and night operation is somewhat more marked. It is of interest to note that in each of the six comparative studies on the Missouri zone, the average vehicle was closer to the centerline at night than during the day. On the national standard zone, the night placement for the average vehicle was, in four of the six studies, farther from the centerline than the day placement. In the remaining two studies, the difference between the day and night placement was less than in the corresponding studies on the Missouri zone.

3. Since observance of no-passing zone marking is very largely a voluntary matter, the extent to which drivers comply is a significant measure of the effectiveness of the markings. The average infringement on the no-passing zone area by drivers observed completing passings is greater at the locations where the barrier line is in the middle of the driving lane, and on this count also, the national standard shows superiority.

4. Direct interview of a representative sample of driver opinion, consisting of 1,005 motorists who had just left the test section, reveals no decisive preference for either type of marking. This is as true for Missouri drivers as for drivers from states bordering Missouri and for drivers from other states.

5. Even though some slight improvement in placement occurs when the barrier line is extended with a dashed or solid line, driver observance of the extended zone is poor, and this cannot be termed an effective means of bettering operating conditions, regardless of the type of no-passing zone.

CHARACTERISTICS OF LEFT-TURNING PASSENGER VEHICLES

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SYNOPSIS

GENERAL characteristics of left-turning passenger vehicles have proved to be of current interest to those connected with geometric design. The study locations chosen provided two basic conditions; namely, 90-deg. alignment of the vehicle to the intersecting road, and a zero vehicular speed at the beginning of the turn. Data collection was made by a photographic method. Both rural and urban locations were chosen for the study.

The wider range of turning speeds was found to occur at the urban location. The 85 percentile value at the urban location was found to be 21.4 mph., while at the rural location the 85 percentile value was 16.9 mph.

The maximum acceptable side friction factors displayed a reflection of the speed characteristics in that the frequency distribution curves were of the same general shape as those for speed. This suggested that the minimum radii occurring within each speed group must remain nearly constant for the range of speeds observed at each intersection. It is of importance to note that of the total sample only one third of the drivers used a side friction factor lower than or equal to the generally accepted comfortable value of 0.16.

The paths of the left-turning vehicles could not be expressed mathematically as second- or third-degree equations. Both the front and rear wheel paths took the form of a transitional spiral. Front and rear wheel paths blended from transitional spirals at either end of the turn into a central circular arc. The minimum turning radii were found to occur within the first 30 deg. of the 90-deg. directional change. In all cases the shorter-radii transitional curves were at the beginning of the turn, with the longer-radii transitional curves occurring at the end of the turn.

A correlation of turning paths with speed groups at each intersection proved that the shape of the turning paths remained approximately constant for speed groupings at each intersection. However, comparing similar speed groups at both intersections revealed a difference in the geometric shape of the turning path. This precluded any attempt to make a general formulation that would enable prediction of turning paths on the basis of speed.

The characteristics of transverse placement at the beginning and end of turning maneuvers were constant for all samples observed in the study. Transverse placement from the curb at the beginning of the turning maneuver increased with increased speed while at the end of the turning maneuver it remained constant for all speed groups.

Evidently the drivers used some common criteria to position the vehicle at the completion of the turn. Investigation showed that final transverse placement with respect to the roadway cross-section features was such that an immediate lane change was possible.

Analysis revealed a correlation between time and distance required to traverse a turning curve and the speed attained at the final tangent point. It was found that higher speeds, measured at the final tangent point, do not decrease the time required to traverse a left turn. These higher speeds do increase the total distance traveled. The increased distance is not evidenced by an increased turning radius, but it occurs through the use of a longer transitional spiral at the completion of the turn.

● INTERSECTION and channelization design requirements depend upon assumptions as to the type and characteristics of the vehicle, actions of the driver, and speed of the vehicle. The design of the curvature and the pavement edge at channelized intersections, the end shape of medial strips at openings, and the width and the length of medial strip openings depend upon the operating characteristics of vehicles while negotiating a turn. Vehicular left turns from a complete stop occur at the majority of intersections at grade, at protected areas on divided highways, at parking facilities and at various other situations where vehicles are required to stop.

The project, in its initial stages, was conceived and planned as a study that would reveal information which would make possible the derivation of formulas depicting the path of a left-turning vehicle mathematically. Furthermore, the project was to yield information that would enable prediction of turning paths on the basis of various speeds.

Early in the analytical stages of the project it was clearly seen that the original concept of deriving mathematical formulas would have to be modified. It was therefore decided to analyze the data with an ultimate objective of reporting all characteristics of left-turning vehicles that could conceivably be of future use in geometric design. As the project was carried forward all analyses and reporting were done with the above objective in mind.

Many assumptions are made in designing facilities providing for left-turning movements. While these design assumptions are acceptable, factual information concerning characteristics of left-turning vehicles supplies heretofore unavailable data and forms a stronger foundation for present design assumptions. Hence, the purpose of this paper is to analyze left-turning movements occurring from a complete stop and to further describe their characteristics.

