REPORT OF COMMITTEE ON SAFE APPROACH SPEEDS AT INTERSECTIONS

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The means of obtaining an accurate picture of present practical use of safe approach speed methods was to determine to what extent traffic engineers were applying their knowledge of these methods Many interesting facts were brought to light in the questionnaire survey made of 45 state traffic and highway engineers and 46 city traffic engineers The survey indicated that there seems to be considerable confusion and lack of understanding of the basic principles of safe approach speed studies Numerous engineers apparently thought of the problem solely in the light of stated speed signs and overlooked the more important aspects of the problem

A field project was undertaken and a number of observations made at various selected intersections A pattern of driver behavior on approaching blind intersections was obtained by utilizing a new method of checking vehicle speeds The speeds were checked at six or more consecutive intervals in a 176-ft approach trap In the past an 88-ft. or 176-ft speed trap was used to obtain an overall average speed on intersection approaches These approach speed patterns may be used (1) to determine actual vehicle operation on approach to blind corners in an endeavor to determine why people react safely to certain bad intersections and not to others, (2) to assist in determining points from which to make visual observations, (3) as a check against computed safe approach speeds, and (4) as a research approach to the whole problem of safe approach speeds

The report includes a description of the field test procedure used and the analyses of data from three typical intersections The Committee recommends, as a future research project, the further development and expansion of this method of obtaining approach speed patterns, including the development of equipment for checking speeds automatically

PURPOSE OF PROJECT

The purpose of this project, is (1) to review the present use of "Maximum Safe Approach Speeds At Intersections" data, (2) arrive at a clearer understanding and a more uniform and accepted method of determining maximum safe approach speeds at intersections, and (3) to develop and undertake a research program that will evaluate present and future uses of maximum safe approach speed information.

Maximum Safe Approach Speed is the speed at which vehicles may safely approach street intersections As illustrated in Figure 1, if vehicles A and B can be brought to a stop by a normal operator before reaching the point of collision with the other, they are approaching the intersection at a safe speed

The means of obtaining an accurate picture of present practical use of safe approach speed methods was to canvass the field and determine to what extent traffic engineers were applying their knowledge of these methods Many interesting facts were brought to light in the questionnaire survey made of 45 state traffic and highway engineers and 46 city traffic engineers The survey indicated considerable confusion and lack of understanding of the basic principles of safe approach speed studies Numerous engineers apparently thought of the problem solely in the light of stated speed signs and overlooked its more important aspects

In order to inject new ideas and suggestions into the picture, a field project was undertaken and a number of observations were made at various selected intersections A pattern of driver behavior on approaching blind intersections was obtained by utilizing a new method of checking vehicle speeds. It is hoped that this new development will form the basis for a future program of evaluating safe approach speed information and a general working procedure for obtaining field observations.

For the foregoing reasons this committee of the Traffic Department, Highway Research Board, presents the following report in the hope that it will add incentive for continuation of studies on safe approach speeds at intersections.

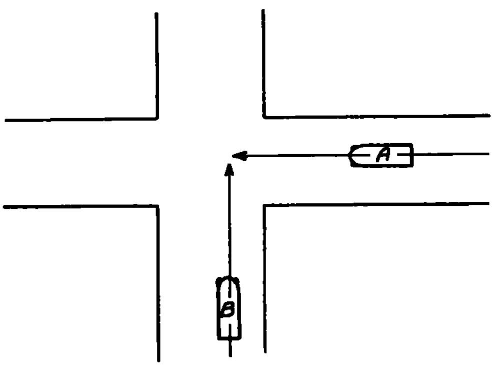


Figure 1

FINAL REPORT ON NATION-WIDE SURVEY

Present Use of Safe Approach Speed Data

In an endeavor to obtain a more accurate picture of the various uses of safe approach speed data, 20 city traffic engineers and 45 state traffic and highway engineers were requested to answer eight questions, which resulted in the information given in Table 1 concerning the types of uses and the number using each.

Table 1 indicates that from 88 to 100 per cent of those replying to the questionnaire make use of the data as listed in the first five items: (a), (b), (c), (d), and (e). However, a more detailed analysis of the comments received in this group show that a majority do not depend entirely on approach speed information to correct hazardous conditions. Approach speeds are used in conjunction with accident records, volume counts and various other data in arriving at a proper solution to the intersection problem. Typical of the general reaction to safe approach speed data is the following

TABLE 1

Use of Data	Number of Engineers		
	City	State	Total
a) As a warrant in determining the use of stop signs, slow signs, and other speed limiting devices	17	8	25
b) As a basis of installing traffic regulations and equipment	17	6	23
c) As a warrant justifying the removal or correction of a physical hazard	16	7	23
d) Restriction of parking at corner	14	8	22
e) To disprove demands for unwarranted traffic control measures	15	7	22
f) As a posted speed on a stated speed slow sign	11	5	16
g) As a general safety index or measurement of one intersection against another	9	3	12
h) By Police Departments and courts in motor vehicle law enforcement programs	8	1	9

comment received from one of the city traffic engineers:

"Safe approach speeds seldom need be determined with great accuracy since they are presented and used along with an accumulation of other data and the summation of the whole rather than one factor determines the action."

In connection with item (a) relating to the use of stop signs, slow signs and other speed limiting devices, a majority of the state traffic authorities indicated that stop signs were placed on all approaches to a state highway regardless of the condition. This regulation, of course, would automatically eliminate the necessity of using safe approach speed data; further verified by the fact that only 18 per cent of the states contacted made practical use of safe approach speed studies.

Only 64 per cent of those replying to the general questionnaire gave indication of use of safe approach speed data as a posted speed on a stated speed slow sign, item (f) This question brought forth more controversy and discussion than any of the others, chiefly because of more definite reaction on the use of these signs. Practically all of the comments showed that stated-speed signs were not reducing speeds or accidents, and in one case speeds and accidents increased after the signs were installed. Typical comments are as follows:

"Stated speed signs proved ineffective in reducing speeds or accidents "

"After the installation of 12 m p h signs, speeds and accidents increased."

"There was no reduction in speeds after posting 50 stated speed signs "

"Newspapers and the public ridiculed use of odd figures for stated speed signs "

"12 m p h stated speed signs were replaced by SLOW signs and accidents were reduced 80 per cent."

"10 and 15 m p h. signs were installed reducing accidents 33 per cent, although no appreciable reduction in speed "

These comments seem to indicate that the problem of stated speed signs is far from a practical solution, and other means of applying safe approach speed data may prove more effective. A possible explanation for the apparent failure of this type of sign may be found in the statement of one of the traffic engineers as follows. "It is practically impossible for a driver approaching an intersection to perceive the sign, adjust his speedometer to the stated speed and at the same time keep an eye on the intersection". However, one traffic engineer reported that accidents were reduced 75 per cent after the installation of 14 m p h. signs.

Items (g) and (h) dealing with a general safety index and motor vehicle law enforcement program, brought favorable replies from only 48 per cent and 36 per cent of the engineers respectively. Many engineers claimed lack of adequate enforcement is responsible to some extent for the disregard of stated speed signs.

All of the foregoing comment tends to indicate that there is apparent confusion among the traffic engineers between safe approach speed technique and the use of stated speed signs. This attitude is brought about partly because of disappointing results, and partly because of dependence on other types of studies for solution to intersection problems, but largely because of the probable lack of sufficient knowledge of safe approach speed information. This should prove further warrant for an extended program of research activities in order to clarify present misunderstanding and establish the entire problem on a basis that will be accepted by the majority.

