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PRELIMINARY

AN INVESTIGATION OF THE POTENTIAL FOR PATHWAYS SHARED BY PEDESTRIANS AND BICYCLISTS

Appendix W of the Pedestrian Planning Procedures Manual

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FOREWARD

This report was prepared for the Federal Highway Administration by RTKL Associates, Inc., in partial fulfillment of Contract DOT-FH-11-8816, "Feasibility Analysis and Design Concepts and Criteria for Community-Wide Separate Pedestrian Networks." This report will later be included as an appendix to a manual which offers a methodology for planning for pedestrians in Central Business Districts and other Multi-Land Use Districts. In order to expedite the flow of this information on the interaction of pedestrians and bicyclists, this report is being distributed at this time.

INVESTIGATION OF POTENTIAL FOR SHARED PATHWAYS--PEDESTRIANS & BICYCLES

INVESTIGATION OF POTENTIAL FOR SHARED PATHWAYS--PEDESTRIANS & BICYCLES

I. Introduction:

There is an increasing utilization of bicycles for short to medium length trips in urban areas. The characteristics of these bicycle trips with respect to length (time of trip) and purpose is often very similar to walking trips. In high density urban areas walking is already an important part of tripmaking both from transportation terminals to final destination and for internal circulation. If bicycles are to become a purposeful trip-making vehicle it will be necessary to provide facilities leading into the high employment or other high use areas. However, the intense vehicular traffic in and around these concentrated activity areas often precludes safe bicycling. Separate bicycle facilities in these areas are likely to be costly or infeasible in many situations. The opportunity is presented to increase the feasibility of facilities for pedestrians and bicycles by design of pathways for mixed use.

II. Level of Service and Volume Measurement:

The concept of Level of Service was developed originally in the field of traffic engineering in recognition that to design for maximum capacity or some percentage of maximum capacity was to plan for some level of congestion. The levels of design as established in the Highway Capacity Manual are based on service volumes and an evaluation of the level of driver convenience. The evaluation includes the freedom to:

1. Select and maintain a desirable vehicle operating speed.
2. Overtake and pass other vehicles.
3. Change lanes.

The Level of Service concept for vehicles provides a useful model as well for the design of pedestrian pathways. As developed by Fruin in Pedestrian Planning and Design,[1] the pedestrian service standards at various concentrations are similarly based on the freedom to:

1. Select normal walking speed.
2. Bypass slow-moving pedestrians.
3. Perform cross and reverse flow movements.

The Level of Service categories are based on a range of pedestrian area occupancies. If the pedestrian traffic is comprised of commuters or workers then the higher design volumes in a given range may be assumed. The lower range of design volumes would be recommended if traffic is comprised largely of shoppers, persons carrying baggage or if there are conflicting traffic movements.

The quantatative description of the levels-of-service, pedestrian flow volume, area relationships, and speed is shown in Table 1. The description of the qualitative aspects of each level of service is as follows:[2]

Level A

Sufficient area is provided for pedestrians to freely select their own walking speed, to bypass slower pedestrians, and to avoid crossing conflicts with others. Average walking speed is 264 feet per minute.

Level B

Sufficient space is available to select normal walking speed, and to bypass other pedestrians in primarily one-directional flows. Where reverse-direction or pedestrian crossing movements exist, minor conflicts will occur, slightly lowering mean pedestrian speeds and potential volumes. Average walking speed is 250 feet per minute.

Level C

Freedom to select individual walking speed and freely pass other pedestrians is restricted. Where pedestrian cross movements and reverse flow exist, there is a high probability of conflict requiring frequent adjustment of speed and direction to avoid contact. This level-of-service represents reasonably-fluid flow; however, considerable friction and interaction between pedestrians is likely to occur, particularly in multi-directional flow situations. Average walking speed is 230 feet per minute.

Level D

The majority of persons would have their normal walking speeds restricted and reduced, due to difficulties in bypassing slower-moving pedestrians and avoiding conflicts. Pedestrians involved in reverse-flow and crossing movements would be severely restricted, with the occurrence of multiple conflicts with others. At this level-of-service there is some probability of intermittently reaching critical density, causing momentary stoppages of flow. Average walking speed is 200 feet per minute.

Level E

Virtually all pedestrians would have their normal walking speeds restricted, requiring frequent adjustments of gait. At the lower end of the range, forward progress would only be made by shuffling. Insufficient area would be available to bypass slower-moving pedestrians. Extreme difficulties would be experienced by pedestrians attempting reverse-flow and cross-flow movements. The design volume approaches the maximum attainable capacity of the walkway, with resulting frequent stoppages and interruptions of flow. Average walking speed is 110 feet per minute.

Level F

All pedestrian walking speeds are extremely restricted, and forward progress can only be made by shuffling. There would be frequent, unavoidable contact with other pedestrians, and reverse or crossing movements would be virtually impossible. Traffic flow would be sporadic, with forward progress based on the movement of those in front. Average walking speed is less than 110 feet per minute.

Level of Service Category	Square Feet of Area Per Pedestrian	Pedestrians Per Foot Width Per Minute	Average Walking Speed in Feet Per Minute
	(M) Module	(PFM)	(FPM)
A	35+ sq. ft.	7 pfm	264 fpm
B	25-35 sq. ft.	7-10 pfm	250-264 fpm
C	15-25 sq. ft.	10-15 pfm	230-250 fpm
D	10-15 sq. ft.	15-20 pfm	200-230 fpm
E	5-10 sq. ft.	20-25 pfm	110-200 fpm
F	5- sq. ft.	up to 25 pfm	100- fpm

TABLE 1[3]
Level of Service--Pedestrian Walkways

It is possible to apply the Level of Service concept to bicycle as well as pedestrian pathways.

Level of Service criteria for bicycle facilities (which parallel those defined for motor vehicles and pedestrians in the "Highway Capacity Manual" and "Pedestrian Planning and Design") are as follows: [4]

Level A
Free flow with low volumes and full choice of velocity and lateral lane position. Average velocity usually above 11 miles per hour.

Level B
Stable flow with significant volumes and slight slowing of average stream velocity (10.5 to 11 miles per hour), but there is still a reasonably wide range of velocities present.

Level C
Flow is still stable, but speeds are markedly depressed. Maneuverability is restricted and velocity is largely determined by stream/velocity rather than choice. Average velocity is in the 9.5 to 10.5 mile per hour range.

Level D
Flow speed is greatly depressed and maneuverability is highly restricted. Velocity is in the 8 to 9.5 miles per hour range.

Level E

Flow speed is tremendously reduced. Maintaining balance may become a factor. Velocity is in the 6 to 8 miles per hour range.

Level F

Traffic may be stop and go. Flow is very unsteady. Velocity is unpredictable.

Level C conditions are specified as the minimum desirable service quality for engineering design. Increasing Level of service D is used in high density urban areas but more out of necessity than as the desirable standard. Levels below this (Figure 1) describe only service quality and are not design standards. Where feasible and where usage appears to warrant, provision of multiple lanes and level of service A or B conditions is recommended. Where multi-lane facilities are not feasible but width reservation above Level C minimum is possible, such reservation is recommended.

The minimum (Level of Service C) clear R.O.W. for a separate bicycle path including shy distance from intermittent lateral obstructions is 60" (5'-0") with 42" of the width actually paved. For facilities which are to be used bi-directionally only by bicyclist or for facilities to allow comfortable passing or side by side operation the minimum R.O.W. is 108.0" (8'-10") with 90" of the width paved. If a bicycle facility shares a right-of-way with pedestrians a minimum of 3 feet (36") additional paved width should be provided.[5,6]

The recommended clear R.O.W. for a single lane bicycle path is 68" (5'-8") with 50" paved and 118" (9'-10") with 100" paved for a two lane path. Level of service A and B conditions cannot be achieved until width for multiple-lane operation is provided.[7]

Typically, bikeway capacity requirements are not readily definable in terms of daily or hourly flow rates. Critical capacity conditions occur when individual bicyclists or groups of bicyclists encounter one another for brief periods of time, and are defined by brief, temporal flow rates.

It is rarely necessary to measure or estimate bicycle flow rates in bikes per second. Level of service conditions as defined in Figure 1 remain constant over virtually the full range of flow rates normally encountered in the most intense urban situations.

Only when flow rates above 0.6 bikes per second per lane--36 per minute--are anticipated (such as at class change periods on a college campus) need a planner be particularly concerned about specific flow rates.[8]

Normally, theoretical capacity is not the critical factor in determining facility width. Once basic service minimums are met, width becomes either a question of how much space can be made available (physical or economic feasibility) or a design policy decision of whether to provide enough width to permit bicyclists in company to ride side by side.

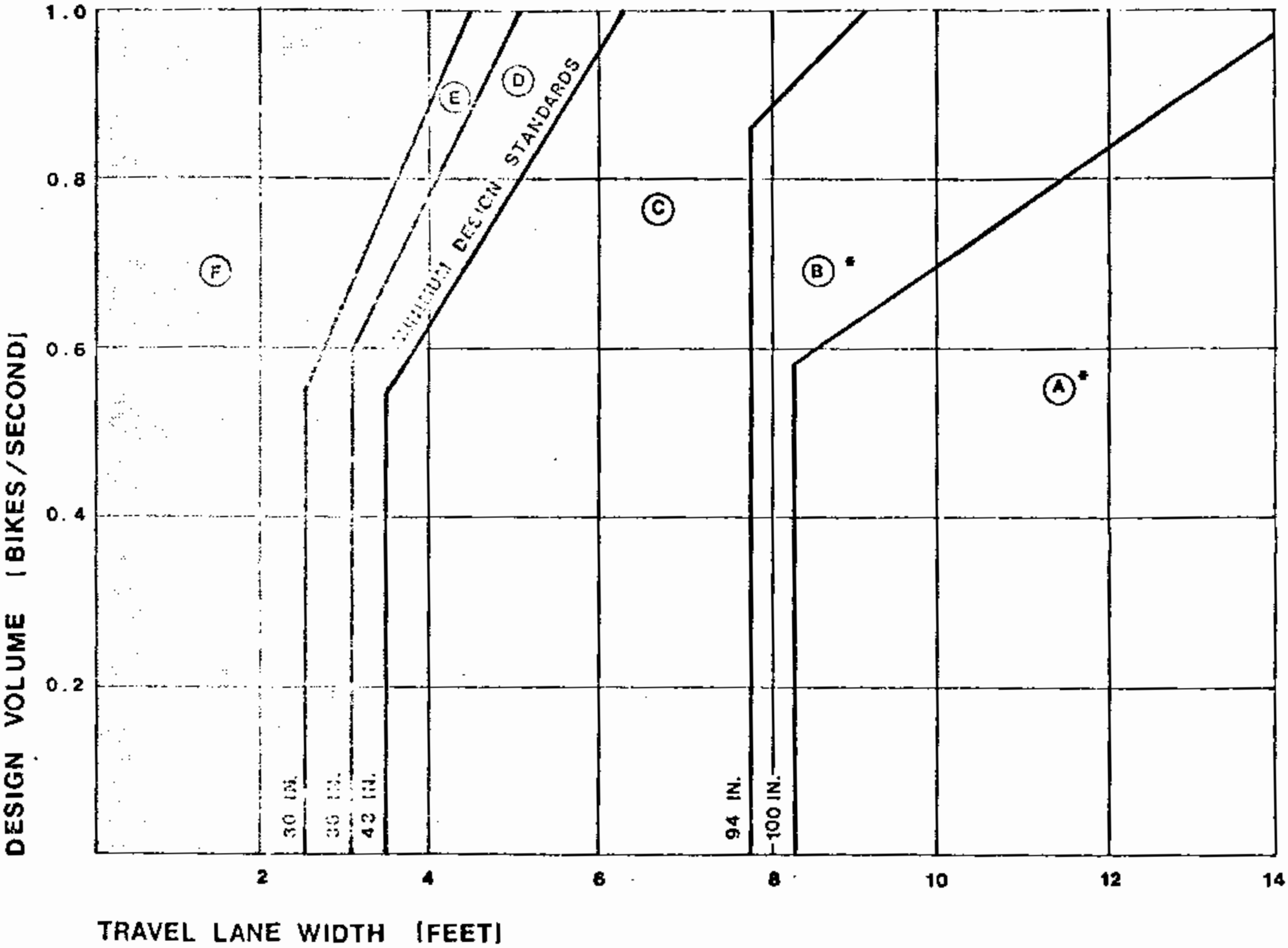
Level of Service Category	Square Feet of Area Per Bicycle	Bicycles* Per Foot Width Per Minute	Average Bicycling Speed	
	(M) Module	(BFM)	(FPM)	(MPH)
A	200 + sq.ft.	4.4+	968+	11.0+
B	143-200 sq.ft.	4.4 - 6.6	924 - 968	10.5 - 11.0
C (Minimum)	83-143 sq.ft.	6.6 - 10.0	836 - 924	9.5 - 10.5
D	59 - 83 sq.ft.	10.0 - 11.9	704 - 836	8.0 - 9.5
E (Capacity)	40 - 59 sq.ft.	11.9 - 13.2	528 - 704	6.0 - 8.0
F	40 - sq.ft.	Up to 13.2	528 -	6.0 -

* Minimum width for which these figures apply are approximately as follows:

Level of Service A: 8.0 Ft.] For these levels, a minimum of 2 lanes is deemed
Level of Service B: 7.5 Ft.] necessary to allow free overtaking.
Level of Service C: 3.5 Ft.
Level of Service D: 3.2 Ft.