Conditions, other than that of the vehicle being completely stopped, were imposed upon the study. It was decided to record data only on vehicles that stopped perpendicular to the intersecting roadway and to record these data only at locations where the intersection angle was 90 deg., or as close thereto as possible. There are two reasons for imposing these conditions. Firstly, all other data on turning movements are available only for 90-deg. turns; hence, if any value from a general correlation is desired in the future all data must be presented on a common basis. Secondly, the broad characteristics obtained would, within reason, be representative of left turns other than 90 deg. Furthermore, it was felt that traffic conditions resulting from surrounding culture would have a marked effect on turning characteristics. For this reason two intersections were investigated; one surrounded by urban culture, and the other surrounded by rural culture.

Time limitations and difficulties involved in obtaining a reliable sample of trucks restricted this investigation to a study of passenger vehicles.

METHOD OF STUDY

There are several methods available for recording field data in a turning movement study: (1) use of marking apparatus mounted on a test vehicle which leaves a trace of the path on the pavement surface; (2) coding data on a moving tape such as is employed in the Esterline Angus 20-pen recorder; (3) taking time motion pictures of left-turning vehicles at predetermined time intervals.

The first two methods have a common disadvantage of supplying a restricted amount of data. The first method necessarily confines the data to those obtained from chosen test vehicles, while the second method requires a large field crew and a close placement of the equipment to the study location, both of which are a disadvantage if the data is to be recorded unobserved by the driver. The photographic method[1] was selected as the most efficient manner to record data on turning movements.

Figure 1.

Intersection Selection

The limiting conditions imposed on the turning vehicles required the choice of an intersection where fairly strict observance of stop regulations was present and surrounding culture was either entirely urban or rural. In selecting the intersection, not only was it necessary to fulfill the required conditions, but it was highly desirable to have an elevated camera position in the correct quadrant from which it would be possible to record the data. Sufficient lateral distance, as well as height, was also required for the camera position to insure sufficient coverage of the turning movements. Several camera lenses of various focal lengths and optical angles provided some flexibility with regard to the camera position. An investigation of intersections fulfilling the requirements and lying within a reasonable working radius revealed that all were unsatisfactory. All intersections which fulfilled the imposed conditions of the investigation were completely lacking in available camera positions. Clearly then, this called for an alteration in the study technique.

Provision of a stable camera position yielding the necessary height and lateral distance was provided through the use of a truck upon which was mounted a 35-ft. swivel-base extension ladder. A small platform at the top of this ladder provided the necessary camera position. This equipment is shown in Figure 1.

Upon the innovation of a portable camera position, the selection of intersections became relatively easy. The locations, chosen on the basis of fulfilling all requirements of the investigation, were the intersections of US 1 and US 1A in East Haven, Connecticut, and Edgewood Avenue and Boulevard Street in New Haven, Connecticut.

The physical features of these intersections are shown in Figures 2 and 3. The turning movements studied are as indicated. Edgewood Avenue at its intersection with Boulevard Street is a divided one-way street. The restricted width of Edgewood Avenue provided good vehicular alignment with respect to Boulevard Street. In addition, the existing stop signs and heavy through traffic on Boulevard forced the majority of vehicles on Edgewood Avenue to a complete stop. The 60-ft. divider strip on Edgewood Avenue provided ample maneuvering and parking space for the ladder truck.

US 1A terminates at its intersection with US 1. Those vehicles desirous of making a left turn are forced to use a one-way opening in the divider strip. Prior to this investigation traffic making the left turn from the divider opening was not required to stop but proceeded at the discretion of the driver. Excessive opening width also permitted promiscuous maneu-

[1] Greenshields, B. D., "The Photographic Method of Studying Traffic Behavior," Proceedings of the 13th Annual Meeting of the Highway Research Board, 1932.

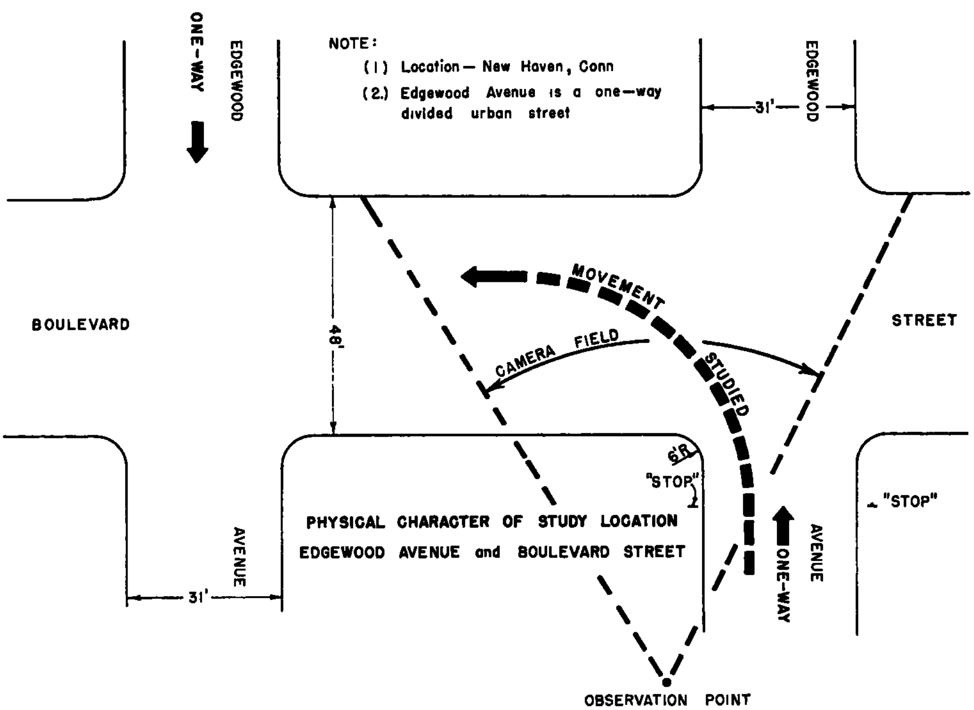

Figure 2.