NUMERICAL VALUES AND ASSUMPTIONS USED IN COMPUTING SAFE APPROACH SPEEDS

Much of the procedure, when determining safe approach speeds at intersections, depends on three factors; the driver, the vehicle and the physical conditions of the intersection. In order to evaluate these factors, numerical values and assumptions must be applied to each. Therefore, a comparison of values in use by traffic authorities throughout the country is presented herein to serve as a basis for suggested assumptions for general application

Driver Reaction Time

Since the greater percentage of our present street systems were not designed to relieve the driver of making critical decisions, there are a number of courses of action that must be correctly decided upon before he is to proceed safely through an intersection. Deciding upon the course of action that the driver ultimately takes requires time, which is referred to as "reaction time" in the calculation of safe approach speeds at intersections. It equals the driver perception time, plus driver mental reaction time, plus driver physical reaction time up to the point of full application of the brakes. Driver reaction time, when applied to the determination of safe approach speeds, is expressed by the term driver reaction distance, and is equal to (Vt) when V is the speed in feet per second and t is the time in seconds. Because of the lack of general agreement on all phases of the over-all reaction time, it is necessary to make certain assumptions. Replies received from the questionnaire show the following assumed reaction times in use at present.

Reaction Time	No of Engineers		
	City	State	Totals
sec			
0 60	2	1	3
0 75	13	5	18
1 00	10	6	16
2 00	1		1

In addition to these data, the results of a questionnaire originating from an entirely different source,[1] shows the following values:

Reaction Time	No. of Cities
sec.	
0 625	1
1 0	21

The American Association of State Highway Officials in their July, 1940, report on "A Policy on Intersections At Grade" allows one second for "perception" time and one second for "brake reaction" time when approaching a signed intersection. Perception time, as stated in this part of the report, is the time required to read the sign and observe the hazard. Reaction time is then the time required to begin whatever action is necessary after the sign has been passed, and is assumed to be one second.

Vehicle Braking Distance

The vehicle contributes a factor which plays an important part in the determination of safe approach speeds; namely, "braking distance". Braking distance may be defined as the distance required to bring a moving vehicle to a complete stop after the brakes are fully applied. Mathematically, braking distance on a level roadway is given by expression $\frac{V^2}{2a}$ when V is the velocity of the vehicle in feet per second and a is the rate of deceleration in feet per second per second[2] Since the deceleration value depends upon the braking efficiency of the individual vehicle and the roadway surface, at present controversial subjects, it is still necessary to depend on values that are seldom more than assumptions. Returns from city and state traffic engineers show the following distribution of deceleration rates:

Rate of Deceleration	Equivalent "f"	Number of Engineers		
		City	State	Total
14	0 44	2	1	3
16	0 50	8	5	13
17	0 53	9	5	14
20	0 62	4		4

[1] M. V Greer, "The Influence of the Parked Car on Intersection Operation" Bureau for Street Traffic Research, Yale University, 1939-1940.

[2] Deceleration rate a = fg, where f = coefficient of friction between vehicle and road surface, and g = 32 16 (effect of gravity)

Again referring to the report of the American Association of State Highway Officials, a friction factor of 0.4 (i.e., deceleration of 12.9 ft. per sec. per sec.) is assumed for all intersections. Bureau of Standards tests indicate a rate of deceleration of 16.1 ft. per sec. per sec. as the maximum for comfort, and the Motor Vehicle Department of New Jersey assumes as a comfortable rate of deceleration of 17.4 ft. per sec. per sec. The National Safety Council has adopted a deceleration rate of 17 ft. per sec. per sec.

Safe Approach Speed for Major Street

The safe approach speed at which vehicles may enter the intersection on the major street constitutes the third assumption. This speed may be based on actual observation at the intersection selected for study, or upon estimated speeds. The 91 engineers gave the following varied answers, although the majority use 85 or 90 per cent respectively. Four traffic engineers use estimated speeds only.

Major Street Safe Approach Speed Based Upon

	Number of Engineers		
	City	State	Total
Actual Speed			
Average	1		1
80%	2	1	3
85%	11	3	14
90%	9	1	10
Top	2		2
Estimated Speed	3	1	4

Vehicle Position on Street

Whether the vehicles approaching an intersection travel near the curb or center of roadway constitutes the fourth principal assumption in determining safe approach speeds at intersections. In most instances it is assumed by traffic engineers that the vehicle travels in the most dangerous lane on the highway. Sometimes that lane is at the extreme left (one way street) or right side of roadway or next to the center line. Computations on this basis naturally furnish the lowest safe approach speed.

Factors Recommended for Adoption

The completed study of the foregoing assumptions further substantiates the suggested assumptions of last year. However, an analysis shows that approximately 75 per cent of the engineers are guided in their assumptions by those used in the various methods. The remaining 25 per cent have devised their own methods and use their own formulated assumptions. Some question the value of specific methods when dealing with the human element and contend that there are too many variable factors involved. Very little, as yet, is known of perception and reaction time and the variable friction values involved in deceleration rates. The report of the American Association of State Highway Officials, previously described, gives the equation of safe stopping distance as $d = 2.93^V - .083^{V^2}$ which assumes 2 sec. reaction time and a deceleration value of 12.9 ft. per sec. per sec. Although these values are assumed for all speeds, there is considerable contention among engineers that differences will exist in assumptions for rural and urban areas, and that these assumptions are largely applicable to rural areas. However, until further research confirms or rejects present practices it is suggested that an agreement be reached on the following factors:

1. Reaction time—1 sec.
2. Rate of Deceleration—17 ft. per sec. per sec.[3]
3. Safe Approach Speeds for major thoroughfares—85 per cent
4. Vehicle position on street—8 ft. or $\left(\frac{W}{2}\right)$ from right curb.

[3] Further specialized research on deceleration rates is being undertaken which may materially alter this value.

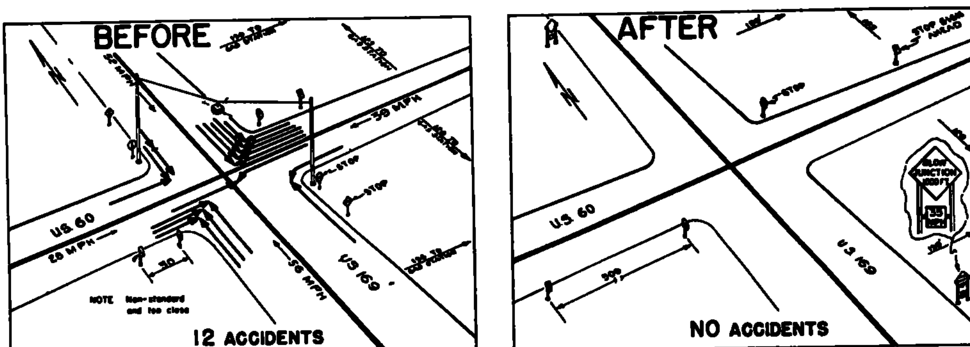
An Unusual Application of Safe Approach Speed Studies

An unusual application of safe approach speed studies is brought to your attention in the following report submitted by Richard L. Burton, Traffic Engineer, Department of Public Safety, State of Oklahoma, and as the 21st example in the "Getting Results Through Traffic Engineering" series issued each month by the National Conservation Bureau. This example describes how an intersection of two major highways with 12 STOP signs on the four approaches, and a record of 12 accidents, was studied on the basis of approach speeds. The speeds at which 85 per cent of the motorists were travelling on each of the

SPEED ZONING AND PROPER SIGN PLACEMENT ELIMINATE ACCIDENTS

PROBLEM.