TABLE 2

LEVEL OF SERVICE - BIKEWAYS



Ⓓ LEVEL OF SERVICE

* Double lane widths required as minimum condition to achieve levels of service A & B.

FIGURE 1

PATHWAY WIDTH – LEVEL OF SERVICE

III. Potential for Shared Pathways:

The central issue in a determination of the feasibility of joint use pathways is the compatibility of bicycles and pedestrians. This issue has two components:

1. Compatibility of physical design standards and criteria of each type of pathway.
2. Compatibility of the operational and behavioral characteristics of each mode.

The compilation of design standards for pedestrian and bicycle facilities is included in Table 2 attached. In many cases design standards for one mode are not applicable to the other mode but do not inherently contribute to an incompatibility of mixed use pathways.

In summary, Table 2 demonstrates that the speed of bicycle movement necessitates a number of design standards to accommodate safely the bicycle moving at the design speed. These standards include requirements related to:

1. Curvature
2. Curve Widening
3. Superelevation
4. Stopping Sight Distance
5. Sight Distance for Vertical Curves
6. Sight Clearances at Intersections
7. Horizontal Sight Clearance

In certain configurations curvature for bicycles may increase pathway length for pedestrians and excessive superelevation may result in walking difficulty. However, with recognition of these minor limitations there are no standards for bicycle pathways which would preclude their use by pedestrians.

PEDESTRIAN WALKWAYS	BIKEWAYS
Design Speed: normal walking speed of 265 fpm or 3 mph is not of sufficient magnitude to require design considerations related to speed.	Design Speed: normal bicycle operating speeds require pathway design in accordance with the following criteria: 1. 20 mph recommended design speed for bikeways with grades between +3% and -7%[1] 2. 30 mph recommended design speed for grades steeper than -7%[1] 3. 15 mph recommended design speed for one-way grades of greater than +3%[1]
Turns: there is no necessity for the use of a curve radius in pedestrian walkways. Right angle turns are permissible and curvature should not be used if it increases trip time or trip distance.	Turns: Adequate curve radii are necessary to provide a smooth transition in change of direction. The size of curve radius is directly related to design speed. The following linear equation determines the desirable curve radius to the speeds bicycles normally travel:[3] $R = 1.25\,V + 1.4$ where V = Speed in MPH R = Curve radius in feet If the angle between consecutive tangents is 10° or less no curve is required.
Curve Widening: There is no necessity to widen curves on pedestrian walkways.	Curve Widening: There is a tendancy for cyclists to lean to the inside in a turn and thus increase the lateral space occupied. To compensate for this bikeway pavements should be widened on short radius curves. The State of Oregon has developed a standard methodology for widening bikeway curves with radii of less than 100 feet. Maximum widening is limited to 4 feet.[1]

TABLE 3

<table>
<tr><th>PEDESTRIAN WALKWAYS</th><th>BIKEWAYS</th></tr>
<tr><td><u>Superelevation</u>: There is no need for superelevation in pedestrian pathways and the existence of superelevation of any significant degree increase walking difficulty and cause pathway impedence.</td><td><u>Superelevation</u>: The use of superelevation or banking of curves is used on bikeways to increase bicycle stability and reduce the required curve radius. The superelevation for bikeways is based on the standard highway curvature/superelevation equation. Superelevation for bikeways should never exceed .12 foot per foot and the State of Oregon recommends that a maximum of .06 foot per foot superelevation be used when pedestrians constitute 50% or more of the traffic. In areas where icing conditions are anticipated the .06 maximum is also advisable.[1]
The tendency of cyclist to lean into the turn may reduce the need for superelevation in many circumstances.[3]</td></tr>
<tr><td><u>Stopping Sight Distance</u>: There is no need to provide for stopping sight distance on pedestrian walkways. The pedestrian is capable of a near instantaneous stop.</td><td><u>Stopping Sight Distance</u>: The required stopping distance for a range of typical bikeway speeds on various grade profiles is represented by the equation:
$$S = \frac{V^2}{30f \pm G} + 3.67V$$
where: S = stopping sight distance, ft.
V = velocity, mph
f = coefficient of friction (use 0.25)
G = grade, ft./ft. (rise/run)

The maintenance of sight clearance areas to permit a safe stopping distance is required at all locations of possible conflict.</td></tr>
</table>

TABLE 3 (Continued)

PEDESTRIAN WALKWAYS	BIKEWAYS
Sight Distance for Crest Vertical Curves: There is no need to apply criteria related to sight distance for crest vertical curves to pedestrian pathway design.	Sight Distance for Crest Vertical Curves: The stopping sight distance for cyclist cresting vertical curves is determined by the following formula: $L = 2S \frac{200 (\sqrt{h_1} + \sqrt{h_2})^2}{A}$ when $S > L$ $L = \frac{AS^2}{100 (\sqrt{2h_1} + \sqrt{2h_2})^2}$ when $S < L$ where: S = stopping distance A = algebraic difference in grade h_1 = 4-1/2 feet.--eye height of cyclist h_2 = 1/3 ft.--height of object L = minimum vertical curve length

TABLE 3 (Continued)

PEDESTRIAN WALKWAYS	BIKEWAYS
Sight Clearance for Intersections: The low speed and capability for instantaneous stop characteristic of the pedestrian permit a reduction of intersection sight clearances from those required for bicycles. Sight lines must be clear to permit the driver to see a pedestrian which may step from the pathway into the street and, likewise, permit the pedestrian to see vehicular traffic prior to entering the roadway.	Sight Clearance for Intersections: At the intersection of a bikeway with a motor vehicle roadway at a safe stopping distance from the crossing, the cyclist must be able to see any opposing vehicle which would pose a conflict at the crossing. The time for intersection clearance from the "stop-go" decision point is given by: $t_1 = \frac{S + W + 6}{Vb}$ where S = Stopping Distance (including perception and reaction time) at design speed taken from Figure 19 W = Width of crossing Vb = Actual bikeway typical approach speed (rather than design speed) Time for near side lane(s) clearance is given by: $t_2 = \frac{S + W/2 + 6}{Vb}$ A crossing cyclist at the "decision point" must be able to see any vehicle which would threaten conflict in the crossing within time t_1 or t_2. Thus, the cyclist at the decision point must be able to see approaching vehicles at the following distances: near side $X = t_2 V_{mv} = \frac{V_{mv}}{Vb} (S + W/2 + 6)$ far side $y = t_1 V_{mv} = \frac{V_{mv}}{Vb} (S + W + 6)$ Projections between the "stop-go" decision points and the points given by x and y define the sight clearance areas.

TABLE 3 (Continued)

PEDESTRIAN WALKWAYS

Horizontal Sight Clearance: There is no necessity to apply horizontal sight clearance criteria to pedestrian pathways design.

Grades: The maximum recommended grade for ramps on pedestrian walkways is one inch per foot or 8.33% grade. Ramps should have level platforms at 30 foot intervals.[2]

BIKEWAYS

Horizontal Sight Clearance: The maintenance of sight clearance on curves is necessary to allow sufficient stopping distance before a fixed object. The computation of minimum sight distance and clearance on horizontal curves is determined by the equation:

$$M = R\left(\text{vers}\ \frac{28.655}{R}\right)$$

$$S = Sv_1 + Sv_2$$

where R = Radius of curvature
S = Safe stopping distance along lane centerline (see distance)
M = Obstruction offset from lane centerline
Sv_1 = Stopping sight distance of vehicle 1
Sv_2 = Stopping sight distance of vehicle 2

Grades: The maximum recommended grade for bicycleways is 5%. The length of grades recommended is as follows:[4]

	Maximum Length	Desirable Length
5%	300'	100'
2%	1500'	500'

A 10% grade can be used for short runs.

-inued)

PEDESTRIAN WALKWAYS	BIKEWAYS
Surface, Base and Subgrade: The desirable surface treatment for walkways is generally the same as that for bikeways.	Surface, Base and Subgrade: Candidate surface and base materials include: stabilized earth, stone chip, soil cement, asphalt cement, hot-mix asphalt concrete, colored hot-mix, cold-mix asphalt concrete, soil asphalt, concrete and moveable walks. The surface of the pathway should provide a consistent smooth texture.
Paved Width: The minimum paved width for a pedestrian walkway is 4 ft.	Paved Width: The minimum paved width required for a two-way bikeway is 8 feet and for a one-way bikeway 6 feet. Widths greater than these are desirable and should be considered whenever large amounts of bicycle traffic or bicycle and pedestrian traffic is anticipated.[1]
Horizontal and Vertical Clearance: The minimum vertical clearance is 8 feet for interior walkways and a minimum 10 foot clearance is recommended for exterior pathways.	Horizontal and Vertical Clearance: The desirable vertical clearance is 9.5 feet and should not be less than 8.5 feet. The horizontal clearance between the edge of the bikeway pavement and any obstruction should be two feet (signs, vegetation, etc.). Standard bridge or other crossing structure is 12 feet.[1]

TABLE 3 (Continued)

PEDESTRIAN WALKWAYS

Vertical Change: Vertical change on a pedestrian pathway can be accomplished by means of ramps, stairways, escalators or elevators. Each one of these vertical change elements has certain characteristics of cost and utilization which is generally expressed in tabular form as follows:

	Pedestrian Energy Expenditure	Pedestrian Time Delay	Capacity	Costs
Ramps	H	L	H	L
Stairways	H	L	H	L
Escalators	L	L	M	H
Elevators	L	M-H	L	M

where H = high
M = moderate
L = low

BIKEWAYS

Vertical Change: Vertical change on a bikeway can only be accomplished by means of a ramp. Stairways, elevators or escalators are clearly not appropriate means of vertical change on a bicycle pathway.

TABLE 3 (Continued)

TABLE 3 REFERENCES

1. Oregon State Highway Division. Bikeway Design Salem, Oregon. January 1974

2. Institute of Transportation and Traffic Engineering. Bikeway Planning Criteria and Guidelines. Los Angeles, California. School of Engineering and Applied Science, University of California. April 1972

The design standards for exclusive pedestrian walkways do present difficulties for bicycles. The use of 90° turns on pedestrian walkways is common and often mandatory in highly urbanized areas. Turns of this type are difficult for cyclist and present significant safety hazards. Additionally, the use of stairways, escalators or elevators on the pathway preclude its use by bicycles.