vering within the shadowing area. Permission was obtained from the State of Connecticut to erect two "Keep Right" barriers within the divider opening and a "Stop" sign at the right edge of the opening. Thus the desired alignment and operation of the vehicle were obtained. Existing area within channelizing islands provided the necessary space for parking and maneuvering the ladder truck.

Physical Character of the Intersections

Before proceeding with the field work of turning movement data collection, it was necessary to determine the characteristics pertaining to the physical layout of the intersection. The radius of all curb returns, especially that one involved in the movements to be studied; roadway widths; existing lane widths; position of crosswalks; and positioning of existing installations, such as light standards and regulatory signs, are all pertinent data required for intelligent preliminary planning of the pavement grid system and its positioning.

It is to be noted that the intersection of Edgewood Avenue and Boulevard Street was taken as being a right angle intersection. The

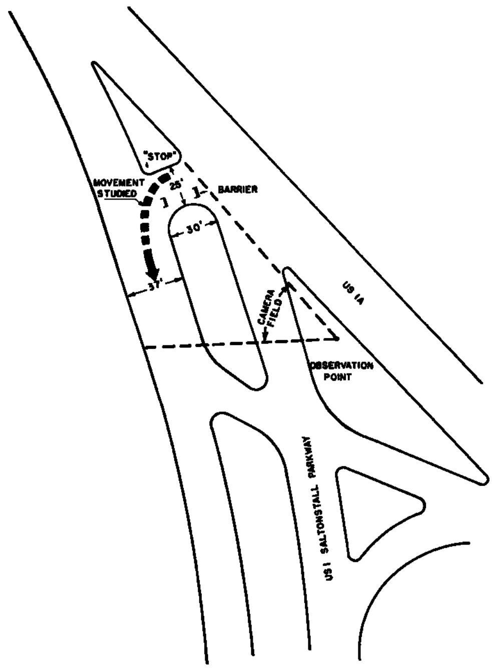

Figure 3. Physical character of study location on US 1 and US 1A at East Haven, Connecticut.

actual right deflection angle was 89 deg. 50 sec. This slight difference from a right angle was assumed to have no effect on transverse placement even at the extremities of the completed turn.

The median strip opening at the intersection of US 1 and US 1A was considered as being at right angles to the intersecting lanes of US 1. A measurement of the intersection angle between the centerline of the opening and the pavement edge of US 1 showed this to be true within 1 deg. The assumption of a 90-deg. intersection angle with this resulting 1-deg. error would not influence the final results since it was decided beforehand that data would be recorded to the nearest even foot. Hence a deviation of 1 deg. based on the length of the field of vision of the camera was allowable.

Camera Arrangement

As previously mentioned, the method of study chosen involved the use of a motion-picture camera to record data. The camera equipment available included a 16-millimeter Eastman Cine-Kodak Special, an assortment of lenses and an auxiliary electrical timing mechanism. When film is exposed at the rate of 88 frames per minute, the speed of the vehicle, in miles per hour, is equal to the distance traveled during successive frame intervals. The distance between successive frame intervals is easily obtained during analysis; hence, an exposure rate of 88 frames per minute was used in this study. This film speed is obtained by the use of an auxiliary timing mechanism actuating an electrical shutter release.

For the purposes of reference and checking, each film frame records the number showing on the counting mechanism. An auxiliary lens focuses the camera for a clear indication of each number. The counter is actuated electrically by the timing mechanism and the sequence takes place so that the numbers are advanced one digit for each frame while the camera shutter is closed.

There are several criteria to be considered when taking time motion pictures for the study of traffic movements. Each picture should (1) contain the details necessary for successful completion of the investigation; (2) involve the least possible amount of parallax, which introduces error in recording data from the film; (3) produce clarity of details, which requires a stable camera position to eliminate all extraneous camera movement; and (4) show full intersection coverage, which requires sufficient elevation and lateral distance. Elimination of parallax is not practical, since this would require great height directly above the study location. Camera positions located at the top of tall buildings are often used as a compromise in the above criteria.

It was found that the use of a camera secured to the top of a truck-mounted extension ladder produced satisfactory results. Once the camera had been secured at the top of the ladder, all optical adjustments were made and the ladder was guyed from two directions with the weight of a person at the top of the ladder. This was done to maintain the proper field of vision and to reduce sway. When these preliminary adjustments had been made, remote-control cables were run from the camera to the timer, which was operated at ground level. By using this procedure the camera was operated undisturbed throughout each field study.