At the intersection of US 60 and US 169 on the eastern edge of Nowata, Oklahoma, motorists were disregarding the existing traffic regulations, largely because the signs were too numerous and improperly placed



ACCIDENT FACTS.

In a one and one half year period prior to the installation of the present improvements there were 12 personal injury and property damage accidents at this intersection Most of these accidents were caused by motorists ignoring the STOP signs

FIELD STUDIES

Observation revealed that 12 signs were used to regulate the flow of traffic A four-way STOP sign suspended in the center of the intersection consisted of a box constantly illuminated, with the word STOP in red facing all flows of traffic This sign was supplemented by STOP signs at all four corners, and these in turn were supplemented by four additional STOP signs placed approximately 30 feet in advance of the other signs Only 4 of these 12 STOP signs conformed to the standard set by the American Association of State Highway Officials in the "Manual on Uniform Traffic Control Devices" A check was made on each approach to the intersection to determine the actual approach speeds This study revealed that 85% of the motorists were travelling at or below speeds indicated in the sketch above A 24-hour volume count was made to determine the approximate flow of traffic This count showed an average of 4754 vehicles using US 169 and 2366 using US 60 Filling stations on the northeast and southeast corners partially obstructed driver vision The distance of these stations from the centerlines of the highways is indicated on the sketch

SOLUTION.

The speed checks and volume counts showed that it was only necessary to halt the traffic flow on one highway, and that a definite limitation should be placed on the speed of traffic approaching along the major highway All of the STOP signs were removed, with the exception of two of the standard type signs located on US 60 Standard STOP SIGN AHEAD signs were placed at points 500 feet in advance of these signs On US 169 a 35 MPH speed zone, in conjunction with a SLOW JUNCTION 1000 FT warning-type sign, was established The total cost of the improvement at this intersection was approximately $130

CHECK BACK

In a one-year period following the above improvements there have been no accidents at this intersection This record is attributable to the speed zoning and to the proper placement and standardization of the signs

Figure 2

four approaches was the basis for determining the more important highway and arriving at the proper solution As a result of these studies, all but two STOP signs were eliminated, and these placed on the minor highway with proper advance warning signs. The major highway was zoned for a definite speed through the intersection and an advance warning sign placed at the same location as the speed sign indicating the distance to the junction. The remarkable results of this treatment showed a no accident record for the same period of time following improvement A more detailed description of this problem is given in Figure 2.

FIELD OBSERVATIONS

The progress report up to this point has dealt entirely with past and present practices and uses of safe approach speed information It is the intent of the Committee to inject new ideas and suggestions in the balance of the report and establish criteria for future expansion of research activities.

Approach Speed Patterns

In an endeavor to investigate shortcomings and to develop new fields of usefulness, a new method of studying safe approach speeds at intersections was devised It was decided to obtain patterns of driver behavior when approaching blind corners. To our knowledge no one has as yet utilized the pattern method (speed checks at six or more consecutive intervals in a 176-ft approach trap) as most engineers depend on an 88 ft or 176 ft. speed trap to obtain an overall average speed on intersection approaches. The more important reasons for using approach speed patterns are enumerated below.

Approach speed patterns may be used:

(1) To determine actual vehicle operation on approach to blind corners in an endeavor to determine why people react safely to certain bad intersections and not to others.

(2) To assist in determining points from which to make visual observations.

(3) As a check of actual against computed safe approach speeds

(4) As a research approach to the whole problem of safe approach speeds in order to arrive at a clearer understanding of safe approach speed information.

FIELD TEST PROCEDURE

Before field tests could be undertaken, a definite course of action had to be formulated to avoid confusion and misunderstanding under operating conditions. Therefore, the following brief description will clarify the procedure used in obtaining data for this report, and is recommended for adoption for similar studies.

Personnel and Equipment: Two or three observers and one recorder are needed to checks speeds at specified distance intervals on one approach. Equipment necessary includes stop watches, clipboard, tape, chalk or crayon, tabulation sheets and a car.

Description of Method: At the intersections selected for study, speed patterns are obtained on all appraches affected by a blind corner. If a condition diagram of the intersection is not available, the street is measured for width and distances from curb to corner obstructions. By using the near curb line of the cross street as a reference point, 22 ft. is measured along the approach to be tested in order to obtain the zero point From this point, five successive 22-ft. intervals and one 66-ft. interval are measured to obtain an overall speed trap of 176 ft. Figure 3 clearly shows the proper method of marking. After proper marking of these points[4], speeds are

[4] Marking may be done with chalk or crayon, but it was found that 6-foot strips of 3-inch white tape proved more permanent and effective

checked on approximately 100 cars[5]. All stop watches are started as the front wheel of the approaching vehicle crossed the first mark and then stopped successively as each mark is reached[6]. In this manner, the 66-ft. interval was the shortest section timed with a stop watch, the second mark being an 88-ft trap, the third a 110-ft. trap, etc, until the zero mark is reached at the end of the 176-ft. trap. The two men operating stop watches have one interval to check simultaneously so as to allow for discrepancies in judgment. The best position for observation was found to be at the approximate midpoint of the trap and on the opposite side of the street (Fig. 3). Similarly, speeds were checked

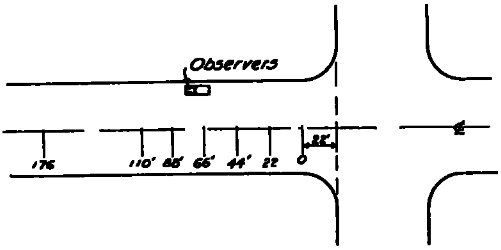


Figure 3. Method of Marking Pavement

on each of the approaches to the intersection that were affected by a blind corner.

When all of the necessary data were obtained and tabulated in increasing time intervals, as the vehicle moved from one end of the trap to the other, speeds were computed for each interval. The speeds in the first interval were obtained by using the stop watch reading for the 110-ft. mark and converting into miles per hour. The second and successive interval speeds were obtained by subtracting the reading at the greater distance mark from the reading at the next lowest.

