Vehicular Paths In Certain Types of Intersection Areas

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The design of rural highway interchanges has been based on the mechanical capabilities of the automobile, with the assumption that if the interchanges are properly signed the motorist can follow any set of directions. It was considered desirable to study various design features of Wisconsin interchanges in terms of the driver's reaction.

To trace the paths of vehicles through the interchange being observed, a movie camera with a shutter actuating mechanism was attached to a 30-ft portable TV tower. Pictures of the vehicles were taken at a rate of one per second. Data were then transcribed from these pictures onto plan views, and the data grouped for statistical analysis.

Several important conclusions are derived from this research study, as follows:

1. Weaving lanes should be of sufficient length to allow traffic to blend in with free flowing traffic rather than dart in as required on short segments. Approaches should be tangent or of only small degree of curvature. If necessary, overhead signs should be erected to channelize traffic properly prior to entering the weaving section to avoid the unnecessary internal friction caused by weaving from the outside lanes.
2. A driver should never be confronted with more than one problem or decision at a time. If more than two alternatives are available to the driver, complete compliance cannot be expected. Interchange design features should incorporate such alignment as to make it unnecessary for the majority of motorists to take any action to accomplish their desires.
3. Intersections should be designed so that turning movements are not in conflict with the better judgment or intuition of the motorist. When conflict arises, as many as 10 percent of the motorists involved may rely on their judgment in preference to the signs erected.
4. Medial strips should be designed so that there is no change in alignment for oncoming traffic.
5. In some cases the topography is such that left turns at grade can be accomplished without the use of a stop sign if said traffic movement is infrequent and the total volume of the intersection light to medium.

It is important to realize that signs have their greatest effectiveness when they are incorporated with intersectional design such that together they produce logical solutions to the driver's dilemma. Whenever a driver is directed to perform an act which is contrary to his better judgment, such as turning left in front of oncoming traffic in order to make a right turn, hazardous confusion is created wherein 100 percent compliance with this channelization is an impossibility.

● THE INTERSECTION of two roads has always been troublesome because it introduces "cross interference" and, if the abutting property development has been uncontrolled, there is an increase in "marginal interference." A major objective in the design of intersections is to reduce the various types of interference to a minimum in order to reduce the incidence of accidents without restricting the normal traffic flow. Although the design has corrected or even eliminated interference, in some cases it has produced an unnatural situation requiring the driver to exercise good judgment, good control, and rapid judgment. The existence of safety features does not necessarily mean that the driver will utilize them. They may serve only to confuse an already somewhat perplexed motorist. It is necessary, therefore, to observe not only the normal or average response but also the abnormal reaction. Previous studies have concentrated on analysis of vehicle position at a particular point of an intersection. In this study the complete path of each vehicle through the intersection area was unobtrusively observed to analyze the driver's response to design features.

A movie camera taking single frame pictures provided the necessary continuous record of vehicles moving through the intersection. Since the time interval between pictures was controlled, the speed of the observed vehicles was also measured. By mounting the camera on a 30-ft sectional television tower a better perspective of the intersection was obtained. A turntable motor with a speed governor operating from a 6-volt automobile battery (and through a coaxial cable and eccentric wheel) tripped the camera shutter at a speed of one frame per second.

A satisfactory grid reference system was adopted to get accurate positioning of vehicles. Pairs of wooden blocks were spotted every 25 ft along the highway in the observed areas. The position of each block was identified on the plan view so that the vehicles could be plotted after their position, in relation to the blocks, had been observed by the projection of the film strip. In bright sunlight, where the shoulders were bleached out, waste oil was used to establish a reference grid. For distances greater than 250 ft from the camera, the blocks could not be accurately identified in the film projection. Where intersections were paved with portland-cement concrete the bituminous filled joints provided a reference grid. For asphaltic concrete pavements the centerline marking, which were alternating 15-ft lengths of white and 35-ft lengths of black, was used as a reference grid.