Data Collection

After the pavement markings were placed on the road surface, the ladder truck was maneuvered into a position that would give adequate camera coverage of the intersection. It was found through trial and error that a rough approximation of the camera's field of vision when mounted on the extension ladder was 1.5 times the sum of the height of the camera above ground level, plus the lateral distance from the nearest curb, if that curb was roughly parallel to the plane of the film. This rough approximation applies only when a 15-millimeter wide-angle lens is used on the camera.

After placement of the pavement grid and positioning of the camera, the timing mechanism was placed in the circuit. The equipment was operated only when a potential left-turning vehicle appeared, hence the maximum amount of useful data were recorded on a minimum amount of film. This selective recording of data also eliminated later screening of vehicles to determine the ones making the required turning movement.

Recording Procedure

After the field work and film processing were completed, the vehicular movements recorded on the film were projected onto a perspective grid. This grid, which was constructed from the pavement grid markings, was placed on heavy white cardboard that formed a screen on which to view the vehicular movement.

By using a piece of cardboard for a grid screen, the grid can be adjusted to each frame image by moving it into line with previously located landmarks. The pictures are then projected onto the grid screen. An auxiliary motor is normally used to advance the film through a sequence of vehicular movements and a reversing lever is used to return this sequence to its beginning. This operation is required to determine acceptable movements if undesirable influencing factors are known to be present during the field recording of data.

Field procedure permitted the recording of only those vehicles making left turns, and the presence of normal influencing factors was not deemed undesirable. Hence, the auxiliary motor and reversing lever were not used for sequence studies. Each frame was advanced individually by a manual advancing knob and the data recorded directly. The inside (left) front and rear tires were used as reference points from which data were recorded to the nearest foot.

DEFINITION OF TERMS

Since the speed of the turning movements under investigation varied from zero at the start of the turn to a desired speed at the completion of the turning maneuver, it was necessary to define a point at which vehicular speed could be measured. The speed attained at the completion of the turn is termed the tangent speed. The point of tangency at which the tangent speeds were measured is that point where curvilinear motion becomes linear motion.

In the analysis of the turning paths, reference lines had to be chosen in order that median values of path could be plotted. The reference lines chosen were, in all cases, the intersecting curb lines to the left of the vehicle. Transverse perpendicular distance from these curb lines is called placement. Minimum radii refers to the average value of the minimum radii of the paths for the inside left front and rear wheels.

DATA COLLECTION

Through the use of grid coordinates,[2] the data recorded directly from the film were: (1) deflection of front wheels at the beginning of the turn; (2) coordinates of the left front and rear wheel for each frame; (3) turning time in frame numbers.

Successive positions of a vehicle were determined from the film by the use of the grid system. For each sample, vehicular positions were plotted as a turning curve and formed the basis for constructing median turning paths. Inability to construct a smooth curve connecting a sequence of plotted points with various types of French curves, showed that the paths of left-turning vehicles could not be expressed as a second- or third-degree equation. The use of a flexible spline to construct a smooth curve through successive points indicated that the paths of both the front and rear wheels were some form of a transitional spiral.

When the vehicular path had been established, speed, placement, minimum radii, side friction and the total time required to negotiate the turn were calculated directly from the data transcribed from the film.

SPEED EVALUATION

Based upon the hypothesis that speed is a determining factor in the choice of turning paths, the speed attained at the end of the turning maneuver was assumed to be the critical speed since its final value would be a direct result of the rate of curvilinear acceleration used during the turn. It is evident that acceleration is an influencing factor in the choice of path because the normal component of the curvilinear acceleration, together with the minimum path radius, determines the value of the unbalanced side thrust. Side thrust is adjusted to the driver's judgement of a safe or comfortable value. Hence the velocity at the completion of the turn would be a suitable basis of comparison for the various path and turning characteristics.

[2] Greenshields, B. D., Schapiro, D., Erickson, E. L., *Traffic Performance at Urban Street Intersections*, 1947, pp. 119–120.

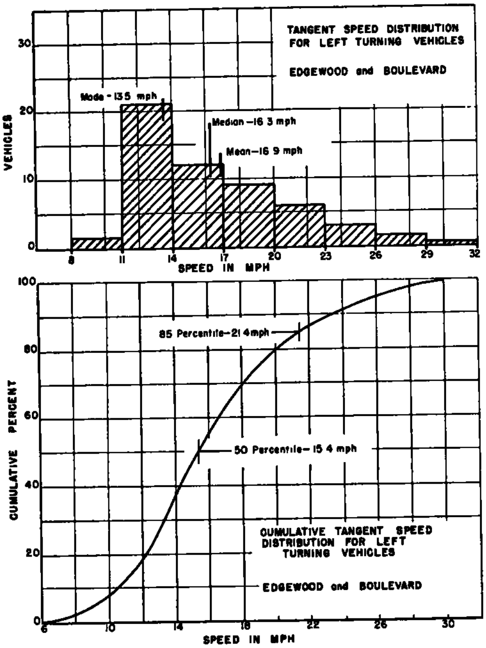

Figure 4.