The review of the physical design parameters of pedestrian and bicycle facilities indicates that mixed use pathways are possible given certain compromises and limitations of the design (ex. longer distances due to curves; ramps instead of stairs, etc.). In many highly urbanized locations, however, such design compromises may not be possible and separate facilities are necessary based solely on the physical design criteria.

The second issue in the combination of pedestrian and bicycle pathways is the compatibility of the operational and behavioral characteristics of each mode. The characteristics which have been identified as contributing to conflicts are as follows:

1. The normal walking speed of 265 fpm or 3 mph compares to the average operational speed for bicycles of 12 and as much as 30 mph on downhill grades. The bicycles will typically be moving at 4 times and occasionally as much as 10 times the speed of pedestrians creating both psychological stress and potential safety problems for both pedestrian and cyclist.
2. Pedestrians are extremely mobile directionally and often,unpredictably change direction laterally within the pathway. Bicycles are not particularly mobile laterally and have difficulty making sudden adjustments in direction. This factor coupled with the difference in travel speed leads to a high conflict potential.
3. If the utilization of the mixed use pathway approaches capacity, conflicts are inevitable. The volumes of pedestrians and bicycles must both be in the low-moderate range with neither mode predominating over the other.

IV. Measurement of Conflict Potential

The investigation of conflict between pedestrians and bicycles is the measurement of the number of avoidance maneuvers that each mode is required to make in order to prevent either collisions or passing closer than the minimum clearance space. The minimum clearance space is defined as the personal comfort zone which exists for both the pedestrians and cyclists. It includes the space actually occupied by the person or bicycle, an additional lateral space requirement because neither mode travels in a true straight line and an additional shy clearance from lateral obstructions.

The number of potential conflicts between pedestrians and cyclists results to a large degree from the difference of operational speed. A bicycle at its operational speed of 12 mph or 1056 fpm will travel along a distance in 1 minute ual to distance a pedestrian travels in 4 minutes.

The number of pedestrians actually passed by the cyclist in 1 minute will vary depending on the relative direction of travel. If the direction of travel is the same, a cyclist will pass only "3 minutes" of pedestrians in one minute. If the direction of travel is opposite, a cyclist will pass "5 minutes" of pedestrians in 1 minute. This difference is a result of the combined speed or closing speed of the two modes which is either 15 mph (12 mph + 3 mph = 15 mph) or 9 mph (12 mph - 3 mph = 9 mph).

With the distribution of travel assumed to be even in each direction, a cyclist will pass an equivalent of 4 minutes of pedestrian volume on the pathway in 1 minute of travel time.

On a pathway 10 feet wide with a pedestrian volume at the capacity of level of service A (35 sq. ft./person or 7.5 persons/ft./min. or 75 persons/min.) a cyclist traveling at an average speed of 12 mph will pass 300 pedestrians/minute. One bicycle lane with sufficient operating space plus minimum clearances is 5'-0" (Section II). Therefore, a bicycle operating on the 10 foot wide pathway would be involved in conflicts or avoidance maneuvers with approximately one half (5'-0" is 50% of 10'-0") or 150 pedestrians per minute or 2.5 conflicts per second.

The number of conflicts per bicycle per minute on a pedestrian pathway can be calculated for each level of service with the following formulas:

1. The number of "minutes" of pedestrians passed per minute of bicycle travel equals:

$$T_i = \frac{V_b}{V_{pi}}$$

where T_i = number of pedestrian "minutes" within a bicycle minute for pedestrian level of service i

V_b = speed of bicycle in feet/minute

V_{pi} = speed of pedestrians in feet/minute for pedestrian level of service i

2. The number of pedestrians moving along a pathway in one minute equals:

$$P_i = \frac{V_{pi} \times W}{M}$$

where P_i = pedestrians per minute for pedestrian level of service i

V_{pi} = speed of pedestrians in feet/minute for pedestrian level of service i

W = width of the pathway in feet

M = space module (sq. ft.) per pedestrian for level of service i

3. The percentage of pedestrians in the pathway which would conflict the bicycle equals:

$$A_i = \frac{5.0}{W}$$

where A_i = percentage of pedestrians on pathway which would require an avoidance maneuver to prevent conflict.
W = width of the pathway in feet.

4. The number of conflicts per bicycle per minute is equal to:

$$C = T_i \times P_i \times A_i$$

Table 4 and Figures 2 & 3 tabulate the number of conflicts for each of five levels of service for a walkway width of 10'- 0".

Level of Service	Speed	Space Module Per Person	T_i	P_i*	A_i*	C
	(FPM)	(sq. ft.)	(Min.)	Ped./Min.		
	(V_p)	(M)				$T_i x P_i x A_i$
A	264	35	4.0	75.4	.5	151
B	250	25	4.2	100.0	.5	210
C	230	15	4.6	153.3	.5	353
D	200	10	5.3	200.0	.5	530
E	110	5	9.6	220.0	.5	1056

*assume W = 10.0 ft.

TABLE 4
Pedestrian Bicycle Conflict

The evaluation of the data developed in Table 3 yields two obvious conclusions.

1. The number of conflicts per minute between a single bicycle at its desired travel speed and pedestrians on a walkway quickly becomes excessive as pedestrian volume increases. Even at pedestrian level of service A the number of conflicts would be 2.5 per second.

2. The amount of space available for bicycles to maneuver becomes extremely limited even as pedestrian volume approaches the limit for level of service A.

In an unrestricted pathway (no separation of pathway or designation of separate lanes for pedestrians and bicycles) the number of conflicts must be kept to a level which permits an adequate response time. During this time, between two periods of unimpeded travel, a series of events must take place as follows:

- unimpeded travel
1. recognition of conflict situation
2. determination of alternative actions to avoid the conflict
3. evaluation of alternatives
4. decision as to best alternative
5. initiate and complete avoidance maneuver
- unimpeded travel

The time required to complete these series of events varies primarily as a function of the time necessary to complete the avoidance maneuver. The perceptual and decision making Steps 1-4 will normally require a maximum of a few seconds. The maneuver itself (Step 5) would require at least a similar time and possibly considerably longer. It might be possible for a cyclist to respond mentally and physically to a conflict situation approximately every 5 seconds. This however would require a near continuous process of conflicting avoidance decision making and maneuvers.

An additional consideration is the psychological stress on a cyclist who is required to deal with conflict situations. An uninterrupted series of situations which involve conflict and avoidance maneuvers places considerable stress on cyclist and will significantly affect his psychological comfort and his satisfaction with the pathway. Little research has been done on this issue related specifically to making decisions and completing tasks similar to the sequence previously outlined. However a reasonable limitation can be assumed based on the desirable movement characteristics of the cyclists. It can be stated with confidence that the typical cyclist should be able to deal with an average of two conflict situations per minute without significant effect on psychological comfort. However, it can be stated that one conflict situation in each 5 second period on the average, while perhaps physically possible to deal with, would place considerable stress on the cyclist. This situation would not be an acceptable a condition for a shared pathway.

Therefore a rate of 2 or less conflicts per minute is acceptable and 12 or more conflicts per minute is clearly unacceptable. The maximum level of conflict acceptable for shared pathways lies somewhere between these two figures. This level will by necessity be much closer to the lower range of 2 per minute than 12 per minute to allow sufficient lattitude for the cyclist with a lower level of riding skill or less ability to deal with stress situations.

A more precise identification of this level would require extensive behavioral/psychological experimentation and is beyond the scope of this research effort. However, such precise identification is not necessary for the completion of this investigation of the potential for shared pathways. A threshold of 6 conflicts per minute is chosen as a conservative limit and would require the completion on the average of one avoidance each

10 seconds. The analysis, findings and conclusions of the investigation would not be substantially altered by a somewhat higher or lower figure. This translates to 6 pedestrian to be avoided per minute of bicycle travel (1056 feet). Within a 5.0 foot bicycle corridor this is a pedestrian module of one pedestrian per 880 square feet.

$$M = \frac{V_{pi} \times W}{P_i}$$

$$M = \frac{1056 \text{ ft./min.} \times 5.0 \text{ ft.}}{6 \text{ ped./min.}}$$

$$M = 880 \text{ sq. ft./ped.}$$

At a walking speed of 264 fpm this translates to a pedestrian flow rate of 0.3 pfm.

$$P_i = \frac{V_{pi} \times W}{M}$$

$$P_i = \frac{264 \text{ ft./min.} \times 5.0 \text{ ft.}}{880 \text{ ft.}^2\text{/ped.}}$$

$$P_i = 1.5 \text{ ped./min.}$$

For a 5.0 ft. bicycle corridor:

$$\frac{1.5 \text{ ped./min.}}{5.0 \text{ ft. width}} = 0.3 \text{ ped./ft. width/min.}$$

Thus a pedestrian flow rate of 0.3 ped./ft./min. on a pathway would permit joint use in an unrestricted configuration. The minimum paved width of such a joint use facility, using minimum operating space for both pedestrians and bicycles, would be 78" or 6'-6".

Figure 3 is an expansion of a portion of Figure 2 and shows the previously calculated maximum level of acceptable conflict at .3 PFM. A volume greater than .3 PFM would result in the cyclist responding to more than 6 conflicts per minute or in excess of 1 conflict each 10 seconds. This volume of pedestrians is considerably below the typical range of volume on urban walkways. Therefore, mixing of bicycles and pedestrians on urban pathways in an unrestricted configuration will result in unacceptable levels of conflict.