PROJECTION

The operator of the micro-film projector controlled the film movement, took measurements from the image, and plotted the location of the vehicles on the plan view. The film strip was slipped through the micro-film projector and, therefore, control points on successive frames did not normally fall at identical points on the screen. A plotting grid was drawn on the image screen using the reference grid established in the field and the image position was adjusted to agree with the grid by matching known control points. The true pavement width being known, an adjustable scale was used to measure the lateral position of vehicles and the reference grid to measure their longitudinal positioning. Observed positions for each vehicle were connected to indicate the path of the vehicle. The approximate speed of the vehicles was determined by multiplying the scaled distance between points of observation by 0.682, thereby changing from feet per second to miles per hour.

FIELD OF VIEW

One of the major problems in the use of a camera operating from a remote location was establishing its field of view. A vernier mounted on the camera measured the vertical angle that the camera made with a level plane. A plumb bob aided in keeping the tower perpendicular.

Various lenses were studied to determine their field of view for different vertical angles from the camera mounted on the tower. Tables were prepared for level terrain as well as areas with vertical grades of 1, 2, and 3 percent; they showed the width of view at the lower and upper edge of the picture and the distance from the base of the tower to these points. These tables for various lenses enabled the operator, if the topographic conditions were known, to determine the exact field of view the camera would have when mounted on the 30-ft tower with a pre-set vertical angle.

Knowledge of the terrain of the intersection and the site selection limitations for the tower was necessary for selecting the correct lens and the vertical angle setting. Because the tower had to be some distance from the lanes of moving traffic, only vertical angles of 4 to 12 deg, inclusive, were satisfactory.

In the selection of the proper lens two things were kept in mind: (a) the width of the picture should encompass the area through which the vehicles are moving, and (b) the depth of the picture should cover the pertinent movement. Where pictures were in areas close to the foot of the tower, the 1-in. lens was used; where pictures were a minimum of 400 ft from the tower, the 4-in. telephoto lens was used.

FIELD PROCEDURE

Based on the capabilities of the camera lens, several tentative sites were selected from the office drawings of the intersection (1 in. = 25 ft). If it was apparent that a location materially affected the driver's actions, that site was discarded. Because some motorists are aware of radar speed detectors, the presence of any unusual object or occupied vehicle near the roadway may produce apprehension and distract the driver. Observations made under such conditions are of little value. Vehicles should approach the camera either head-on or perpendicular to the axis of the lens. Tentative sites were investigated in the field, and the most suitable one was selected.

The tower and base were assembled and oriented by line of sight so that the tower pointed to the midpoint of the proposed picture. The base was secured, guy lines attached, and the camera unit and base attached by means of a U-shaped bracket to the top of the tower (Figures 1 and 2). The proper vertical angle was set on the vernier and the equipment was checked for operational difficulties. The tower was then raised.

Use of an overhead structure was much simpler, because a tower was not required, and the field of view was obtained directly by using the viewfinder on the camera (Figure 3).

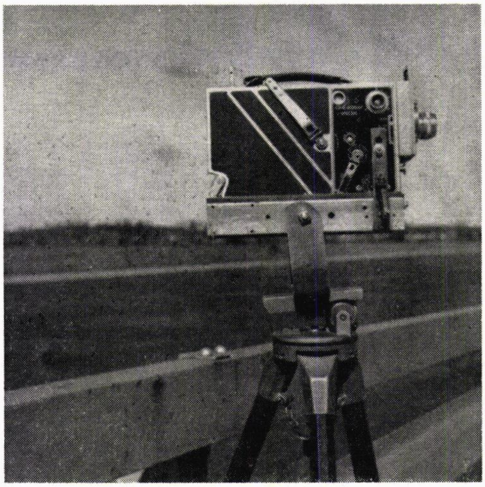

Figure 1. Mounting of automatic camera, showing U-bracket on tripod.

Figure 2. Camera mounted on 30-ft television tower with auxiliary tower for personnel.

Figure 3. Tripod-mounted camera on overhead structure.

FIELD DATA

Five specific movements were investigated. Plan views of the 11 intersections at which 15 set-ups (identified as stations in Table 1) were made are shown in Figures 4, 5, and 6. Pertinent information on geometric design, traffic volumes, conditions of observance, and summarization of observations are included for each station in Tables 1 and 2.