TYPICAL EXAMPLES

Before going into detail on the practical application of the approach speed pattern method, a brief summary of the three methods of computing safe approach speeds at intersections will be given herein. These methods are designated

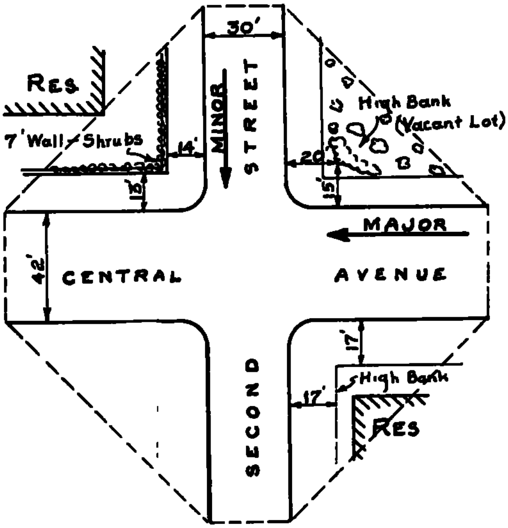


Figure 4. Example 1

COMPARISON OF ACTUAL AND COMPUTED SPEEDS ON MINOR STREET

	Method		
	1 (m.p.h)	2 (m p h)	3 (m p h)
Computed speeds	6 4	12 5	12 4
Observed speeds (median value)	15 0	15 4	15 4
Observed speeds (percentile values)	21 5 (90%)	19 3 (80%)	20 3 (85%)

as numbers 1, 2 and 3. Method 1 is based on the premise that the driver will slow down to a speed from which he can take the additional precaution of stopping or slowing down to prevent accident successfully. For this method the 90 per cent speed on the major

[5] Only 50 cars need be checked on the major street approach if speeds are observed as fairly constant

[6] For test purposes, double-hand stop watches are used, thereby utilizing only two men with two watches. Automatic devices may be used in lieu of watches

street is the speed selected from which to compute critical speeds on the minor street. Methods 2 and 3 are based on the premise that each vehicle, whether on major or minor street, can make an emergency stop before reaching the point of collision with the other. These latter methods utilize 80 and 85 per cent speeds respectively on the major street when computing speed on the minor street All three methods favor a driver reaction time of 1 sec Methods 1 and 3 use a deceleration rate of 17 ft. per sec. per sec and Method 2 used a deceleration value of 16 ft per sec per sec

In order to demonstrate the practical application of the approach speed pattern method, three typical intersections were selected with varying conditions of visibility and without stop signs or signal treatment to materially affect driver behavior on approaches Accident records were analyzed for the worst corner condition and off-peak volume counts were made to indicate traffic flow on the approaches studied Approximately 50 vehicles were checked on each of the approaches Following is a detailed description and analysis of each of the three intersections.

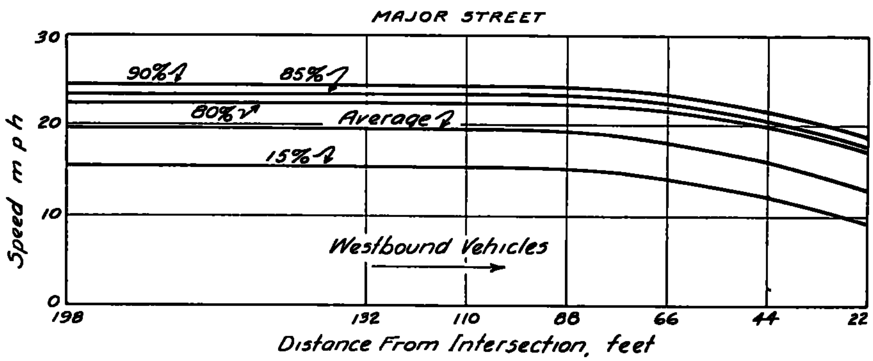


Figure 5. Ridgefield Park, N. J., Central Ave. and Second Street

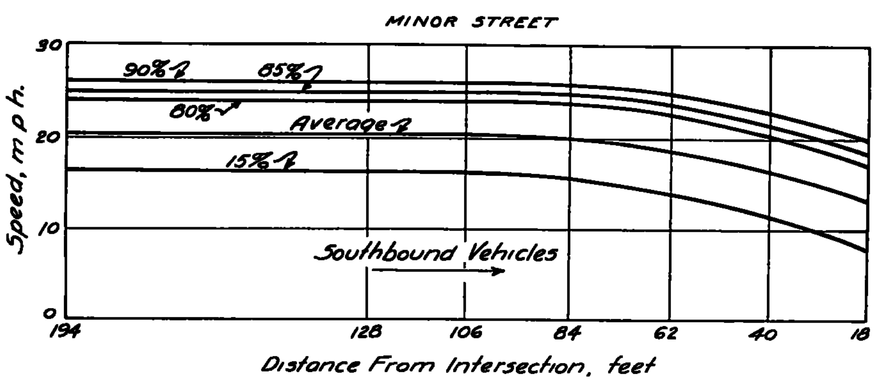


Figure 6. Ridgefield Park, N. J., Central Ave. and Second Street

Example 1. The intersection of Central Avenue and Second Street in Ridgefield Park, New Jersey, had no traffic regulation and the accident record showed an average of five personal injury and property damage accidents per year over a five-year period Off-peak volume counts indicated approximately 150 vehicles per hour on Central Avenue (the major thoroughfare) and 60 vehicles per hour on Second Street (the minor thoroughfare) This count is based on two-lane operation on both thoroughfares As shown by the condition diagram (Fig 4), three corners of this intersection

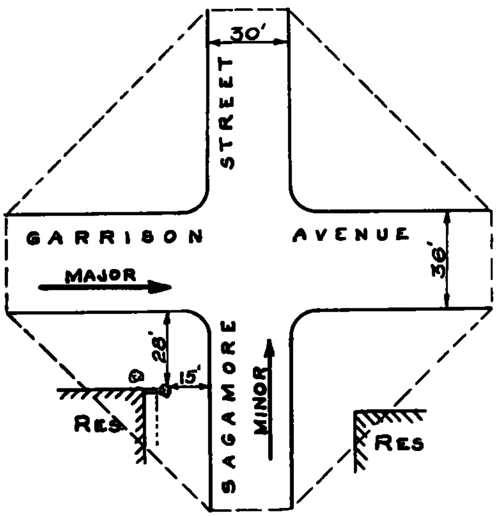


Figure 7. Example 2

COMPARISON OF ACTUAL AND COMPUTED SPEEDS ON MINOR STREET

	Method		
	1 (m p h)	2 (m p h)	3 (m p h)
Computed speeds	7 75	14 4	14 5
Observed speeds (median values)	15 3	15 8	15 7
Observed speeds (percentile values)	21 0 (90%)	19 0 (80%)	19 9 (85%)

are blind, but accident records indicated that practically all collisions involved westbound vehicles on Central Avenue and southbound vehicles on Second Street This unusual condition may perhaps be accounted for by the fact that the northeast corner does not appear to be so blind to the approaching motorist as the opposite corners and therefore he pays little attention in that particular direction

Speeds were checked on each approach by the method previously described and pattern curves plotted (Figs 5 and 6). In order to obtain a representative range, curves were plotted for 15 per cent, average (median), 80, 85 and 90 per cent values The speeds on the major street representing these values were those where the vehicle is farthest from the intersection and approaching at uniform speed as indicated by the straight line curve before deceleration begins By taking these selected speeds on the major street as the actual observed speeds, computations were made for each of the three methods of computing safe approach speeds at intersections The safe approach speed for the minor thoroughfare thus computed was then checked against actual observed speeds by locating the point on the minor street curve representing the stopping distance from point of collision with a vehicle on the major street Figures showing computed speeds and actual observed speeds for the three methods are tabulated below the Condition Diagram on Figure 4

Example 2 The intersection of Garrison Avenue and Sagamore Street in Teaneck, New Jersey, had a similar accident record to the intersection described in Example 1 Off-peak volume counts indicated an approximate two-lane flow of 200 vehicles per hour on Garrison Avenue (the major thoroughfare) and 100 vehicles per hour on Sagamore Street (the minor thoroughfare) A majority of the accidents involved vehicles northbound on Garrison Avenue and westbound on Sagamore Street, thus indicating a hazardous condition at the northeast corner At the time speed checks were made SLOW signs were installed on each of the four approaches to the intersections but apparently had little or no effect on the driver on the major street, as indicated by the speed pattern chart (Fig 8)

