement of the motorist in the lane being studied when compared to speed and displacement of average single vehicles. Speed reductions were found to range from 0.34 to 2.94 mph. Displacement reductions ranged from 0.09 to 0.51 feet.

7. The 20-pen event recorder used throughout this research was effective for measuring speeds to the accuracy desired. It should have further application for future speed studies where detailed information is needed.

Recommendations for Further Study

1. Investigate case 4 conditions for narrow streets where adequate sample sizes can be obtained, possibly by using a "test bicycle" in the study area.

2. Help to develop and co-ordinate a safety program which adequately includes bicycle safety for the greater Lafayette area for all age levels, grade school to adult. Emphasize the importance of understanding the meaning of all traffic signs and markings, traffic laws and ordinances, the bicycle as a viable mode of transportation, basic bicycle riding skills and safety philosophy and habits as applied to motor vehicle driving, bicycle use, and traffic safety.

3. A research project should be undertaken to evaluate the effects of bicycles on traffic flow where bicycle lanes currently do not exist. Roadways should be selected for study with traffic volumes, motor vehicle speeds, and roadway geometrics similar to those of this research project.

4. The actions of the bicyclist while on the roadway should be studied and evaluated. The effectiveness of the bicycle lane as a restricted right-of-way should be examined from the viewpoint of both the motorist and the bicyclist.

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APPENDIX A

Table A-1
General Information About Each Study

Site	Phase	Date of Study	Day of Week	Weather
Third Street	I	6/8/73	Friday	Sunny, Warm
	II	8/3/73	Friday	Sunny, Warm
	III	9/11/73	Tuesday	Cloudy, Cool
University Street	I	5/22/73	Tuesday	Cloudy, Cool
	II	6/29/73	Friday	Sunny, Warm
	III	9/25/73	Tuesday	Sunny, Warm
Grant Street	I	6/1/73	Friday	Sunny, Warm
	II	7/6/73	Friday	Sunny, Hot
	III	9/18/73	Tuesday	Clear, Cold
Salisbury Street	I	6/4/73	Monday	Warm, Rainy
	II	7/13/73	Friday	Sunny, Warm
	III	9/11/73	Tuesday	Sunny, Cool

FIGURE A I. THIRD STREET STUDY SITE

FIGURE A 2. UNIVERSITY STREET STUDY SITE

FIGURE A 3. GRANT STREET STUDY SITE

FIGURE A 4. SALISBURY STREET STUDY SITE

APPENDIX B

Table B-1
Accommodation of Bicycle Traffic

Source: AASHO Operating Subcommittee on Traffic Engineering
(July 1973)

State	Bicycle Facilities					Bicycles Allowed on High Speed or High Volume Highways			
	Shared Roadway	Exclusive Lane	Separated Path	Sidewalk	Other	Excluded	Travel Lane	Shoulder	Separated Path Exclusive Lane
Alabama	X	X					X		
Alaska	X	X		X			X	X	
Arizona	X						X	X	X
Arkansas	X			X				X	
California	X	X	X	X				X	X
Colorado	X	X	X	X	X		X	X	X
Connecticut	X			X		X			
Delaware	X			X			X	X	
Florida	X	X	X	X			X		
Georgia	X		X				X		
Hawaii	X	X	X	X			X	X	
Idaho	X	X	X				X	X	
Illinois					X		X	X	X
Indiana	X	X			X		X	X	
Iowa	X	X	X	X			X		
Kansas	X			X	X		X	X	
Kentucky	X			X			X	X	
Louisiana	X						X		

State	Bicycle Facilities					Bicycles Allowed on High Speed or High Volume Highways				
	Shared Roadway	Exclusive Lane	Separated Path	Sidewalk	Other	Excluded	Travel Lane	Shoulder	Separated Path	Exclusive Lane
Maine					X		X	X		
Maryland	X	X	X	X			X	X	X	
Massachusetts		X						X		
Michigan	X	X	X	X			X			
Minnesota	X	X	X	X			X	X	X	
Mississippi	X						X			
Missouri	X						X	X		
Montana	X						X			
Nebraska	X		X				X	X		
Nevada			NONE							
New Hampshire	X						X	X		
New Jersey			X				X	X		
New Mexico	X						X			
New York	X		X	X			X	X		
North Carolina	X	X	X				X	X		
North Dakota	X						X	X		
Ohio					X		X	X	X	
Oklahoma	X	X					X	X		
Oregon	X	X	X	X			X	X	X	
Pennsylvania	X		X				X			
Rhode Island	X					X				
South Carolina	X						X	X		
South Dakota	X			X				X		
Tennessee	X						X	X		
Texas	X	X	X	X			X			

State	Bicycle Facilities					Bicycles Allowed on High Speed or High Volume Highways				
	Shared Roadway	Exclusive Lane	Separated Path	Sidewalk	Other	Excluded	Travel Lane	Shoulder	Separated Path	Exclusive Lane
Utah	X						X			
Vermont	X		X					X		
Virginia					X		X			
Washington	X		X		X		X			
West Virginia	X						X			
Wisconsin	X		X		X		X	X		
Wyoming	X		X					X		
Summary	43	17	21	18	9	2	41	33	8	0

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