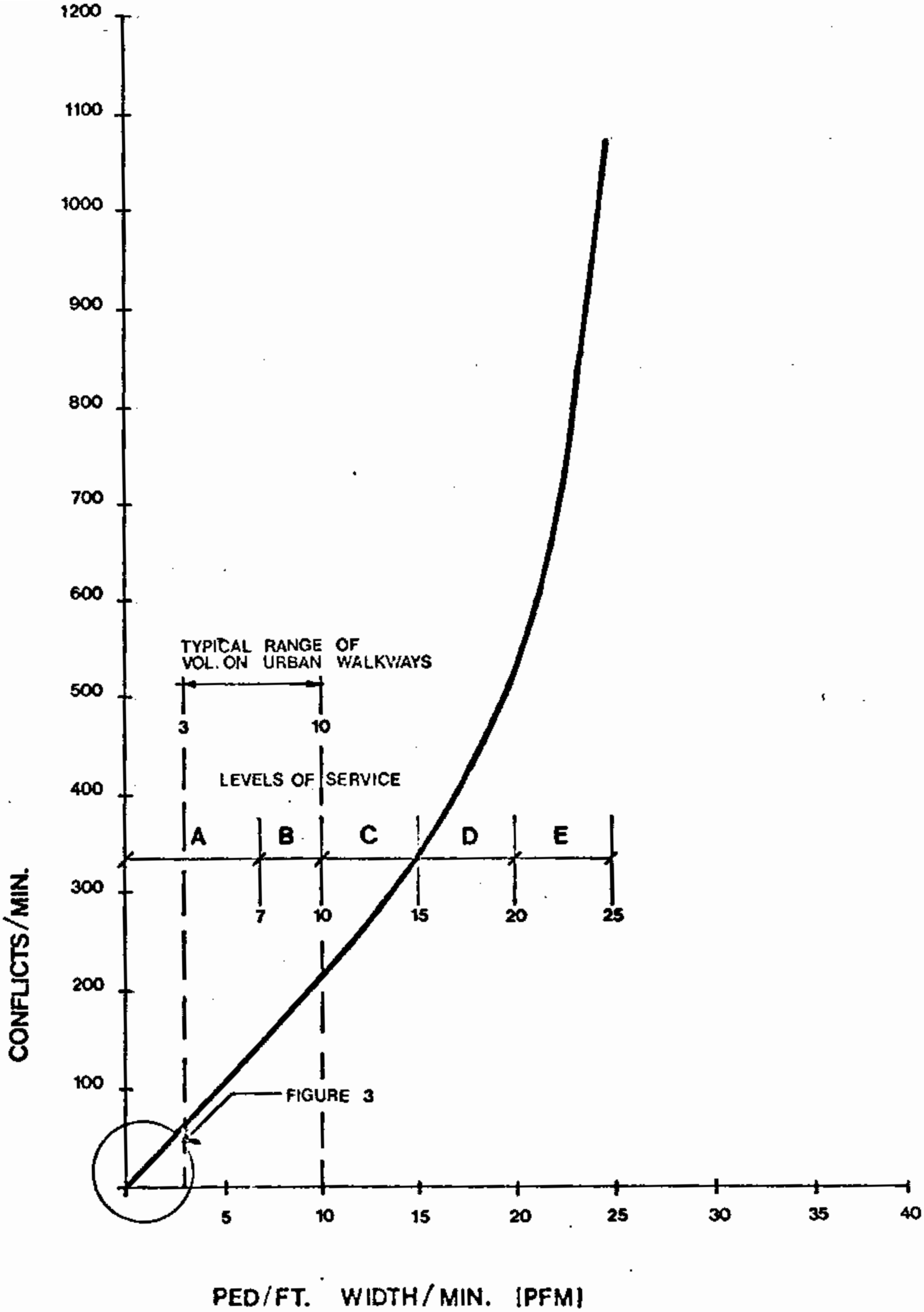


FIGURE 2
PEDESTRIAN/BICYCLE CONFLICTS

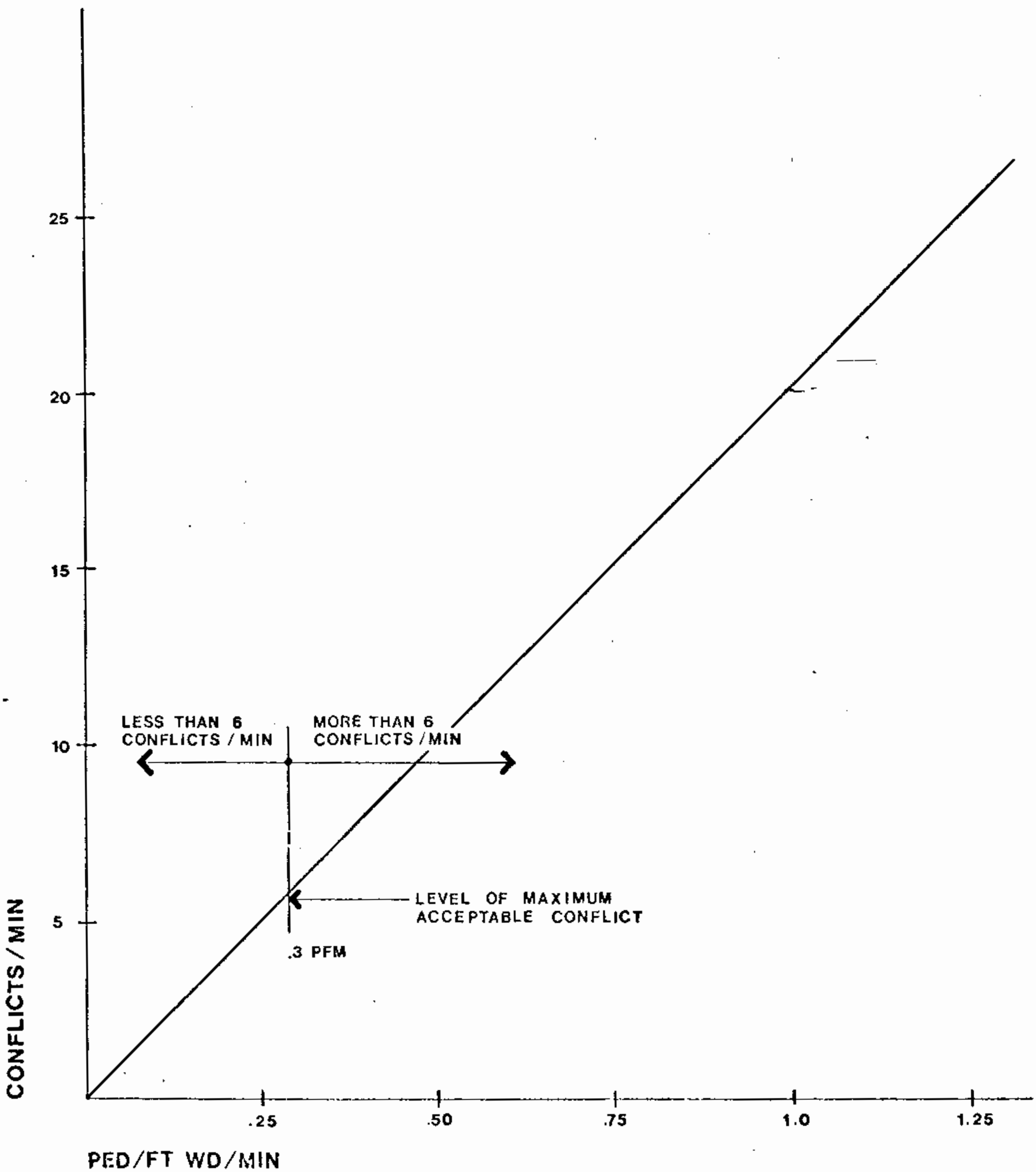


FIGURE 3
PEDESTRIAN/BICYCLE CONFLICTS

V. Potential for Shared Right-of-Way

The excessive number of conflicts which result in mixing pedestrians and cyclists on an unrestricted pathway can be reduced through the development of a protected bicycle lane. This is a pathway in which a positive physical separation is placed between the pedestrian and the cyclist. The separation can be achieved through striped buffer areas or raised median strips. On a pathway with moderate volumes of either pedestrians or bicycles a surface marking such as a painted strip is not recommended. This means of separation does not sufficiently prevent encroachment of one mode into the pathway of the other and will result in excessive conflicts.

The use of a median barrier on pathways does reduce modal conflict but presents other problems:

1. The width (min. 5.0 ft.) required to reserve part of a walkway for bicycles necessitates either a reduction of the width remaining for pedestrians or a widened R.O.W. The narrowing of the walkway width decreases the Level of Service and increases pedestrian-pedestrian conflicts. An increased pedestrian/bicycle R.O.W. will, in most urban conditions, require a commensurate decrease in the vehicular R.O.W. either in terms of elimination or the reduction in size of a parking lane or moving traffic lane.
2. If the barrier is broken for driveways, etc., the accident potential increases substantially as the cyclist, confined to a narrow corridor, cannot take evasive action when a vehicle enters the lane.
3. The conflict at intersections between through cyclists and right turning vehicles is further exacerbated because of lack of space for the cyclist to maneuver and a possible perception by the motorist that the bicycle traffic, in a separate R.O.W., is not in a situation of potential conflict.
4. The bicycle lanes will be difficult to maintain as gravel and debris are likely to accumulate in the relatively narrow lanes.
5. The barriers to separate pedestrian and bicycle traffic are expensive to construct.

References

1. Fruin, John J. Pedestrian Planning and Design. New York: Metropolitan Association of Urban Designers and Environmental Planners (MAUDEP). 1971. 206 p.

2. Ibid p. 80-82

3. Ibid p. 80-82 and p. 42.

4. U. S. Department of Transportation. Safety and Locational Criteria for Bicycle Facilities. Draft, Users Manual Volume II Design and Safety Criteria. Washington, D.C. Report No. FHWA-RD-75-114 February 1976. p. 26

5. Homburger, Wolfgang S. Capacity of Bus Routes, and of Pedestrian and Bicycle Facilities. Berkeley, California. Institute of Transportation Studies, University of California, February 1976 p. 11

6. Op. Cit. U. S. Department of Transportation p. 28

7. Ibid p. 29

8. Ibid p. 32

9. Ibid p. 34

Part B. Field Survey of Joint Use Pathways

I. Introduction

The analysis developed in Part A concluded that the maximum volume of pedestrians on a pathway which would permit shared use with bicycles was 0.3 PFM. This maximum pedestrian volume would require a cyclist, operating at a speed of 12 mph, to perform a maneuver to avoid 6 pedestrians per minute or 1 conflict each 10 seconds. At a higher level of pedestrian volume and thus a higher level of conflict, sufficient time would not be available for the cyclist to recognize and respond to conflict situations. The cyclist would be required to reduce average speed in order to maneuver successfully within the increased pedestrian traffic.

II. Survey Site

In order to test the conclusions regarding the maximum allowable volumes of shared pathways a field survey was conducted. This survey was made on the boardwalk at Ocean City, Maryland on two days, Thursday September 2, 1976 and Sunday September 5, 1976. This site was chosen as it afforded the opportunity to survey a relatively high volume of both pedestrians and bicycles using the same pathway.

The Municipality of Ocean City has had an ordinance since 1965 which prohibits bicycles on the boardwalk from 10:00 a.m. to sunrise of the following day. However, from sunrise each day until 10:00 a.m. both bicycles and pedestrians are permitted to use the boardwalk. The purpose of the ordinance is to separate pedestrians and bicycles by time to some degree and thus reduce the level of conflict. No studies or surveys of the problem were conducted prior to the enactment of the ordinance. One city official stated that "it was an obvious thing, something had to be done." Instead of prohibiting bicycles completely, the ordinance is a compromise in which bicycles are permitted in the early morning hours when pedestrian volume is low and the potential for conflict at a minimum. The time limit was established based primarily on the observed rapidly increasing volume of pedestrians after 10:00 a.m. and a corresponding increase in conflict.

III. Survey Methodology

The survey was taken from 8:30 a.m. to 10:15 a.m. on September 2, 1976 and again from 8:00 a.m. to 10:15 a.m. on September 5, 1976. The second survey period was conducted primarily as a result of a light rain which occurred during the September 2, 1976 survey period reducing both the bicycle and pedestrian volume.

Prior to the survey period two cordon lines were established on the boardwalk a known distance apart and the width of the boardwalk was measured. The observation point for the survey team was located on a third floor deck adjacent to the boardwalk approximately midway between the cordon lines. The observation point permitted a clear view of all points within the survey area.

The data was collected as a series of consecutive 15-minute surveys to permit comparison of fluxuations in volume and conflicts. The number of both pedestrians and bicycles crossing a cordon line were counted during the first 5 minutes of each 15-minute period. The speed and conflicts were measured by selecting at random a pedestrian or cyclist crossing a cordon line and measuring both the time required to traverse the distance between the lines and counting the number of maneuvers required to avoid conflict with pedestrians or cyclists. An individual surveyed was additionally categorized on the survey sheet according to the following:

Sex

M - Male
F - Female

Age

C - Child, age 12-
Y - Young, age 13-23
M - Middle, age 24-60
O - Elderly, age 60+

IV. General Observations

In addition to the survey data collected, several observations were made regarding the specific site and conditions under which the survey was taken and the general behavior of pedestrians and bicycles on a joint-use pathway.

The site specific observations include:

1. The operating speed of the cyclists and walking speed of the pedestrians on the boardwalk are both substantially below that measured in typical urban environments. This can be attributed to the predominant trip purpose of boardwalk users which is recreational walking or cycling and is not strongly destination oriented.
2. The overall level of bicycle riding skill observed was below that observed on typical bicycle routes. The majority of the cyclists were people on vacation who were riding bicycles rented along the boardwalk. The level of riding skill can be attributed to the unfamiliarity with the bicycle and/or the users' lack of experience as a cyclist.
3. The actual width (24') and the effective width (18') of the boardwalk is wider than the typical pathway in an urban area. The wider pathway permits additional room for maneuvering and thus reduces the level of conflict.