Speeds were checked by the pattern method on the two approaches and curves plotted (Figs 8 and 9) for each of the percentile values in the selected range Computations of safe approach speed on off-peak volume count for two-lane operation approximated 200 vehicles per hour for Queen Anne Road (the major thoroughfare) and 75 vehicles per hour for Grayson Place (the minor thoroughfare) Accident records indicated a hazardous condition on the northeast

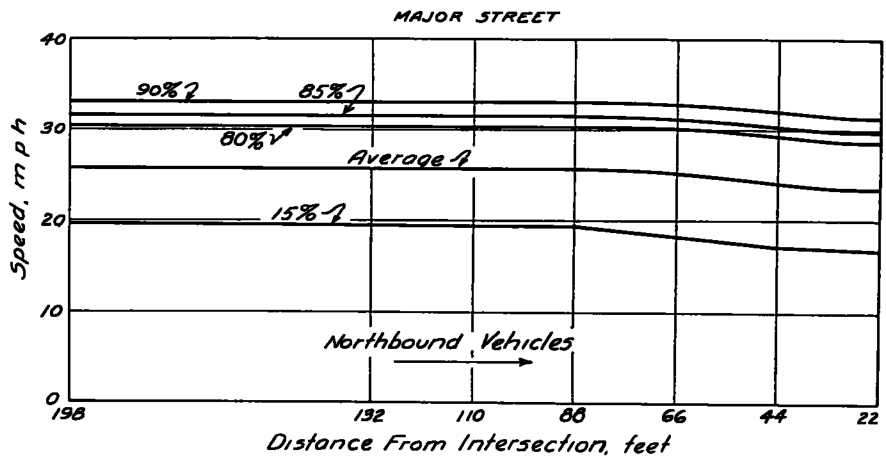


Figure 8. Teaneck, N. J., Garrison Ave. and Sagamore St.

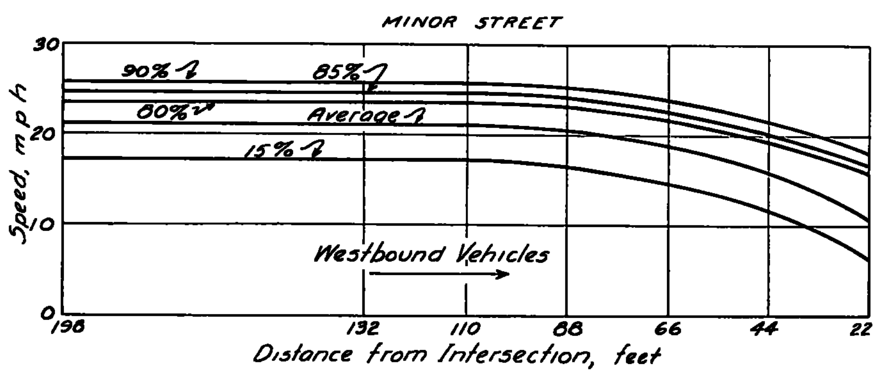


Figure 9. Teaneck, N J., Garrison Ave. and Sagamore St.

the minor street were made and checked against actual observed speeds (See Table on Fig 7).

Example 3. The intersection of Queen Anne Road and Grayson Place in Teaneck, New Jersey, had a similar accident record to the previous two examples; i e., an average of five accidents per year over a five year period. The corner, affecting northbound vehicles on Queen Anne Road and westbound vehicles on Grayson Place. The only regulations in effect at this intersection were "CROSS STREET" signs on the Grayson Place approaches, which seemed to have little or no appreciable effect on driver behavior.

Speeds were checked and curves plotted

(Figs. 11 and 12) similar to the method previously described in the first two examples Results of the comparison between actual and observed speeds are tabulated below the Condition Diagram (Fig. 10).

Summary. As shown by the tabular comparison of computed speeds, there is

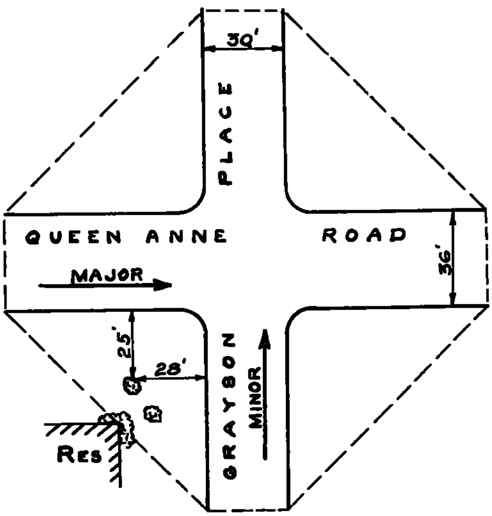


Figure 10. Example 3

COMPARISON OF ACTUAL AND COMPUTED SPEEDS ON MINOR STREET

	Method		
	1 (m p h)	2 (m p h)	3 (m p h)
Computed speeds	8 0	15 0	15 1
Observed speeds (median values)	12 3	12 9	12 9
Observed speeds (percentile values)	16 8 (90%)	15 6 (80%)	16 4 (85%)

considerable variation between Method 1 and Methods 2 and 3 This variation is presumably caused by the premise on which the methods are based Median values are presented merely as illustration, since they are not used in any of the computations Considerable variation is noted in the first two examples between computed and observed speeds, using the proper percentile values for each method Analysis of accident records showed that speeds were in excess of a safe speed in practically every collision, but observation revealed that the majority of vehicles slowed almost to a stop before entering the intersection, thus indicating that the observed speeds were normal for safe vehicular operation Example 3 showed observed speeds checking more closely with computed speeds in two cases. Observation revealed that a majority of the vehicles were slowing down to a stop much earlier and not awaiting a last minute decision to apply the brakes These conclusions are merely tentative as the major objective is to illustrate the type of findings which may may be obtained from approach speed patterns.

CONCLUSIONS AND RECOMMENDATIONS

In summarizing the report several interesting facts are brought to light; not only from results obtained in the questionnaire survey but also as an outgrowth of the application of a new method of studying approach speeds at intersections These facts are reviewed briefly as follows

1 The questionnaire indicates that a large number of traffic engineers are making use of safe approach speed data for some purpose, but generally along with other substantiating studies

2. The apparent confusion among traffic engineers between safe approach speed technique and the use of stated speed signs, resulting in a trend of sentiment against use of the latter

3 Further substantiation of assumptions suggested in the previous progress report, and recommendations for adoption of these important factors.

4 The use of safe approach speed technique for elimination of an excess of stop signs as illustrated by the "Getting Results" example.

5. The development of a new method of studying safe approach speeds which indicates that it may be used for

a. Determining speed patterns on each entering street.