Case 1: Left Turns at Grade at Intersections — Stations 1 and 2A

Observations: Left turns at Station 1 were accomplished from a complete stop through a channelized intersection. Driver compliance with the design channelization was good, with less than 2 percent possibly confused by the design. Traffic flow was dispersed uniformly through the movement. Left turns at Station 2A were accomplished at reduced speed. The design channelization is such that two vehicles made incorrect entrys from the abutting property. Furthermore, the point of greatest dispersion in the flow of left-turning traffic occurs in the area of conflict with northbound traffic on US 51. Instead of a jet flow, the traffic is sprayed through the interesection. Drivers must be allowed to drift if left turns are to be accomplished at reduced speeds, but this enlarges the "field of battle."

Comments: Channelization at Station 2A should be improved by reducing the gap to conform more nearly with the area demanded by existing traffic, as determined by statistical computations of the average vehicle path plus or minus two standard deviations. The gap as shown at Station 2A in Figure 4 has been reduced to discourage unnecessary drifting. The topography at Station 2A enables the northbound traffic on US 51 to obtain a plan view of the intersection and to regulate its movement to minimize conflict. No such opportunity exists at Station 1. In addition, the traffic at Station 1 is double that of Station 2A. These facts necessitate left turns at Station 1 to be accomplished from a stop, prohibiting the driver from making this kind of a decision. Only where the driver's judgment based on complete observation is highly reliable and where the movement has a reasonable chance of success, should left turns at reduced speeds be allowed. Increased traffic and flat topography affect these factors to an extent that stop signs are preferred under these conditions.

Case 2: Medial Strips — Stations 2B, 3, and 4A

Observations: The standard deviations of position were similar for all three stations. The most effective design studied was at Station 3. The medial strip was so constructed that northbound traffic, as it approached the south end of the medial strip, was not required to alter its direction of travel. On the other hand, the diamond-shaped medial strips at Stations 2B and 4A required traffic to shift to the right to stay within the designated traffic lane. None of the designs reduced the vehicular speed.

The shift to the right at Station 2B by the northbound traffic on US 51 caused by the diamond-shaped medial strip had to be altered immediately to avoid conflict with the merging traffic from the right on US 16. A yellow barrier marker

TABLE 1
OBSERVATION CONDITIONS AND SUMMARY OF OBSERVATIONS AT INTERCHANGES

Station	Time	Date	Weather	24-Hr. Volume		Confused		Incorrect Movement		Location
				Total	% Comm.	No.	Percent	No.	Percent	
1	10:30- 1:30	10/27/55	Clear	4,580	25	2	1.6	—	—	US 14-STH 11
2A	10:30- 2:30	8/14/54	Clear	2,190	25	1	0.7	2	1.4	US 16-US 51
2B	9:00-11:15	9/ 8/55	Cloudy	3,690	25	—	—	—	—	US 16-US 51
3	3:30- 5:00	9/ 8/55	Clear	4,010	21	—	—	—	—	US 12-CTH Z
4A	12:00- 2:30	10/16/55	Cloudy	4,840	—	3	2.0	1	0.7	US 41-STH 175
4B	10:30- 1:30	10/10/55	Clear	4,600	—	7	2.8	4	1.6	US 41-STH 175
5	10:00- 1:30	10/20/55	Clear	2,100	23	—	—	1	1.0	STH 145-US 41 and 45
6A	10:30- 1:00	9/13/54	Clear	8,670	20	2	1.0	10	5.0	Knob Hill Interchange
6B	9:30-11:30	9/28/55	Clear	2,860	19	7	4.4	2	1.2	Knob Hill Interchange
7A	8:30- 1:00	11/11/55	Cloudy	4,050	22	4	6.5	2	3.2	US 12-US 14
7B	8:30- 1:00	11/11/55	Cloudy	4,000	20	2	2.6	1	1.3	US 12-US 14
8	10:30- 1:30	8/30/55	Clear	5,560	25	1	0.7	1	0.7	US 16-STH 190
9	2:00- 3:30	11/11/55	Cloudy	6,380	23	5	7.1	3	4.3	Park St. Interchange
10	7:30- 9:00	10/11/55	Clear	11,900	—	1	0.5	3	1.5	US 41 and 45-STH 175
11	10:30- 1:00	9/ 1/55	Clear	6,740	25	2	0.5	20	5.0	US 141-STH 57