The general observations regarding pedestrian and bicycle behavior include:

1. Bicycles often maneuver to avoid conflicts with pedestrians but pedestrians rarely move to avoid bicycles. This is primarily attributed to the relative rate of speed and the area of visual control of each mode. A cyclist, with the greater speed, must be aware of possible impedences in the pathway at a greater distance than that required for pedestrians. As a result, cyclists selecting a route will typically be looking further down the pathway than the pedestrian. Generally, the cyclist meeting the pedestrian will become aware of the potential conflict and begin an avoidance maneuver prior to the

pedestrian recognizing the conflict. The cyclist traveling in the same direction as a pedestrian will overtake maneuver and pass a pedestrian traveling in the same direction. The pedestrian will often be unaware of the cyclist's presence until after the conflict situation has passed.

2. Cyclist traveling about in the same direction experience a series of minor conflicts as adjustments in route are required to prevent encroaching too close to the other bicycle. These parallel conflicts are a normal part of cycling and are not considered significant.

IV. Survey Results

The survey data is documented in Tables 5 through 10 and Figures 4 through 8. Table 5-7 documents the September 2, 1976 survey and Table 8-10 documents the September 5, 1976 survey. Figure 4 is a graphical compilation of the data in Tables 5-10 relative to observed pedestrian and bicycle and pedestrian and bicycle conflict. The distribution of travel speed for both pedestrians and bicycles is illustrated in Figures 5-8.

Time	Interval	Volume of Pedestrians			Volume of Bicycles		
A.M.	Minute	Count	Ped./Minute	PFM	Count	Bikes/Minute	BFM
8:30-8:35	5	7	1.4	.08	42	8.4	.47
8:45-8:50	5	1	0.2	.01	53	10.6	.59
9:00-9:05	5	12	2.4	.13	46	9.2	.51
9:15-9:20	5	18	3.6	.20	52	10.4	.58
9:30-9:35	5	13	2.6	.14	48	9.6	.53
9:45-9:50	5	12	2.4	.13	53	10.6	.59
9:57-10:02	5	13	2.6	.14	12	2.4	.13
10:18-10:23	5	26	5.2	.28	0	0	0
Average	5	12.8	2.6	.14	38.3	7.7	.43

PFM = Pedestrians per foot width per minute
BFM = Bicycles per foot width per minute

TABLE 5

PEDESTRIAN/BICYCLE VOLUME--SURVEY 9/2/76

	Child		Young		Middle		Old		Average		
	M	F	M	F	M	F	M	F	M	F	M&F
Pedestrian	292*	256*	246	228	226	235	226*	230*	237	231	234
Cyclist	849	593*	814	659	697	619	742*	553*	776	630	717

*sample not of sufficient size to be statistically significant

TABLE 6

PEDESTRIAN/BICYCLE SPEED--SURVEY 9/2/76

	Cyclists	Observed Conflicts		Conflict Probability		Average Observation Time	Adjustment Factor	Adjusted Conflict Probability (conflicts/min)		
		w/ped	w/bicycle	w/ped	w/bicycle	T	60/T	w/ped	w/bicycles	Total
8:30-10:15	51	11	25	.21	.49	12.3	4.9	1.0	2.4	3.4

TABLE 7

PEDESTRIAN/BICYCLE CONFLICT--SURVEY 9/2/76

Time	Interval	Volume of Pedestrians			Volume of Bicycles			Total
A.M.	Min.	Count	Ped/Min.	PFM	Count	Bikes/Min.	BFM	PFM & BFM
8:00-8:05	5	13	2.6	.14	34	6.8	.38	.52
8:15-8:20	5	7	1.4	.08	46	9.2	.51	.59
8:30-8:35	5	25	5.0	.28	73	14.6	.81	1.09
8:15-8:50	5	19	3.8	.21	84	16.8	.93	1.14
9:00-9:05	5	23	4.6	.26	119	23.8	1.32	1.58
9:15-9:20	5	25	5.0	.28	90	18.0	1.00	1.28
9:30-9:35	5	34	6.8	.38	84	16.8	.93	1.31
9:45-9:50	5	43	8.6	.48	68	13.6	.76	1.24
10:00-10:05	5	42	8.4	.47	27	5.4	.30	.77
Average	5	25.7	5.1	.29	69.4	13.9	.77	1.06

TABLE 8

PEDESTRIAN/BICYCLE VOLUME--SURVEY 9/5/76

	Child		Young		Middle		Old		Average		Average
	M	F	M	F	M	F	M	F	M	F	M&F
Pedestrian	-	-	-	-	-	-	-	-	-	-	-
Cyclist	763	636*	867	656	683	586	575*	871	757	633	697

*sample not of sufficient size to be statistically significant

TABLE 9

PEDESTRIAN/BICYCLE SPEED--SURVEY 9/5/76

	Cyclists	Observed Conflicts		Conflict Probability		Average Observation Time	Adjustment Factor	Adjusted Conflict Probability (conflicts/min)		
		w/ped	w/bicycle	w/ped	w/bicycle	T	60/T	w/ped	w/bicycles	Total
8:05-8:15	12	1	4	.08	.33	14.3	4.2	0.3	1.4	1.7
8:20-8:30	8	3	1	.38	.13	15.3	3.9	1.5	0.5	2.0
8:35-8:45	16	5	2	.31	.13	12.5	4.8	1.5	0.6	2.1
8:50-9:00	15	5	5	.33	.33	13.1	4.6	1.5	1.5	3.0
9:05-9:15	12	6	4	.50	.33	13.6	4.4	2.2	1.5	3.7
9:15-9:30	18	4	9	.22	.50	13.2	4.5	1.0	2.3	3.3
9:30-9:45	18	4	7	.22	.39	13.4	4.5	1.0	1.8	2.8
9:45-10:00	15	10	3	.67	.20	13.1	4.6	3.1	0.9	4.0
10:00-10:15	10	6	3	.60	.30	11.4	5.3	3.2	1.6	4.8

TABLE 10

PEDESTRIAN/BICYCLE CONFLICT--SURVEY 9/5/76

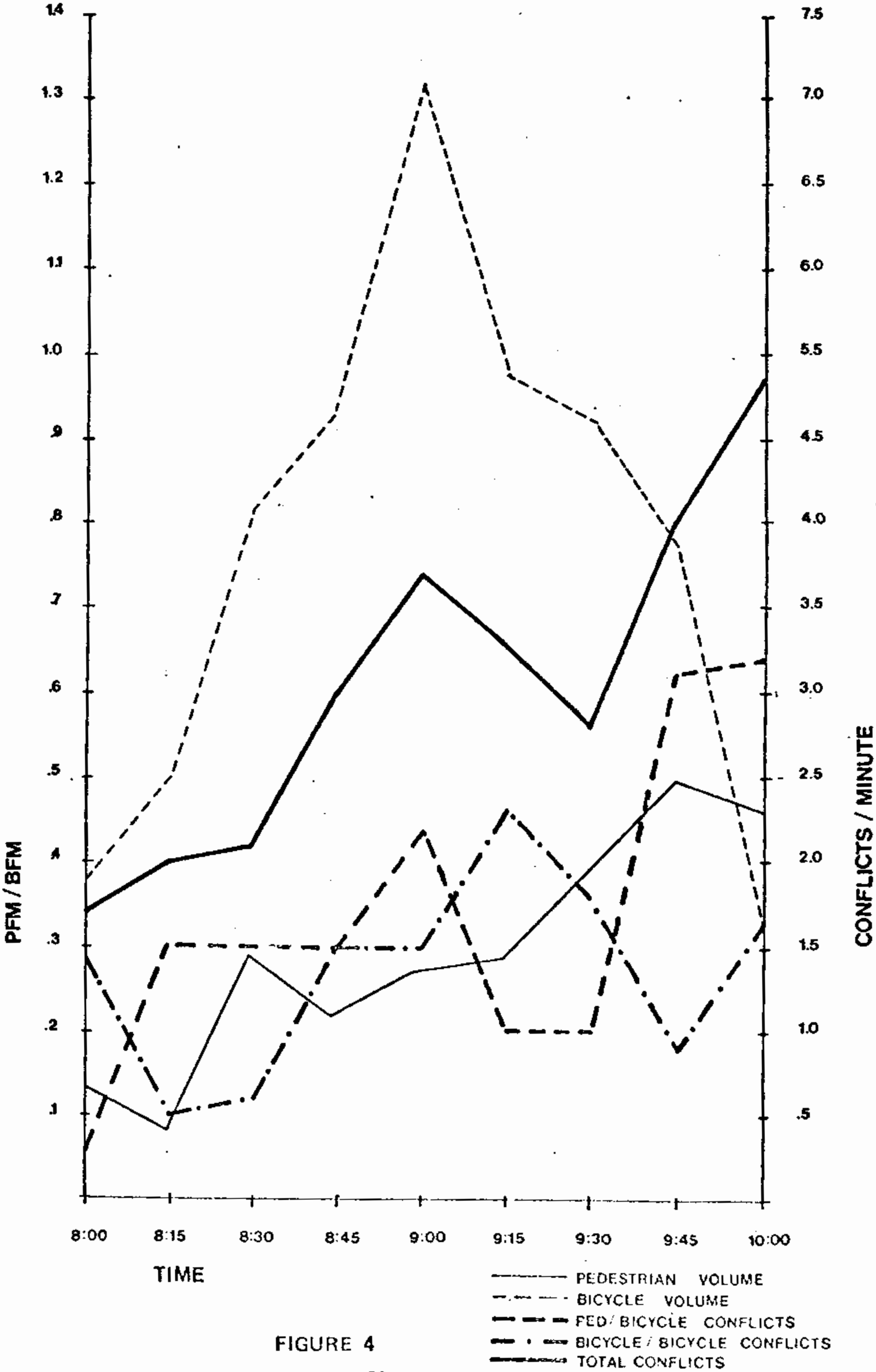
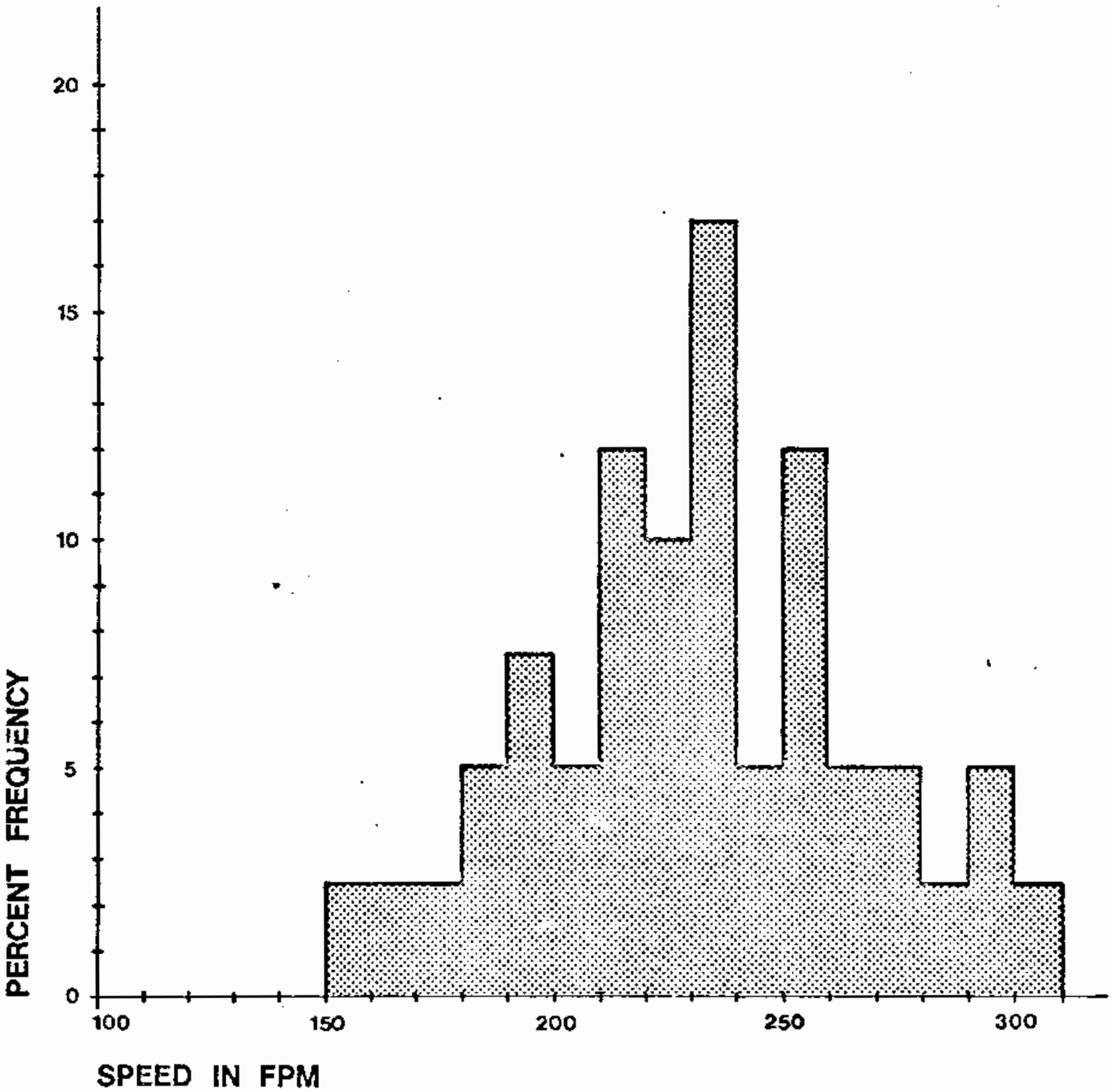
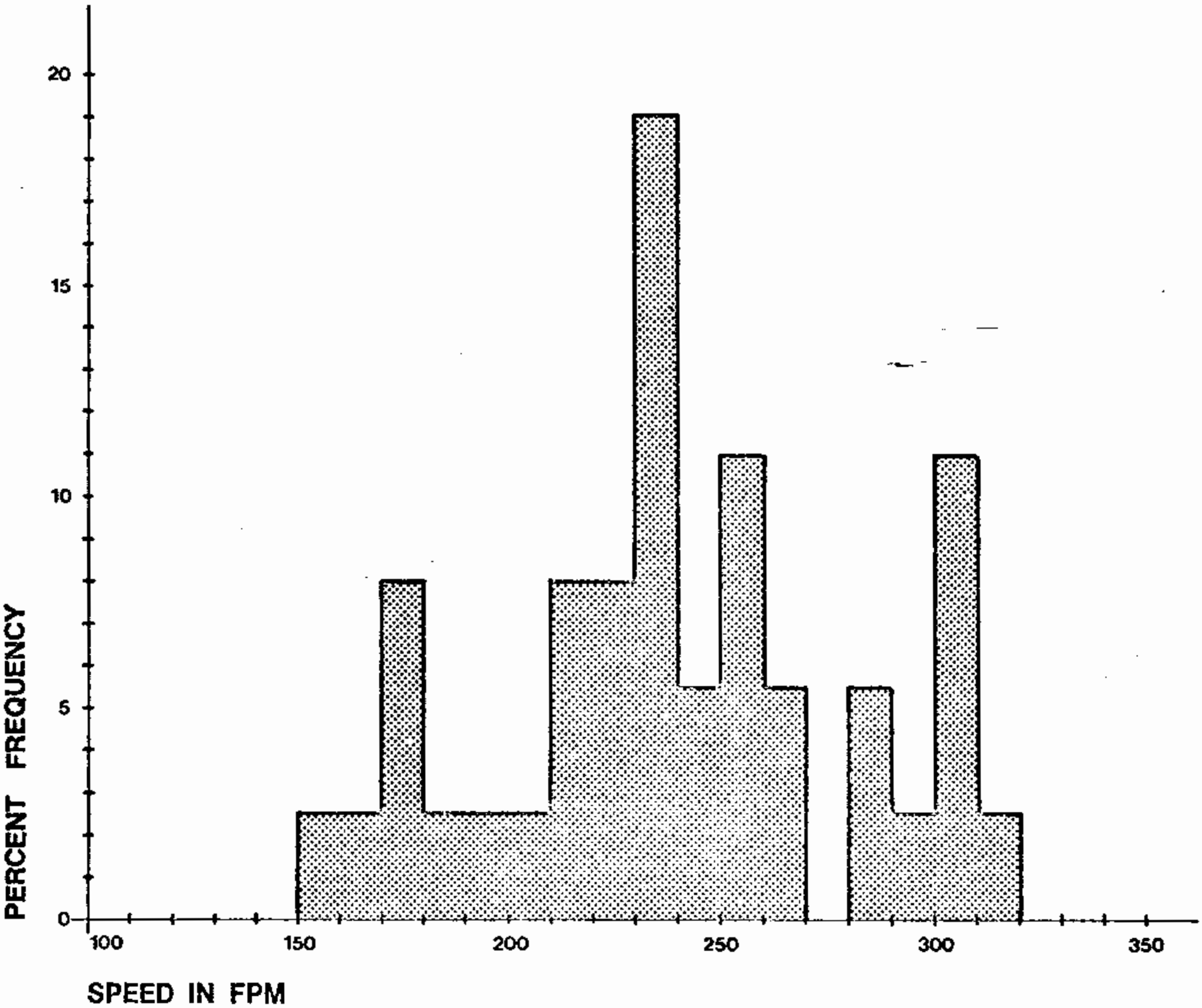