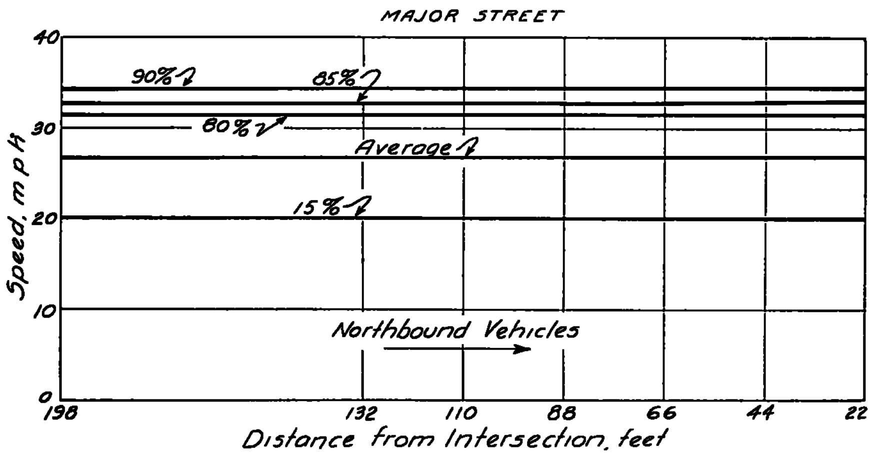


Figure 11. Teaneck, N. J., Queen Anne Road and Grayson Place

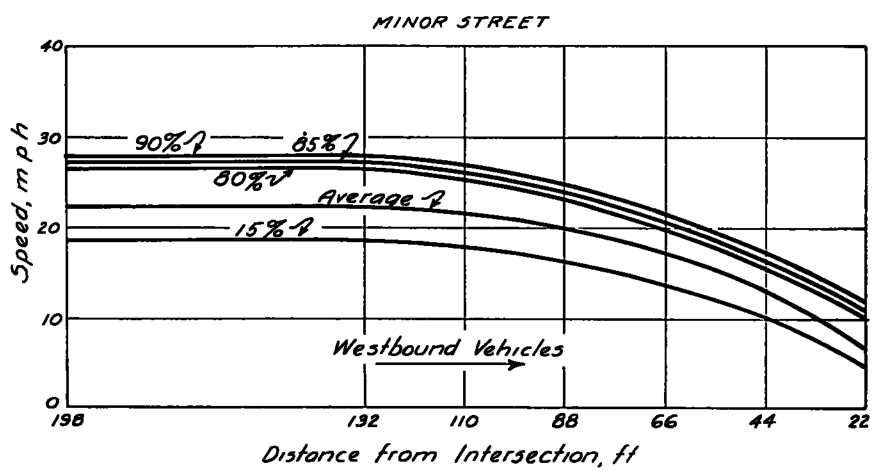


Figure 12. Teaneck, N. J., Queen Anne Road and Grayson Place

b. Relating these patterns to various characteristics of the locations

c. Checking speed and accident records against the computed speeds by the various methods.

d. Determining whether different patterns require different treatment even when computed safe approach speeds indicate similar treatment.

e. Determining when the usual safe approach speed technique is valid.

The new method of attacking the problem, by obtaining approach speed patterns, was devised in the hope of arousing interest in a possible means of arriving at a solution to the problem. The method presented is not meant to be concrete proof that changes should be made, but merely as an illustration of its potentialities. It is conceded that stop watch readings are not accurate enough to present indisputable data, but they should certainly be near enough in accuracy to arouse comment and conjecture.

Some type of automatic speed device would be the answer to accurate field observation of approach speed patterns. An automatic device for field observations was experimented with and it was found that certain changes would have to be made before a satisfactory means of obtaining patterns could be reached. Spot speeds are naturally better than average speeds obtained over 22-ft. intervals. However, though there were minor discrepancies in stop watch manipulation, the points on the curves were close enough to the trend of vehicle behavior to assimilate a fairly accurate pattern.

Because of the broad aspect of the entire problem, it has been impossible to arrive at definite conclusions in a short time. It is recommended that further development and expansion of the suggested method of obtaining approach speed patterns, including development of automatic speed checking equipment, be continued as a representative research program of this Committee

A tentative approach to this expanded activity could be formulated on the following basis. First, canvass the country for approximately 100 typical intersections (two each from 50 traffic engineers) for study on the basis of blind corners, accident records, volume count, collision and condition diagrams, etc. Second, select 50 representative intersections from this group for more extended study and suggest that each engineer submitting intersections participate in the study by making field observations according to the prescribed method. Third, the results of these observations could then be analyzed at the central point, comparisons made and conclusions reached.

The Committee should make every effort possible to promote cooperation in this work from traffic surveys in progress, Universities and City and State Traffic Engineering Departments.

DISCUSSION ON SAFE APPROACH SPEEDS

MR. H. H. ALLEN, *Motor Carriers' Division, Interstate Commerce Commission:* I would like to say that this paper shows the futility of trying to get physical facts by the use of questionnaires; 40 might vote for it and 40 against it, the remaining percentage may vote either way without changing the value at all.

Further, if reaction time is a significant item in determining safe speeds, the formula for reaction time excludes one factor which is probably of itself of great magnitude in addition to the reaction time of the driver, that is. the reaction time of the brakes of larger vehicles, (those equipped with power brakes). From some brake test data which have come to my attention, the mechanical reaction time of the brake mechanism may be several times what you would expect the reaction time of the driver to be.

I should like also to point out the significance of the fact that there are large departures of individual drivers from the "mean" or average behavior. Each driver having a certain set of facilities available to navigate his vehicle in the "upper story"—each accident that occurs at an intersection occurs by one particular driver's "upper story", and it is that fellow that causes the accident. His actions may have little or no relation to the mean of the results that you may obtain from any number of other data.

DR. H. C DICKINSON, *National Bureau of Standards*: The comments which I should like to make are rather comprehensive and will require a brief analysis of the geometrical considerations at intersections.

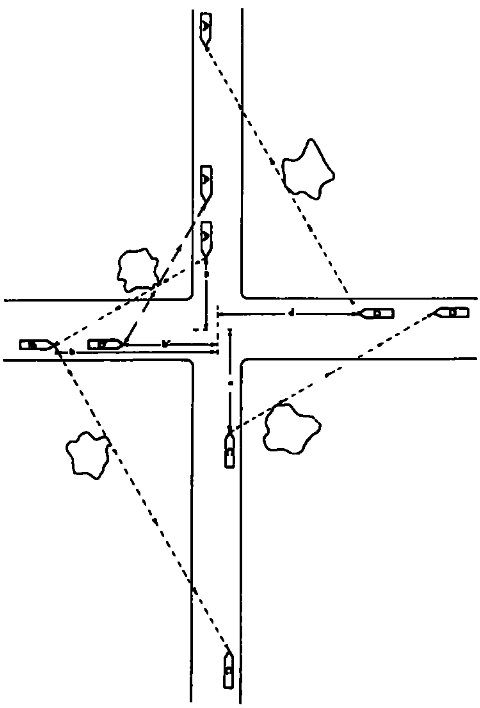


Figure 1

At all intersections where there are obstructions to a clear view of vehicles on the intersecting highway there always is some location between which and the intersection a continuous clear view may be had To illustrate this note Figure 1

Assuming that this intersection is a normal one at which each driver must stop only for the one on his right according to the usual rule, it appears that *A* can see *B* along the line *AB*. If he passes point *A* and sees the road clear at *B* he can proceed without other legal concern for traffic on the cross road except for the usual general precautions. *A* then must be prepared to stop in distance (*a*) if he is to be safe Similarly the "safe approach stopping distance" for *B* is (*b*), for *C* is (*c*), and for *D* is (*d*).