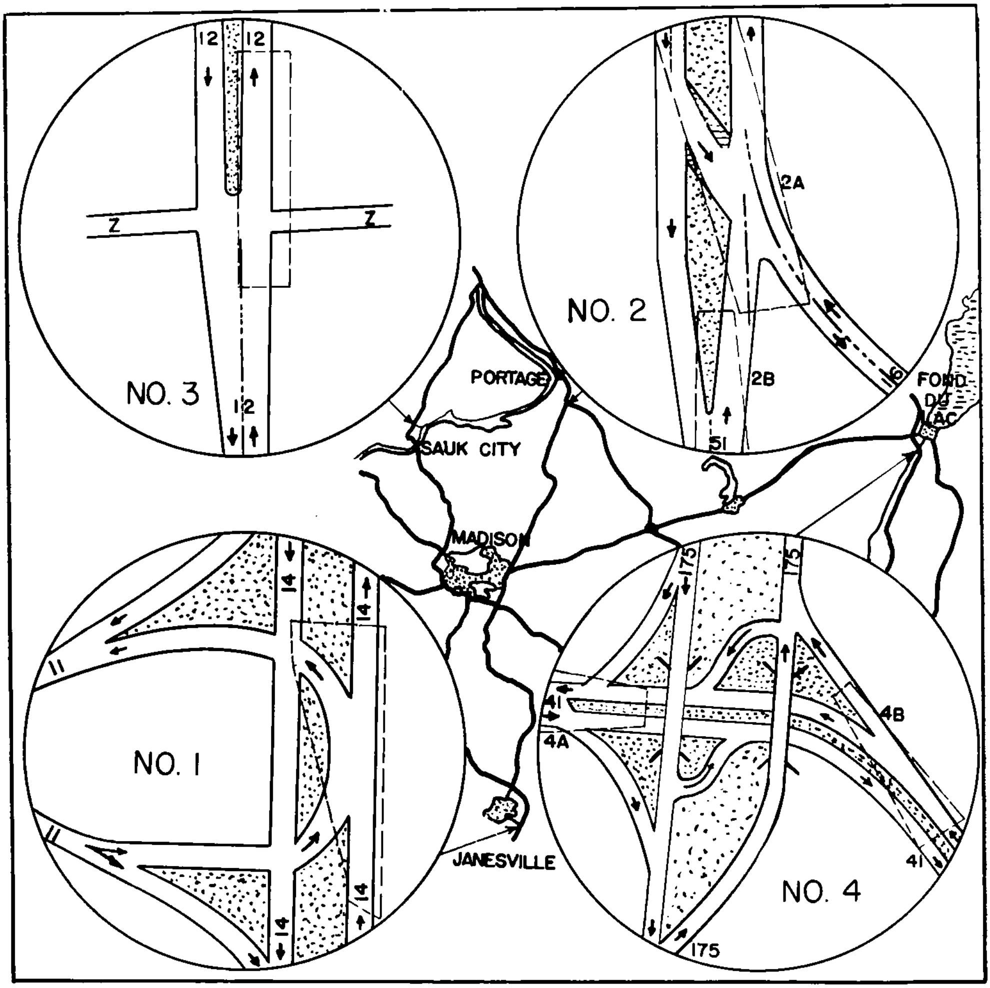

Figure 4. Plan views of intersections 1, 2, 3 and 4.

painted on the highway is used to channelize this traffic to the left. However, as noted in Table 3, the response was inconsistent. As the motorist approached the intersection in the right-hand lane of US 51 he was deterred from shifting to the left by the marginal friction to his left caused by the southbound vehicles on US 16 waiting to cross the northbound lane of US 51. When there is marginal friction present from the direction in which traffic is required to shift, 65 percent of the motorists did not respond to the design features.