1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
PFM / BFM
7.5
7.0
6.5
6.0
5.5
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
CONFLICTS / MINUTE
8:00
8:15
8:30
8:45
9:00
9:15
9:30
9:45
10:00
TIME
PEDESTRIAN VOLUME
BICYCLE VOLUME
PED/ BICYCLE CONFLICTS
BICYCLE / BICYCLE CONFLICTS
TOTAL CONFLICTS

FIGURE 4



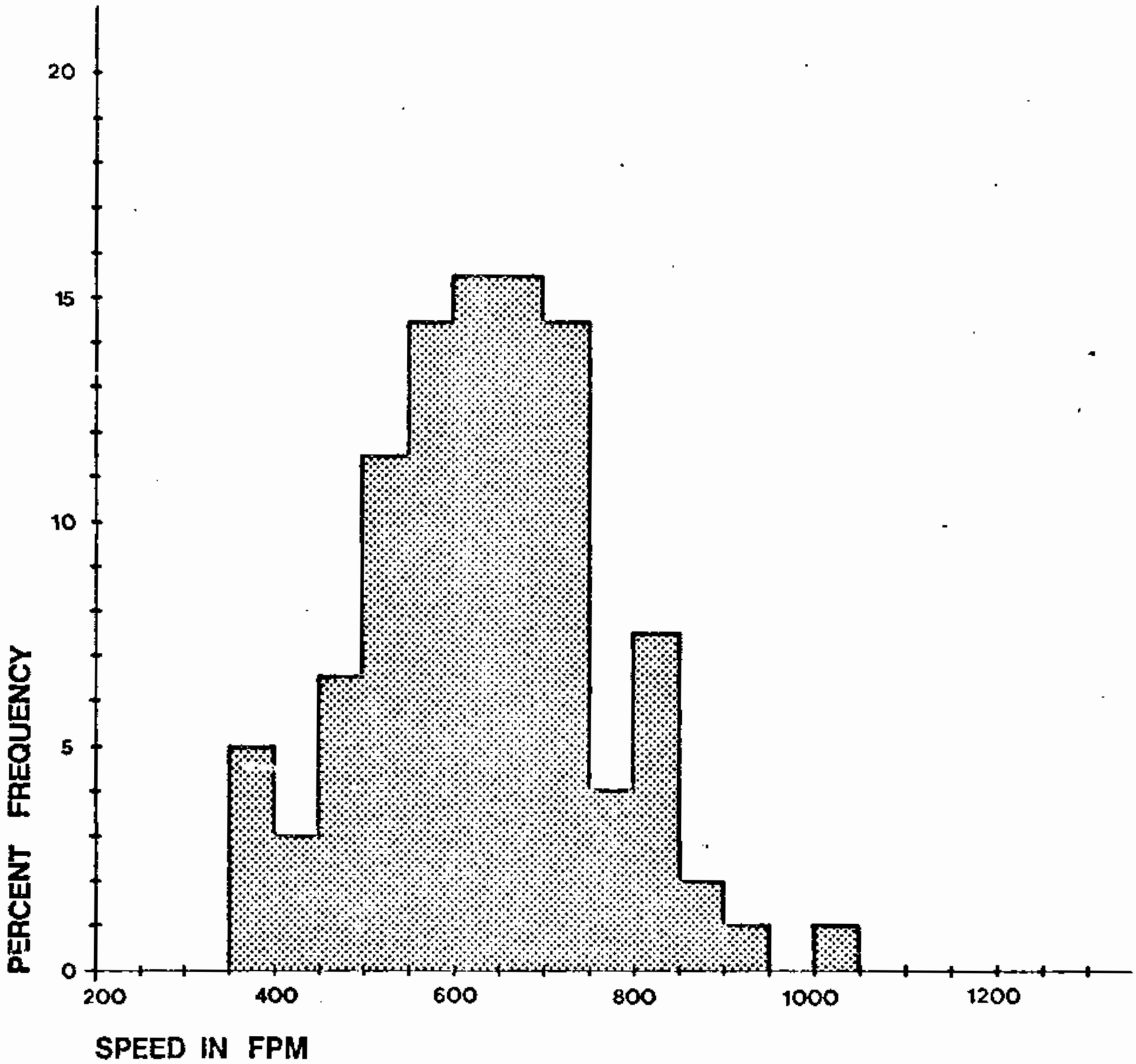
FEMALE PEDESTRIANS

FIGURE 5
WALKING SPEED DISTRIBUTION FOR FEMALES



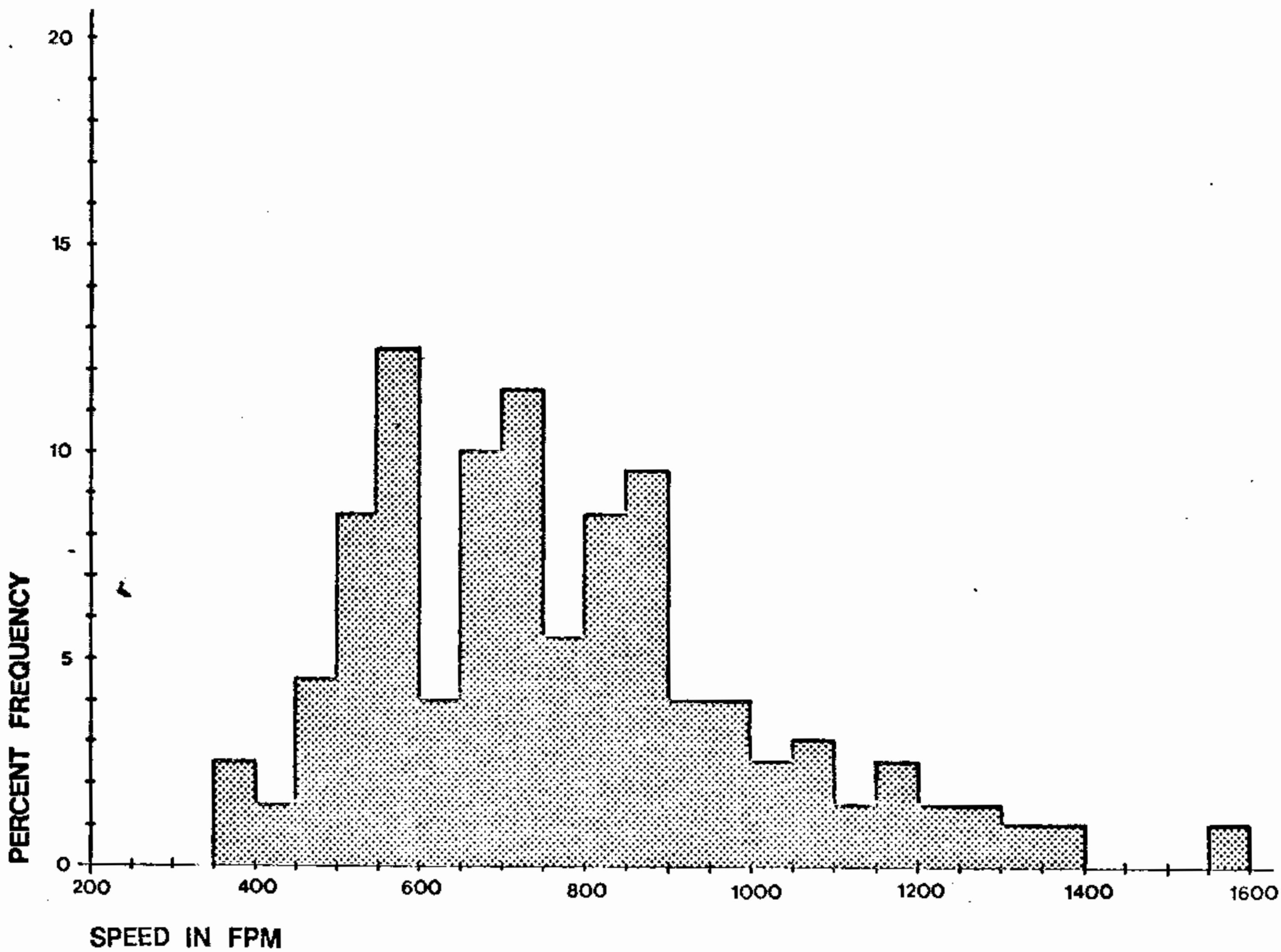
MALE PEDESTRIANS

FIGURE 6
WALKING SPEED DISTRIBUTION FOR MALES



FEMALE CLYCISTS

FIGURE 7
CYCLING SPEED DISTRIBUTION FOR FEMALES



MALE CYCLISTS

FIGURE 8

CYCLING SPEED DISTRIBUTION FOR MALES

V. Conclusions--Part A & Part B

The measurements taken during the field surveys conducted on the boardwalk in Ocean City showed pedestrian volumes both above and below that calculated in Part A as the maximum allowable for shared facilities. However, the speed of bicycle traffic was only an average of 7.9 mph or approximately 2/3 of the 12 mph speed typical of urban bikeways. This lower speed is attributed to the recreational and non-destination oriented nature of bicycle traffic in Ocean City. The level of conflict therefore does not exceed the maximum calculated level of conflict of 6.0 conflicts/minute. However, several conclusions can be made from the results of the survey:

1. The total level of conflict in a shared facility is primarily a function of the volume of pedestrians on the pathway rather than the volume of bicycles. The level of conflict (conflicts/minute) between bicycles remains relatively constant within the range of volumes typically experienced. The level of conflict between bicycles and pedestrians increases substantially as pedestrian volume increases.

   Discussion:

   Figure 4 documents graphically the conflicts and volumes of both pedestrians and bicycles and illustrates clearly the facts upon which the conclusion stated above is based. The volume of bicycles increases sharply from 8:00 a.m., the beginning of the survey period, until 9:00 a.m. After 9:00 a.m. there is an equally sharp decline until 10:00 a.m. This reflects the characteristics of the bicycle rentals which are for a minimum of one hour. Cyclists are informed of the 10:00 a.m. curfew on the boardwalk and thus few "new" riders are generated after 9:00 a.m.

   Pedestrian volume increases almost continuously and exceeds the volume of bicycles near the end of the survey period.

   The level of conflict between bicycles and pedestrians increases only slightly during the peak 15 minutes of bicycle volume. However, the level of conflict does increase as pedestrian volume increases and is not effected appreciably by the decrease of bicycle volume.

2. The maximum acceptable level of conflict, 6.0 conflicts/minute (associated with a pedestrian volume of .3 pfm) which was hypothesized from calculations presented in Part A is very close to the actual limit of conflict based on field observations.

   Discussion:

   At no measured time period during the survey did the combination of pedestrian volume and bicycle speed produce a level of conflict of 6.0 conflicts/minute. The highest level measured during the survey period was 4.8 conflicts/minute. The conclusion of the survey team was that the 4.8 conflicts/minute was an acceptable level of conflict. Sufficient time and space was available in all but a few situations to complete maneuvers without major impedence or danger of collision to either cyclist or pedestrian.

The flow of pedestrians and bicycles was clearly altered by the presence of the other mode. The general tendency of pedestrians was to stay to the outside of the pathway leaving the center area to the cyclist. Pedestrians walking several abreast is less frequent due to the conflict situation this configuration presents to the cyclists. Observations indicate that the cyclist is clearly aware that the pedestrian is a congestion element with considerable mobility and potential for sudden direction change. Cyclists ride slower and operate their bicycles in a more cautious manner while in the presence of pedestrians. The average cyclist speed of approximately 8 mph substantially increases the ability of cyclists to avoid conflicts without sudden maneuvers and near collisions. The bicycles traveling near the speed of 12 mph were observed to experience both a higher rate of conflict and more difficult conflict situations to avoid, requiring a higher degree of riding skill.