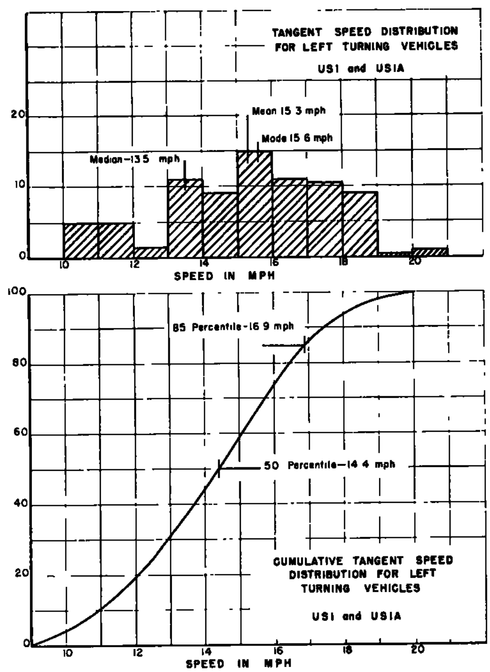

Figure 5.

TANGENT SPEED CHARACTERISTICS

Speed data, directly readable as the distance between successive vehicular positions recorded on the film, were tabulated and plotted as frequency and cumulative distribution curves as shown in Figures 4 and 5. Speed intervals used in the distribution curves were calculated by the interval formula.[3] At both intersections the lower end of the speed range was 10 mph., while the upper end at the Edgewood Avenue location was 30 mph., and at the US 1 and US 1A intersection it was 20 mph. The 50 percent increase in the upper range of speed at the urban location was observed in the field to be a direct result of heavy traffic pressure from both directions forcing the driver to reach these higher velocities through the necessity of increased acceleration. The data in dicated that the tangent speeds were predominantly at the lower end of the range for the urban location. The cumulative distribution curve yielded the fact that nearly 85 percent of the turning vehicles were within the lower half of the speed range. Thus it is seen that relatively few drivers were forced to use the higher turning speeds.

The rural location showed a slight tendency toward a positive skewness, which is just the opposite of the urban location. The positive skewness was not marked, however. At the rural location, the majority of the distribution was within the central portion of the 10-mph. speed range.

SIDE FRICTION EVALUATION

In all cases the minimum radii of the turning paths were evidenced within the first 30 deg. of the 90-deg. directional change. The radii within this limit were used in the evaluation of maximum side friction factors. Precise measurement of side friction as affecting the geometric form of the path due to driver behavior was not possible, since the unbalanced side thrust that affects a driver's comfort acts through his center of gravity. To obtain a side friction factor resulting from driver comfort, which could then be related to a choice in turning path, the minimum radius of the driver's center of gravity should properly be used. Hence a compromise in using available

[3] The standard formula for calculating the class interval is. Class interval = Range/(1 + 3.322 (log N)), where N = number of samples.

data as against theoretical requirements was accepted. An average of the minimum radii of the inside front and rear wheels and the average speed obtained within the first 30-deg. measuring limit was used in computing maximum side friction factors.

SIDE FRICTION CHARACTERISTICS

The frequency and cumulative distribution curves of maximum side friction factors (Figures 6 and 7) display a direct reflection of tangent speed characteristics in that the distribution of maximum side friction factors is of the same general shape as the speed distribution.

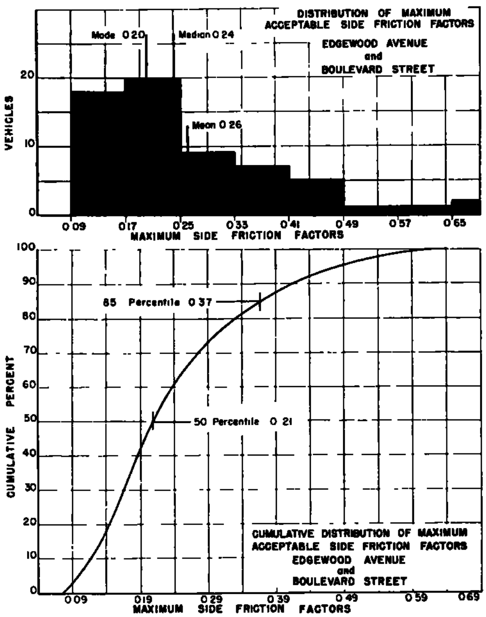

Figure 6.

At the urban location a negative skewness, as indicated by a modal value of 0.20 and a median value of 0.24, proved that the majority of drivers chose a low value of side friction factors while a relatively small number used values shown in the upper range of factors. Eighty-five percent of the side friction factors accepted at the urban location were within the lower half of the range.

The frequency distribution for the rural location presents a tendency toward grouping in the central portion of the range as was found in the case of speed. The 85 percentile value of 0.24 reveals that the majority of drivers accepted friction factors within the first 60 percent of the range.

In considering both urban and rural locations, it is important to note that of the total sample, only 30 and 35 percent respectively used the generally accepted comfortable side friction factor of 0.16. Also, the similarity of speed and side friction distribution would seem to qualify speed, and not path, as the critical factor used by the driver in determining safe and comfortable side thrust resulting from the acceptable side friction factors. This in turn would suggest that the minimum radii must remain approximately constant for the range of speeds involved.