At the north end of Station 4A the average speed of 50 mph was 5 mph higher than at the other stations, probably due to the lack of marginal friction at this station. The medial strip was introduced at the same point as the one-way direct connection ramps. Introduction of these two features simultaneously presented some indecision and forced through traffic to the right and into conflict with the ramp traffic. Traffic was not separated into its component parts until the ramp entrance was reached. Three accidents have occurred at this point wherein vehicles attempted to make U-turns around the medial strip from

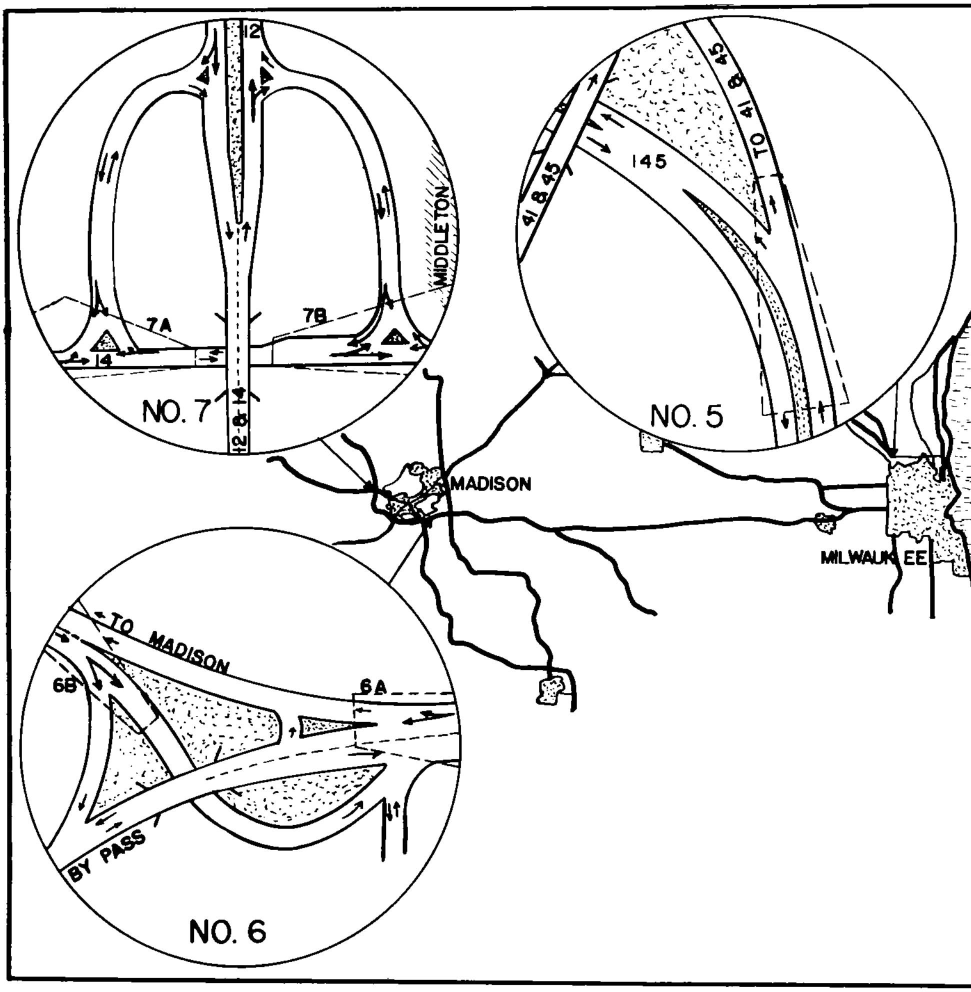

Figure 5. Plan views of intersections 5, 6 and 7.

the one-way ramp entering the northbound traffic lanes on US 41.

Comments: The medial strip should be extended for at least 150 feet west beyond its present location at Station 4A in order to separate this design feature from the ramps and allow the driver to concentrate on each feature separately. This will facilitate traffic separation and eliminate U-turns.

The merging traffic from the right at Station 2B should be carried by a separate merging lane, which would make the barrier marker and the shifting of northbound traffic on US 51 unnecessary. It appears that barrier markers and similar channelization are no substitute for additional merging or acceleration lanes when required.

Medial strips are most successful when their alignment is such that oncoming traffic is not required to alter its path at the time of initial contact with the strip.