The flow of pedestrians and bicycles during the survey period was not uniform and random peaks of traffic were observed. During these brief periods, which could not be accurately measured, the level of conflict reached and exceeded the rate of 6.0 conflicts/minute. Within these peak surges of traffic, bicycle speed was substantially reduced as cyclists traveling in both directions attempted to maneuver around and through the pedestrian traffic. Both cyclists and pedestrians experience a significant amount of uncertainty regarding the best route choice. One avoidance maneuver often led immediately to another conflict situation requiring another maneuver. The level of conflict observed during these surges of traffic volume was above that judged acceptable by the survey team. The survey results and observations, while not providing sufficient data to confirm the limit of acceptable conflict at 6.0 conflicts/minute, does support the maximum level as being very near this point.

3. The volume of pedestrian traffic typically experienced on high density urban pathways is within the range of 3-10 pfm. This is substantially above the .3 pfm which would permit a bicycle to operate at its desired rate of travel and not exceed 6.0 conflicts/minute. Therefore, the development of shared facilities for pedestrians and bicycles in highly urbanized areas is not advisable. The volume of pedestrian and bicycle traffic experienced in the low-moderate density residential areas, typical of new communities and planned unit developments (PUDs), is within and generally considerably below the limit for acceptable conflict. In these locations shared facilities would be appropriate if the facilities provided conformed with the minimum design standards for a shared pathway.

4. The development of shared rights-of-way with pedestrian and bicycles separated by means of a median or other barrier has extremely limited potential in the high density urban area. The existing ROW is typically fully utilized by pedestrian and vehicular facilities. The development of a separate pathway for bicycles would require a reduction of the space currently provided for one or both of these modes. This reduction is not generally feasible. In addition, the maximum volumes of bicycles which could typically be expected to use a separate bicycle lane in a high density area would produce a relatively low travel rate in terms of persons per foot width of ROW per minute. Pedestrian walkways and vehicular streets would produce substantially higher travel rates. The provision of completely separate bicycle lanes would not be an efficient use of transportation rights-of-way in high density urban areas.

Summary of Conclusions

The incompatability of the physical design parameters and the operational and behavioral characteristics of each mode preclude the development of shared pathways for pedestrians and bicycles in high density urban areas. The characteristics of bicycle travel in this environment is more compatible with vehicular traffic than with pedestrian traffic. As vehicular volume and traffic signalization cause a decrease in vehicular speed, the speed differential between vehicles and bicycles is reduced. The slower speed increases the ability of vehicle and bicycle to utilize the same pathway. Additionally the design standards for a bicycle pathway are generally compatible with vehicular standards. The design standards for pedestrian facilities in many cases are not compatible with bicycles.

The evaluation of the potential for shared pathways utilizing the Level of Conflict approach demonstrates that the mix of pedestrians and bicycles can only be successful in very low volume conditions. The excessive conflict which occurs at higher volumes creates psychological stress and safety problems for both pedestrians and cyclists.

APPENDIX I
Speed Distribution

The majority of the conflicts between pedestrians and bicycles can be attributed in part to the speed differential between the two modes. Within certain volume limitations pedestrians and bicycles or bicycles and motor vehicles can successfully mix in a traffic stream if speeds of the two modes are compatible. The distribution of travel speeds for each of the three modes is illustrated in Table 11 and Figure 9 and is based on the following conditions:

1. Pedestrians--level pathway.
2. Bicycles--midblock speed on level pathway, negligible wind conditions.
3. Automobiles--midblock speed in 25 mph speed zone (typical of high density urban areas).

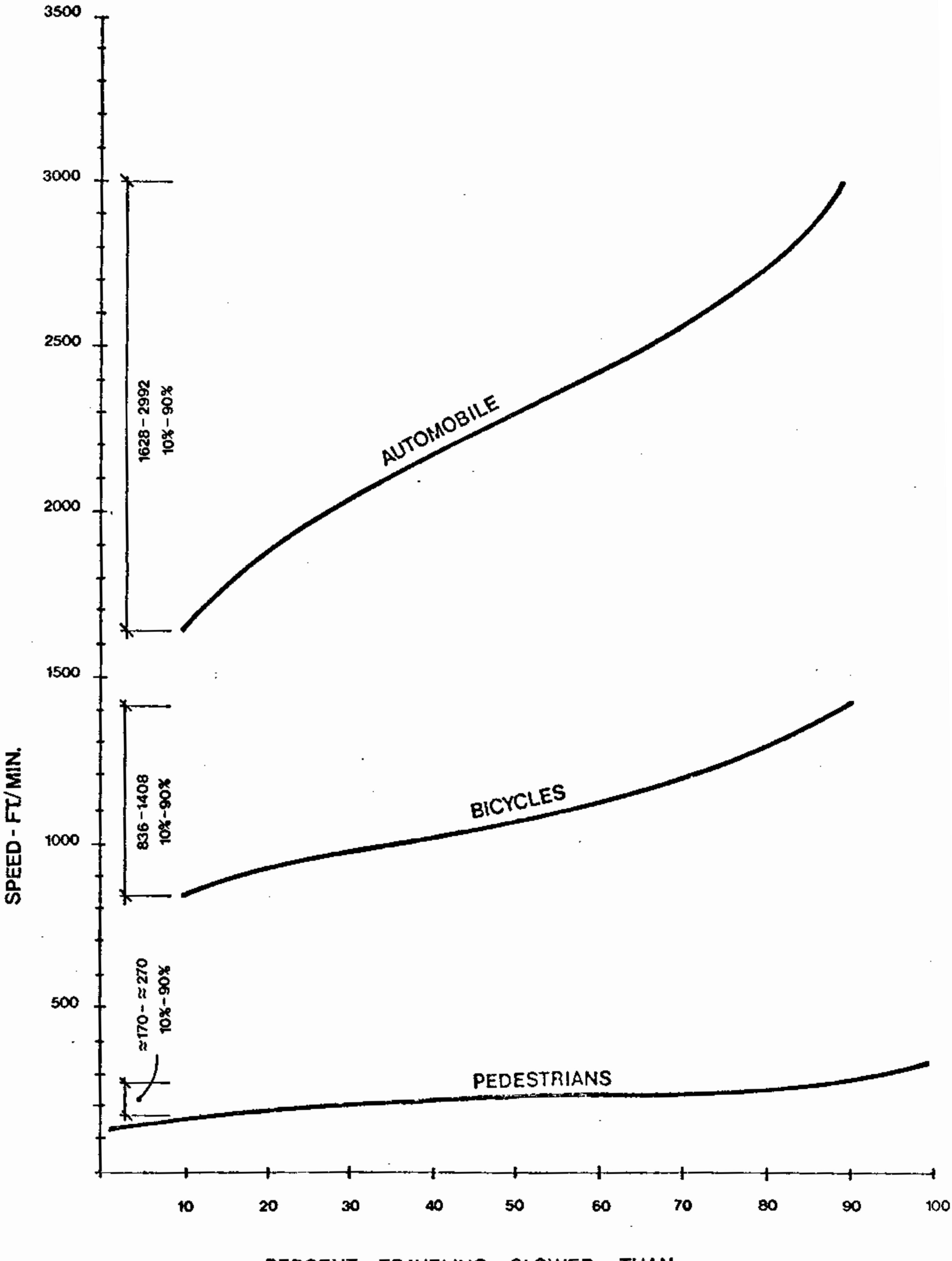
The data indicate that even under free flow conditions at the lowest vehicular speed limit normally encountered in an urban area:

- Virtually all cyclist travel faster than all pedestrians.
- The average cyclist travels more than 4 times faster than the average pedestrian.
- About 90% of all the bicyclists travel slower than nearly all motor vehicles.
- The average cyclist travels about one half as fast as the average motorist.