If the intersection were between a secondary road and a main one with special warning signs on the secondary road then drivers on the secondary road must watch in both directions In this case the safe approach stopping distance will be determined by the visibility in both directions. In the figure *B*'s safe approach stopping distance would be shortened to *b′* instead of *b*

These distances *a*, *b*, *b′*, *c* and *d* are definitely determined except for the angle adopted for the sight lines. This angle will depend only a little on the estimated top speed of cars on the different branches. Thus if cars are all assumed to approach at the same speed the diagonal sight lines might be assumed at 45-deg angles. If the car to the right is assumed to have twice the speed of that to the left then the theoretical angle would be 30 deg. from the cross road. The sight distances are affected so little by this difference between 30 and 45 deg that a 30-deg angle might well be taken as a uniform standard.

Consider the relationship of these sight distances or safe approach stopping distances to the necessary behavior of drivers. Every driver at every intersection knows that if a car appears approaching at his right when he passes the sight point *A*, *B*, *C* or *D*, *he must stop* If any driver does not fully realize this he must be forced to do so if he is to be tolerated on the highways

Stopping in this distance will require (*a*) sight reaction time or distance for seeing the vehicle at the 30-deg angle, and in case of through streets at both sides, (*b*) brake reaction time or distance for applying the brakes, (c) brake stopping distance. By assuming an arbitrary or average value for each of these factors a "safe approach" speed can be calculated.

Sight reaction time (a) however is a very uncertain matter, varying between about ½ sec. minimum and perhaps 3 sec. for a practical maximum. It has some degree of constancy for any one individual but wide characteristic variations between individual and sporadic variations due to varying acuity of attention for the same driver. A range of 0.5 to 3 sec. therefore should be allowed.

Brake reaction time (b) is less variable. It ranges from 0.2 sec. to about 1.5 sec. and is rather closely characteristic of the individual. Also the same individual is likely to be either slow or fast on both reactions if the eyesight is good.

Braking distance (a) may vary from about 17 ft. at 20 m.p.h. as a minimum to 30 ft., the legal limit on dry roads, and up to perhaps 75 ft., or almost anything else on very slippery roads. This corresponds to decelerations between 20 ft. and 5 ft. per sec per sec.

Considering all these factors let us assume a "safe approach stopping distance" of 100 ft.

Let V = car speed in ft per sec. = 88/60 m.p.h.
t_1 = sight reaction time
t_2 = brake reaction time
$t_1 + t_2$ = total reaction time = t
a = rate of deceleration
S = safe approach stopping distance = 100 ft.

We have the equation:

$$S = Vt + \frac{V^2}{2a}$$

or

$$2aS = 2aVt + V^2$$

Solving the equation

$$V = \sqrt{2aS + a^2t^2} - at$$

Safe approach speed therefore is a rather complicated function. If we assume the minimum values for reaction time and the maximum rate of deceleration, $a = 20$, $t_1 + t_2 = t = 0.7$, $S = 100$

$$\begin{aligned} V &= \sqrt{4000 + 400 \times .49} - 20 \times 0.7 \\ &= \sqrt{4196} - 14 \text{ ft. per sec.} \\ &= 65 - 14 \\ &= 51 \text{ ft. per sec.} \\ &= 34 \text{ m.p.h.} \end{aligned}$$

If we assume instead the practical maximum values for reaction time and minimum value of deceleration

$$a = 5 \quad t = 4 \text{ sec.} \quad \text{and } S = 100 \text{ ft.}$$

$$\begin{aligned} V &= \sqrt{1000 + 16 \times 25} - 20 \\ &= \sqrt{1400} - 20 \\ &= 38 - 20 \\ &= 18 \text{ ft. per sec.} \\ &= 12 \text{ m.p.h} \end{aligned}$$

While these are rather extreme cases such differences are real ones and it is not surprising that experience should indicate the futility of signs indicating safe approach speeds in miles per hour, when the actual safe speed may differ by as much as from 12 m.p.h to 34 m.p.h. for the same location, depending only on the driver and the weather.

This is only one of the difficulties with safe approach speed as a basis for regulation. Should the driver wish to determine whether he is within the law by checking the speed at which he approaches an intersection, he must first know at what location he is to reach that speed and next he must be able to know the speed at which he is going. If the chosen points are those which we have indicated on the sketch as A, B, C and D, these locations might be indicated by a marker. But if the car is slowing down at these points, the speedometer will not indicate the correct speed at that point. It has a considerable time lag, different both for different instruments and different decelerations, so that the actual speed and that observed on the speedometer might differ by several miles per hour.

If the driver is watching the speedometer when he passes the critical point *A*, *B*, *C* and *D*, instead of looking for approaching traffic, his observation time lag may be several seconds. In other words he may not see at all the danger which he is supposed to avoid by checking his speed.

If an officer wishes to enforce a safe approach speed regulation he has no practicable means of measuring the speed at which a driver passes the critical position at an intersection unless the road is equipped with a necessarily elaborate time checking mechanism. It is obviously impossible so to equip most intersections.

Practical enforcement of a safe approach speed provision therefore seems quite impossible because (1) the actual safe approach speed differs for every different approach to each intersection and varies between wide limits for different drivers and different weather conditions at any one intersection; (2) the driver has no means of properly measuring the speed at which he passes any point and generally has no means of knowing at what point to make the measurement if he could do so; (3) any attempt of the driver to observe the speed at the critical time would greatly increase the hazard; (4) there is no practical means for the officer to check compliance with the law except at specially equipped crossings

In view of these disabilities we would suggest consideration of a safe approach stopping distance. This is the distance indicated on the sketch respectively *a*, *b*, *c* and *d* It differs for different intersections but is purely a function of the geometry of the situation and can be indicated for every approach to an intersection by means of a marker at the curb or a marker on the pavement.

It involves the uniform regulation that the driver must be able to stop in the indicated distance, whatever this may be. The ability to stop at or before reaching some designated point is one of the best understood and most practiced abilities in all the art of driving. Every driver has to make this estimate every time he comes to a red light, or a stop sign, and every time he stops his car at the curb or anywhere else It is necessary for every driver to be able to make reasonably accurate estimates always of whether or not he can stop before reaching any particular spot ahead of him. No driver is safe until he can do this. A keen realization of this fact is precisely what a safe approach stopping distance indication would require him to have.

If it is desired to enforce a regulation requiring the driver to be able to stop between the marker and the center of the crossroad, it is more nearly possible to do so than to enforce a safe approach speed regulation. All that is needed is a recognized signal from an officer at the intersection calling for the driver to stop. If his speed is too great he can not stop and is obviously a violator. The rigid enforcement of any regulation applying to the complex technique of negotiating an intersection is difficult at best if not impracticable. Certainly this is so for the "safe approach speed."

Therefore we would emphasize the educational value of the regulation. It makes sense to tell a driver that when a vehicle comes into view on the cross road he must be able to stop before hitting it He knows this is true and only needs to have his own knowledge impressed on his mind. It does not make sense to tell the driver that he must not be driving faster than *n* miles per hour when he approaches an intersection. He knows that there is nothing exact or tangible about such a requirement. The speed which is safe obviously depends on many interrelated factors and never can be defined with any accuracy.

In view of the greater simplicity of the safe stopping distance technique as compared with the safe approach speed concept, I would urge that the former be given careful consideration as a means of promoting safety at intersections where some definite regulation is deemed necessary. This will not take the place of the general program for improvement of the conditions surrounding intersections, particularly those in rural areas where important thorofares intersect. This discussion has to do more with the typical urban and rural intersections when the view is partially obstructed.