Case 3: Right Turns — Stations 4B, 5, 6A, 7A and 7B

Observations: At Station 5 there was

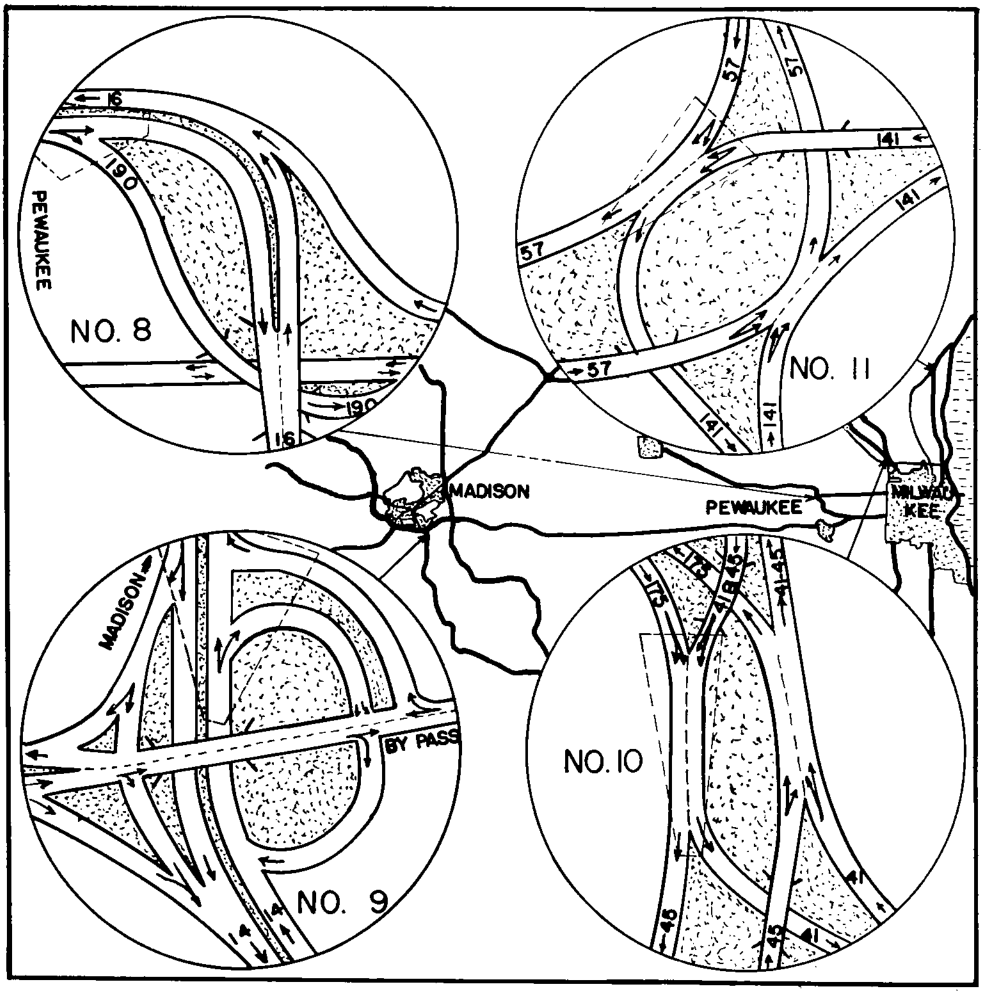

Figure 6. Plan views of intersections 8, 9, 10 and 11.

no apparent confusion, as only one vehicle out of the 103 observed entered the ramp from the left lane. Eighty percent of the traffic continued on a tangential path to the ramp for US 41 and 45.

At Station 4B the tangential ramp accounted for 40 percent of all traffic observed; 60 percent had to turn left to continue on the path of their choosing. The incidence of confusion was considerably higher at Station 4B (see Table 1), as compared to Station 5. Ramp traffic in both instances was well grouped.

At Station 4B northbound traffic is required to bear right at the southern tip of the intersection where the divided highway section begins. If the motorist does not take positive action, his tangential path will carry him into the southbound lane of traffic. Five vehicles in the 2 hours of observation ended up in this predicament. The lateral distribution of vehicle paths observed at Station 4B is shown in Figure 7. As indicated, the grouping of ramp-bound vehicles was excellent except in those cases where the drivers were confused. The grouping of vehicles continuing on US 41 was not as