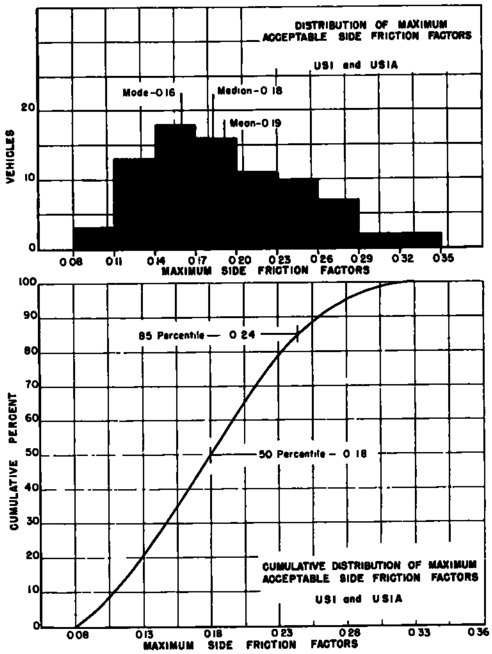

Figure 7.

PATH DESIGNATION

It was desirable to present the space occupancy for the tread of a pair of wheels in order to show not only the space utilized in turning, but also the geometrical shape of the turning path. This objective was obtained graphically in the form of derived turning curves. These curves are based on median values of transverse placement taken from the plotted turning curve of each vehicle.

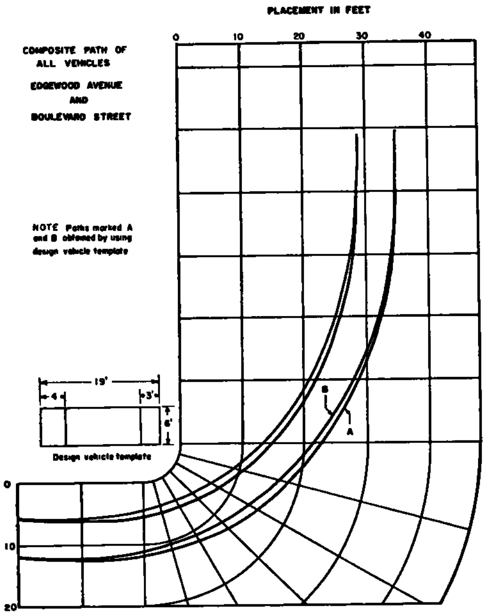

Figure 8.

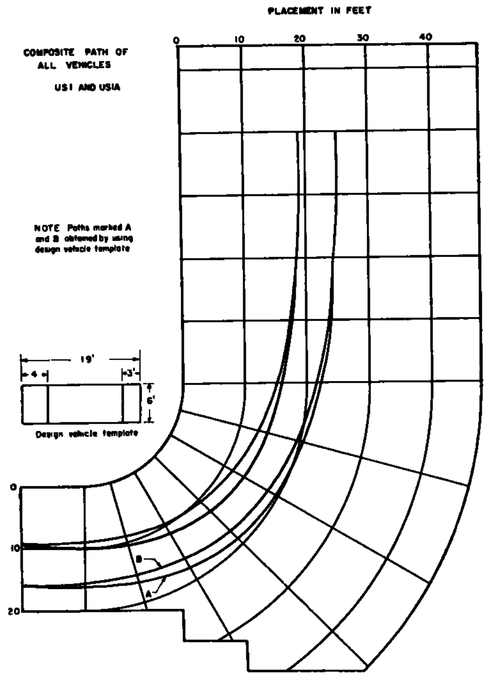

Figure 9.

TURNING AND PATH CHARACTERISTICS

The original hypothesis contained the element of speed which was felt to be an influencing factor in negotiating a turning movement. It was presupposed that its effect would be found not only in the geometric shape of the path but also in the variation of minimum radii acceptable to the driver. However, the characteristics set forth under preceding sections of speed and side friction factors furnished early evidence that perhaps the minimum radii and the over-all geometric shape of the path did not vary appreciably when correlated with speed.

To present a definite answer to this question, path or placement curves were segregated on the basis of speed groupings. Median values of placement for each speed group were then calculated and plotted, thus giving a single set of turning paths for each speed group. A visual comparison of the geometric shape and minimum radii for the curves at each intersection showed at once that the variation in path and radii, when grouped according to tangent speed, was not significant. The variation found between intersections was significant, since it did indicate that the turning path is not identical at both intersections. The above statements do not imply that all drivers at a particular location traverse the same path, since the range in minimum radii used at the urban and rural intersections had a value of from 28 to 52 ft. and 20 to 44 ft. respectively. It does indicate, however, that the majority of drivers at each intersection, for definite speed groups, choose similar paths. It should be noted (see Table 1) that there is a common range of minimum radii at both intersections, even though the upper and lower limits are different.