CHAIRMAN HAMMOND: I would like to comment briefly on Dr. Dickinson's remarks. The sign idea he is suggesting is very much the same as stated speed signs which are not very well received by the engineers today because the signs are difficult to enforce and it is difficult to obtain public obedience We are not saying that the stated speed sign is basically unsound nor that it is not a good idea, rather we are concerned about the way it has been used and the computations that have been applied to determine the stated speed. It appears that the results and stated speeds derived from these computations are quite unreasonable. I believe that the public feel that it is an insult to their intelligence to be told that they should slow down to eight miles an hour when they feel that they can go through that intersection safely at 15 m p h. In making this statement, I have assumed that a majority of the motoring public, or approximately 85 per cent, would feel safe in using the 15 m p h. speed Let me repeat again that the problem of our whole study was to review the subject of safe approach speeds at intersections and to determine their future value. We are not attempting to draw any conclusions yet, particularly about the use of the stated speed sign. It seems to us that the stated speed sign developed in about this way. first, formulas were developed; computations made; and finally, conclusions reached—all without field experimentation. These conclusions were then applied to the signs in the form of stated speeds but never checked back to determine whether the stated speeds or the signs themselves proved practicable. We know very well that we cannot force the majority of the public to do something which they do not want to do. We have to make our formulas and traffic engineering efforts fit the majority of the public A few police officers and traffic engineers will never convince the majority that they are wrong. That is one of the reasons why these few intersection approach speed tests were made in the field and why more tests of this nature are needed, if we hope to bring out the practical side of this whole picture of speed and its control.

MR. BURTON MARSH, *American Automobile Association:* You indicate that the results of safe approach speed computations are perhaps impractical. As I understand it, your reason for this assumption is that the checks of actual observed approach speeds (determined by the "approach speed pattern" method) are considerably higher than computed safe approach speeds. And you state that no one can force the majority to do something which they do not want to do. It appears that you consider the speed which the majority of drivers (or 80 or 85 per cent of the drivers) do not exceed is ipso facto a reasonable safe approach speed

There are several points involved in your apparent reasoning which I desire to discuss. First, I question the location on the major street for which you apparently chose the speed used in the safe approach speed computations. At least as to my method (No. 2 in your comparisons) the major street speed should have been that of vehicles just before entering the intersection. In example No. 1, the speed which I believe you used was considerably higher than that near the intersection; and in example No. 2 the speed which you selected was somewhat higher than that near the intersection. If the major street speeds in these examples had been selected for a location as near the intersection as possible, there should have been considerably less divergence between the computed safe approach speed and your observed speed in example 1. In example No. 2 the divergence would have been somewhat less.

Second, if based on sound assumptions, the computed safe approach speed will be the proper safe approach speed Any differences developed by your "approach speed pattern" method will indicate the extent to which drivers approaching deceptive hazardous locations are incapable of judging accurately the speed at which it is reasonable to approach. For this purpose I believe your "approach speed pattern" idea is very useful. It can be one basis for study as to why drivers are deceived more at certain locations than at others as to reasonable speeds at which to approach That they are so deceived is, I think, indicated by the contrast between results in your examples 1, 2 and 3—even taking into account the changes which would be produced by the use of what I consider to be a more appropriate major street speed. Your "approach speed pattern" study cannot, I think, be appropriately used in determining what the safe approach speeds should be For, the observed approach speeds embody in many cases of deceptively dangerous locations, considerable errors in judgment as to what approach speeds are safe.

Third, if the public becomes really convinced that safe approach speeds are computed accurately on the basis of reasonable assumptions, the great majority will cooperate satisfactorily. This is well illustrated by good observance at many obviously warranted stop signs—and this despite the fact that in general drivers do not like to stop. The greatest merit of the safe approach speed idea is in its application to deceptive hazardous locations where it is not apparent to approaching drivers that they need to slow down considerably. By virtue of that fact, we should not expect unguided drivers to reduce speed adequately at such deceptive locations—and hence your "approach speed pattern" study should produce speeds which are too high, as examples 1 and 2 did. In example 3 it would appear from the considerably greater speed reduction in your observed approach speed pattern that drivers for some reason did have a better recognition of the need to slow down considerably.

The trouble is that the public has never been really convinced that the speeds on safe approach speed signs are soundly computed (taking into account existing deceptive factors) and hence that while they may not appear reasonable, they are in fact proper approach speeds. The major need is for effective public education.

If what you have just said were true, there would be much less warrant for any installation of safe approach speed signs than I consider that there is. For you indicated that 85 per cent or so of the drivers are going to drive at speeds which they deem reasonable anyway. No sign would change their speeds. Hence there would be much less warrant than I claim there really is, for putting up any safe approach speed sign.

DR. DICKINSON: Except for the 15 per cent.

MR. MARSH. The point is that certain intersections are so deceptive that the judgments of many drivers are not satisfactory. It is at such places that drivers need added guidance as to speed.

Obviously under such conditions the soundly computed guidance speed will not be the same as the observed speed. It will be appreciably *lower*.

DR. B. D GREENSHIELDS, *Brooklyn Polytechnic Institute:* It seems to me that the speed with which a driver approaches an intersection depends on his past experience. He, of course, in common with all drivers knows the general ground plan of a road intersection. But it is not this plan that he sees when he approaches. His view is from the side If he has crossed a particular intersection on several occasions he has formed an opinion of its relative safeness and adjusts his speed accordingly.

If he has not crossed this particular intersection, his past experience still influences his speed Either consciously or unconsciously, more likely unconsciously, he has learned to look for "Indian" signs of danger. I say "Indian" signs, for warnings of danger are not confined to the danger or speed signs placed by the highway departments. In fact, the unnecessary or over use of signs may mean that they tend to be excluded from the driver's attention. His attention is confined to "pertinent" factors.

It is the whole appearance of the intersection that determines the approach speed of the driver. He decides at what speed he is going to cross the intersection when he is still a considerable distance away. The higher the approach speed the more in advance has this decision been made. The driver's safety depends on the correctness of this first decision. The intersection with a deceiving appearance is the dangerous one. Not until the traffic engineer knows what it is that deceives the driver will he be able to know how to remove the deception. Not until then can he design his speed signs to fit the conditions.

DR. T. W. FORBES, *Yale Bureau for Street Traffic Research:* From my conversations with various colleagues it appears to me that over the course of time we have gotten a definite tie up between "safe approach speed" and the term "safe speed signs". Perhaps that is unfortunate and perhaps we should look for further fields of application for the technique. Apparently the fact that a large number of traffic engineers are using it for some purpose or other indicates there is some value there.

Now with regard to the reaction time point which was mentioned, it strikes me that one thing has not been considered, that is, what is the effect of two blind corners on reaction time. Theoretically that should lengthen it

Perhaps the most important point involved in this report is the idea of speed patterns as a possible means of giving us a new approach to the problem. Take the one corner where the main street speed continues straight through and there is a big drop on the minor street. On that particular corner it was quite evident, when we were checking the speeds, that the appearance of the intersection was producing this deceleration of the car from the side street. In the other two cases, this was not the case.

In other words, may it not be that this speed pattern technique if followed through as a research method, will give us an indirect measure of the state of mind of the motorist as he approaches the intersection and may thus give us an index of the effect upon the motorist of how dangerous the corner looks. If you can change the appearance of the location to make it look as dangerous as it is you may get better results than by putting a sign there. Perhaps that is the ultimate answer. Of course, that does not indicate that the sign approach may not also be needed.