TABLE 2
GEOMETRIC DESIGN AND TRAFFIC DATA

Station*	Traffic No.	Traffic % of Total	Degree of Curve	Super-elevation, ft/ft	Average Speed, mph Initial	Average Speed, mph End	Length of Section, ft
1	126	100	16	0.03	36.6	0	380
2A	130	100	—	—	37.9	42.2	350
2B	150	100	—	—	45.2	46.5	410
3	100	100	—	—	48.8	52.8	400
4A	126	83.5	—	—	52.5	51.0	380
4B (R)	103	41.6	1.0	0.01	46.9	48.2	300
(L)	145	58.4	2.5	0.04	44.4	45.7	300
5 (R)	81	77	2.5	0.03	43.9	46.0	390
(L)	24	23	2.5	0.02	—	—	—
6A (R)	97	49	2	—	50.7	48.9	300
(L)	102	51	2.2	0.02	48.2	40.0	320
6B (L)	160	96.5	6.5	0.04	45.1	41.1	400
(R)	6	3.5	12	0.04	—	—	200
7A	62	100	20	0.01	35.5	30.7	260
7B	76	100	20	0.01	18.4	38.5	350
8 (L)	212	59.4	3	0.03	53.8	54.5	320
(R)	145	40.6	4	0.06	48.8	50.1	300
9	72	100	25	0.04	46.5	22.3	300
10 (R-R)	34	17	2.5	0.03	49.1	55.2	650
(R-L)	58	29	—	—	51.0	55.1	650
(L-L)	31	15.5	8	0.03	50.6	56.7	650
(L-R)	77	38.5	—	—	51.9	55.2	650
11 (R-R)	51	12.5	2	0.03	42.1	50.7	320
(R-L)	97	24.3	—	—	44.8	51.4	320
(L-L)	168	42.0	10	0.03	44.0	49.4	320
(L-R)	84	21.0	—	—	42.2	49.4	320

* (R-R) = Right-hand section entering and right leaving.
(R-L) = Right-hand section entering and left leaving.
(L-L) = Left-hand section entering and left leaving.
(L-R) = Left-hand section entering and right leaving.
(R) = Traffic leaving right.
(L) = Traffic leaving left.

TABLE 3
BARRIER STUDY, EFFECT ON MOVING VEHICLES, STATION 2B

Reaction	No. of Vehicles	Percent
1. Total no. observed	206	100
Observed barrier	122	59.3
Violated barrier	84	40.7
2. With no merging traffic	190	100
Observed barrier	108	57
Violated barrier	82	43
3. With left turn from 16	34	100
Observed barrier	12	35
Violated barrier	22	65

satisfactory, being bi-modal in character. The tendency to keep right influences many drivers to remain in the right-hand lane as long as possible before making a left turn.

The bi-modal characteristic of the lateral distribution of vehicle paths observed at Station 6A (Figure 7) shows that traffic has not been separated prior to reaching the ramp and that many motorists adhere to the right shoulder when driving, resulting in a high degree of internal friction. The narrowing of the pavement at the ramp entrances from 4 lanes down to 2 lanes further complicates the flow by creating the impression to some drivers that they are entering a divided highway section and thereby encouraging the driver to keep right.

Station 7A concerns the flow of traffic wherein right turns are accomplished by turning left across oncoming traffic to gain access to the ramp. Station 7B concerns direct-connection left turn and right turn movements at the same interchange. As shown in Table 1, the standard design section as covered in Station 7B has less than one-half the amount of confusion that is generated at Station 7A. The design at Stations 7A and 7B was adopted in order to contain the interchange within the boundaries of certain real estate parcels.

Comments: The following general observations are made as a result of the investigations at these stations:

1. Alignment of rural highway intersections should not require the motorist to take positive action to avoid proceding in the wrong direction on a divided highway section.
2. Preferential alignment should be reserved for the major traffic flow as was done at Station 5 wherein the minor flow is required to alter its direction to continue on course.
3. Right-turn ramps handling minor traffic flow should have significant curvature away from the through lanes to accentuate the movement.
4. Narrowing of multi-lane pavements should be accomplished beyond and not at the ramp entrances.
5. Intersections should be designed to accommodate traffic needs and not for the convenience of real estate acquisition.
6. Abnormal traffic movements do not have a satisfactory degree of driver compliance.