Median values of placement for all vehicles at each intersection were calculated and plotted to provide a composite geometric path for each intersection. The unlettered curves in Figures 8 and 9 are smooth curves connecting these points. These curves are not presented as the single-valued path chosen by all drivers. They are presented as being representative of the path most often used by drivers at each intersection. To present a more comprehensive picture, a template of a design vehicle,[4] to proper scale, was moved around the derived paths and the corresponding axle points on the right hand side of the template were marked, thus producing Curves A and B. The result is a more comprehensive picture of the

[4] American Association of State Highway Officials, *A Policy on Intersections at Grade*, 1940, p. 5.

complete vehicular turning path and space occupancy. Considering only the unlettered or derived curves, it is seen that both the steering curve (front-wheel path) and the tracking curve (rear-wheel path) are not simple circular arcs. Both paths are a blending of transitional spirals at either end into a central circular arc.

In all cases the shorter radii transitional curves were at the beginning of the turn, with the longer radii transitional curves at the end of the turn. In observing the individual vehicular paths, it was noted that when extremely sharp wheel deflections occurred, the wheels paths contained no central circular curve but the beginning and ending spirals merged.

Behavior at the beginning and end of turning maneuvers was found to be consistent at both intersections, as indicated by the data presented in Table 1.

It is seen that placement from the curb at the beginning of the turning maneuver increases with increased speed while placement at the end of the turn remains constant for all speed groups. The noteworthy point, however, is the consistency of placement for the tangent point at the completion of the turning maneuver. Evidently the drivers not only line themselves in when stopping to turn, but they also use some common criteria to position the vehicle at the completion of the turn. This substantiates the theory of using reference points in channelization. Figure 10 was prepared to show median values of final placement for all vehicles at each intersection with respect to roadway cross-section features. It is apparent that the drivers have positioned their vehicles so that a lane change is possible.

The uniformity in path and placement for the various speed groups at each intersection poses the question of reasons for uniformity. Do the vehicles, most of which were local traffic turning into the main thoroughfare, produce uniform quantities on the basis of a common concept of comfort and safety? Or are the uniform paths and placement a result of repetitive habit in turning and thus produced by the physical design features of the vehicles? A portion of the data taken from the film was the deflection of the front wheels at the start of the turning maneuver. At the urban location nearly two-thirds of the vehicles started the

TABLE 1
SUMMARY OF DERIVED DATA ON LEFT-TURNING CHARACTERISTICS

	Edgewood Ave. and Boulevard St.	US 1 And US 1A
Tangent Speed		
Median	16.3 mph.	13.5 mph.
Mode	13.5 mph.	15.6 mph.
Mean	16.9 mph.	15.3 mph.
85th percentile	21.4 mph.	16.9 mph.
Maximum.	30.0 mph.	20.0 mph.
Side Friction		
Median	0.24	0.18
Mode	0.20	0.16
Mean	0.26	0.19
85th percentile	0.37	0.24
Maximum	0.67	0.33
Path Characteristics		
Variation of minimum radii and geometric shape of turning path with tangent speed	Very little	None
Over-all range of minimum radii (not based on speed)	28 to 52 ft.	20 to 44 ft.
Behavior at tangent.	Favorable lane change position	Favorable lane change position

Median Placement

Edgewood Ave. and Boulevard St.: Speed	Placement: Start	Placement: Finish	US 1 And US 1A: Speed	Placement: Start	Placement: Finish
8–13 mph.	5.5 ft.	29 ft.	10–12 mph.	8 5 ft.	19 ft.
14–24 mph.	6.5 ft.	29 ft.	13–17 mph.	9.5 ft.	19 ft.
25–30 mph.	6.3 ft.	29 ft.	18–20 mph.	9.0 ft.	19 ft.

	Edgewood Ave. and Boulevard St.	US 1 And US 1A
Percent of sample without wheel deflection	64	44
Turning time	6.8 to 2.0 sec.	6 8 to 4.1 sec.
Distance traveled during turning maneuver	65 to 90 ft.	57 to 92 ft.

turn with no deflection of the front wheels, and at the rural location, almost one-half of the drivers did not turn their front wheels after stopping. This would tend to disprove the concept that the majority of drivers choose a predetermined path through familiarity with the location. Hence for a given location and existing physical features, the hypothesis of similar path and placement characteristics as determined by the driver's common concept

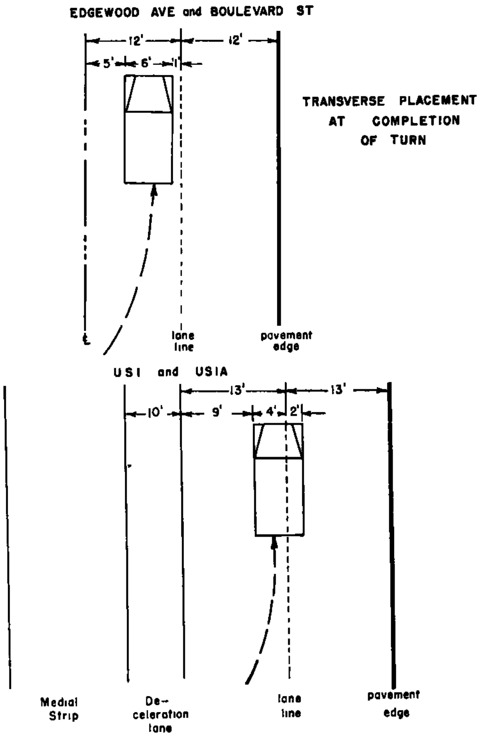

Figure 10.

of safety and comfort would be supported by the data presented above.