Traveling Slower Than	Bicycles[1]	Automobiles[1]	Traveling Slower Than	Pedestrians[2]
%	FPM	FPM	%	FPM
10	836	1628	1	125
20	924	1848	4	150
30	968	2024	12	175
40	1012	2156	29	200
50	1056	2288	55	225
60	1144	2420	78	250
70	1188	2552	92	275
80	1276	2728	97	300
90	1408	2992	99	325

[1]Safety & Location Criteria for Bicycle Facilities, Draft, Volume 1, DOT/FHWA.
[2]Fruin, John J., Pedestrian Planning and Design.

TABLE 11
Travel Speed Distribution



COMPARATIVE SPEED PROFILES
FIGURE 9

APPENDIX II
Pedestrian-Pedestrian Conflict--Fruin

For the purposes of investigation, a conflict is defined as any stopping and shuffling, or breaking of the normal walking pace, due to a too-close confrontation with another pedestrian. These confrontations required immediate adjustments in speed and direction to avoid collisions.

Pedestrian conflicts are a function of walking speed and pedestrian spacing in the traffic stream. Although wider pedestrian spacings provide larger crossing gaps, the corresponding increase in pedestrian speed tends to continue to make crossing the main-stream difficult. The study results shown in Figure 10 indicate that the probability of conflicts due to crossing main-stream traffic exist over a wide range of pedestrian densities. The probability of pedestrian conflict is 100 percent at 17.5 pfm (12.5 sq. ft./ped.), representing the absence of acceptable crossing gaps in the main-stream traffic flow. This rate of flow also corresponds with the region of restricted walking speeds and closing of ranks shown by the pedestrian speed and spacing studies. The reduction of pedestrian flow below 17.5 pfm results in a sharp drop in the probability of conflict, as pedestrian ranks open up. However, there is also a concomitant increase in main-stream walking speed keeping the probability of conflict above 50 percent until a flow of 7.5 pfm is reached. At this point, the probability of conflict drops sharply, to the zero level. At 7.0 pfm (35 sq. ft./ped.) sufficient space is available for main-stream and cross-stream pedestrians to react in time to avoid conflicts with each other.

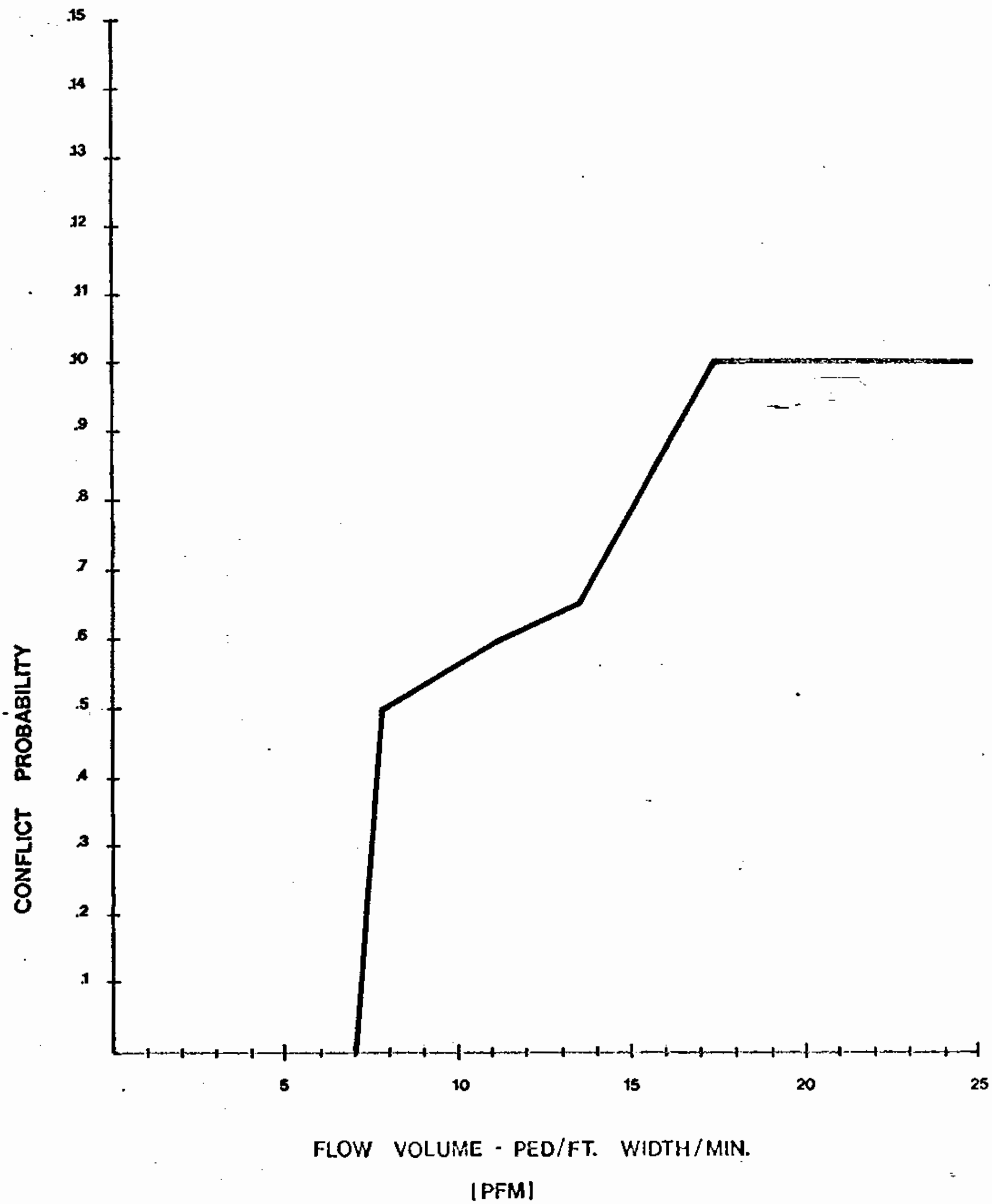


FIGURE 10
CROSS FLOW TRAFFIC - PROBABILITY OF CONFLICT

APPENDIX III
Modal Travel Time Comparison

Many trip purposes are highly sensitive to travel time. The investigation of trip length and associated travel time is one method of identifying the trip which could be made by bicycle or by walking. The total travel time includes both the actual time spent in transit and the terminal time. The terminal time for automobile travel includes the activities associated with parking the vehicle. For bicycle trips the terminal time reflects the time to secure a bicycle in an appropriate facility. The pedestrian, which does not have a vehicle to secure, does not have a time penalty at the terminus of the trip.

As indicated in Figure 11 bicycle trips of up to 5 miles to intense urban activity centers are competitive with motor vehicles in travel time. Pedestrian trips up to 1/2 mile are competitive with the travel time of motor vehicles.

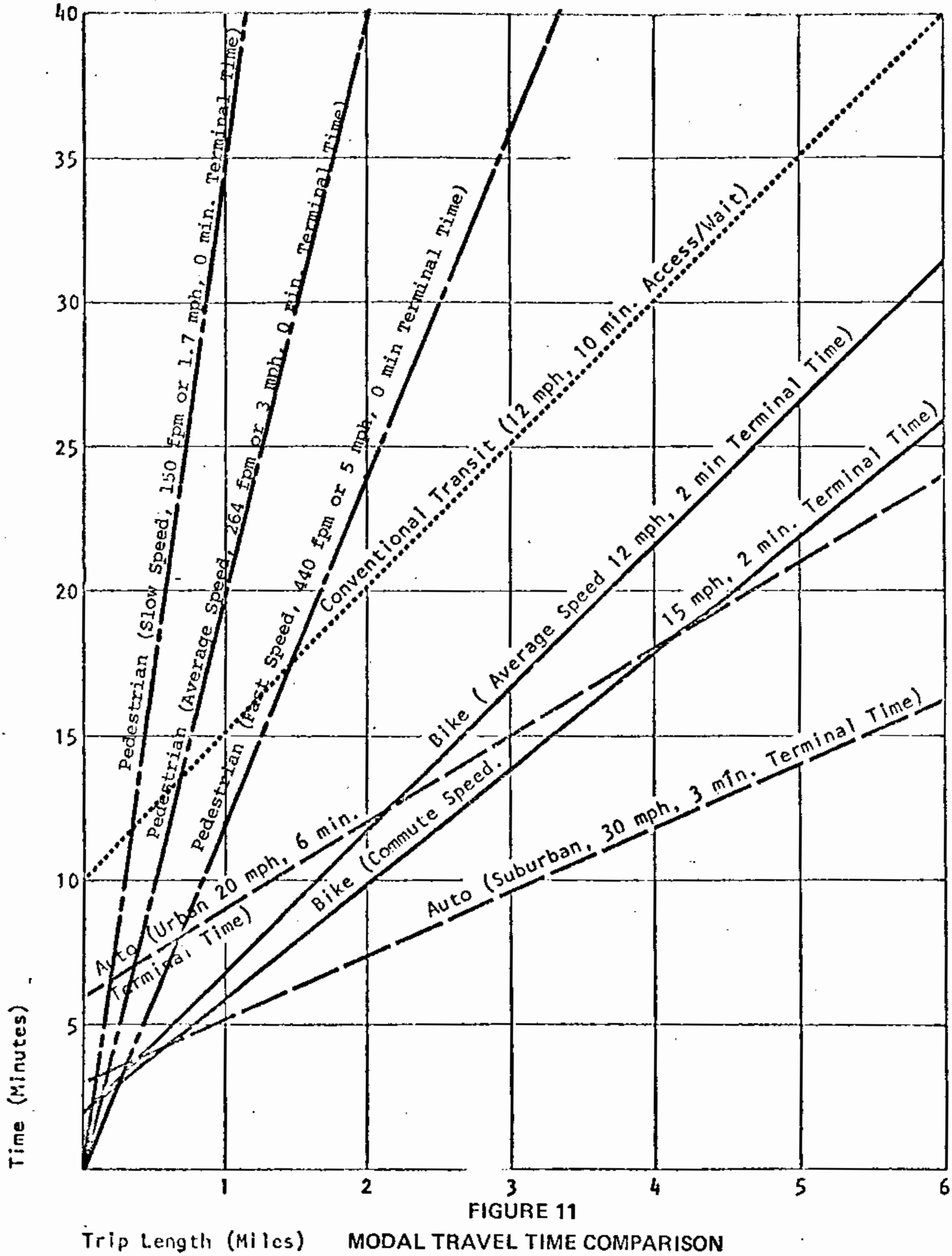


FIGURE 11

MODAL TRAVEL TIME COMPARISON