Visual observation of data revealed a correlation between the time taken to traverse the turning curve and the speed reached at the tangent point. Curves of time versus tangent speed and distance traveled were plotted for both intersections, and as is shown in Figures 11 and 12, there was revealed a flattening out of the time curve toward the higher end of the speed range. This would indicate that the total distance traveled must increase as the tangent speed increases. However, in direct

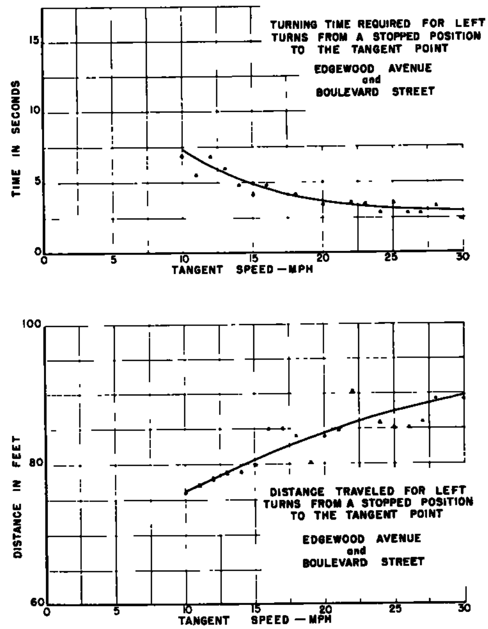

Figure 11.

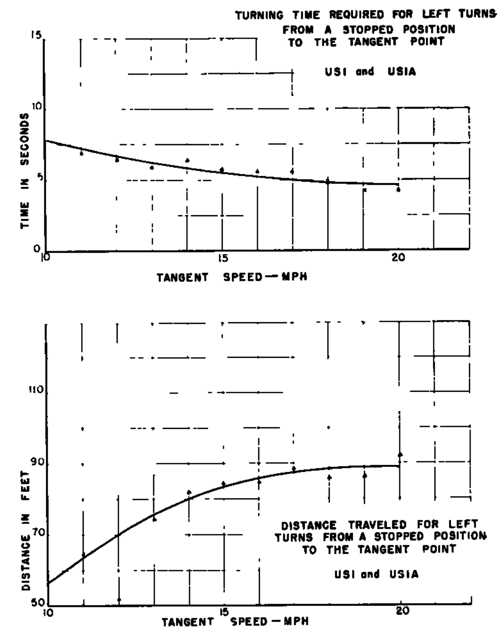

Figure 12.

contradiction to this effect were the facts disclosed above; namely, that transverse placement and minimum turning radii did not vary with speed. Further analysis with regard to time consumed in turning, tangent speed and distance traveled from start to tangent point disclosed the relationships shown in distance curves. It was found that although the minimum radii used did not increase appreciably in the upper limits of tangent speeds, the distance required to reach the final tangent point did increase. Stated differently, the length of the final transitional portion of the turning curve was elongated as the tangent speed increased.

CONCLUSIONS

Analysis based on derived data from this study of left-turning movements indicates that turning paths at individual intersections, segregated according to specified speed groups, have similar geometric patterns, while side friction factors and total distance traveled in turning are factors varying with speed grouping.

Based on the data collected in the investigation of left-turning movements, it is proposed that the following conclusions are true:

The speed with which the *majority* of vehicles complete a left turn from a stopped position is greater at rural locations than at urban locations, as witnessed by the difference in the modal values of tangent speeds shown in Table 1.

Transverse placement for the stopped position at the beginning of the turn increases with an increased tangent speed. Placement at the completion of the turning maneuver has no correlation to speed. The final placement of the vehicle does depend on the driver's desire to attain a favorable lane change position.

The higher tangent speeds used by drivers at both study locations does not decrease the time required to traverse the turn. The higher tangent speeds do increase the total distance traveled. This increased distance is not evidenced by an increased turning radius, but it occurs through the use of a longer transitional spiral at the completion of the turn.

The minimum radius at either location was found to occur, regardless of speed, within the first 30 deg. from the start of the turning maneuver. The majority of the minimum radii used do not vary within any one speed group. However, there are exceptions that occur when front-wheel deflections are large and tangent speeds are high. Under these conditions a minimum radius is maintained over a decreasingly smaller portion of the turning path until the path becomes a merging of the two transitional spirals.

Drivers in most cases do not start a left turn with any front-wheel deflection whatsoever. Those drivers who do begin a turning maneuver with a small wheel deflection still utilize a transitional path going into the turn. Only a small number of drivers begin turning paths with the front wheels in an extremely deflected position, in which case the vehicles start the turning maneuver immediately without any transitional path at the beginning of the turn.

The acceptable side friction factors reflect the speed desires of the driver. Because speed is a direct variable and the side friction factor is an indirect variable and also because minimum radii remain relatively constant for the speed groups considered, an indication is given that speed is the variant used in adjusting the physical senses and psychological attitudes to safe and comfortable turning maneuvers.

Subsequent attempts to formulate left turning paths mathematically, according to speed groups, have not proved successful. Even though the original data indicated that this might be possible, variation of geometrical qualities for identical speed groups occur between individual intersections which precludes generalized formulas.