Case 4: Direct-Connection Left Turns — Stations 6B, 8 and 9

Observations: The degree of confusion at Station 6B as indicated in Table 1 is considerably greater than that observed at Station 8. The presence of two alternatives contributes to the dilemma of the motorist. Only 6 percent of the total traffic desires to make a right turn from Olin Avenue.

At Station 8, 40 percent of the traffic is using the right-hand ramp. The highway is divided, four lanes, and the traffic had separated into the two component parts prior to approaching the intersection area. Although operating at speeds of 50 mph and more, the design is efficient and a high degree of compliance is achieved with less than normal confusion.

Station 9 is a standard cloverleaf design, with which motorists should be familiar, but there is an abnormal amount of confusion. Four of the motorists turned right on the second ramp, which was one-way *from* the By-Pass, indicating a correct reaction but poor timing. The ramp is located on a partially obscuring curve so that the driver does not become aware of the presence of the ramp until he is upon it. Other motorists were confused by the unusualness of the design itself.

Comments: Interchange designs should be standardized insofar as is possible, in order to make the driver responses routine. When interchanges are non-standard, the motorist must rely on signs. However, not all drivers are capable of substituting information obtained from

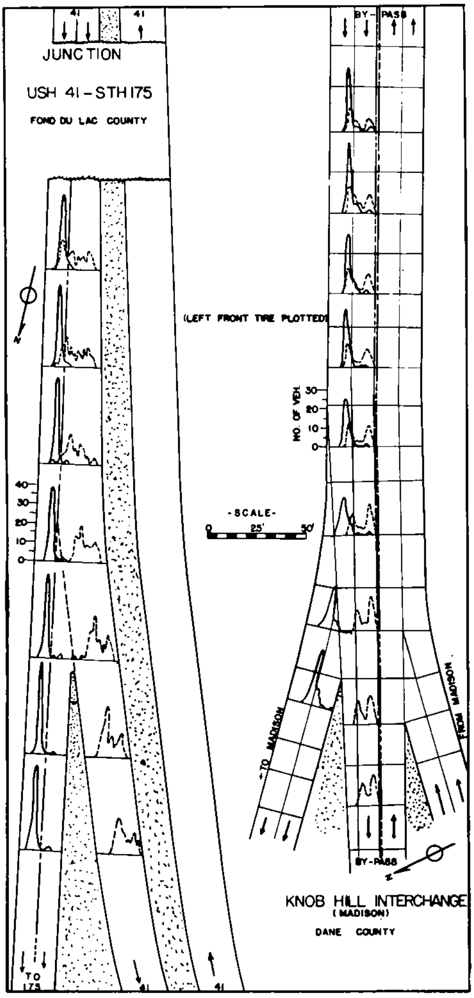

Figure 7. Vehicular path through interchange.

signs for their own judgment. Furthermore, not all motorists are able to visualize information obtained from signs. Only where designs and signs confirm the driver's impulse is a high degree of compliance obtained. Motorists must be able to respond mentally to the visual stimuli, react physically within the alloted design distance for reaction, and have positiveness to their decisions. Direct visual contact with the conflict area is a vital factor in assisting the driver, and signs are a poor substitute for this contact.

A medial strip should be constructed at Station 6B a distance of 200 feet west, thereby making the area immediately preceding the station a 4-lane divided highway. This would enable motorists to handle the design features separately and avoid complex, rapid thinking situations. Another alternative would be to move the right-turn ramp west 350 feet.

Case 5: Weaving Lanes — Stations 10 and 11

Observations: Of the total traffic flow, 67 percent were involved in a weaving action at Station 10, whereas only 45 percent were involved at Station 11. On the basis of origin, 46 percent of the traffic entered Station 10 from the right and 56 percent departed to the right. At Station 11, 37 percent entered from the right and 33.5 percent departed to the right. At Station 10 the length of the weaving section was 650 feet, whereas at Station 11 the length was only 300 feet. There was only slight confusion at either of these stations and little reduction in speed. Weaving lanes are generators of internal friction rather than indecision. At Station 11 the weaving area was shifted to the motorist's right of center, a fact accounted for in two ways (see Figure 9), as follows:

1. On STH 57 most of the weaving vehicles entered this section from the right-hand lane.

2. The average path of vehicles remaining on US 141 shifted to the motor-

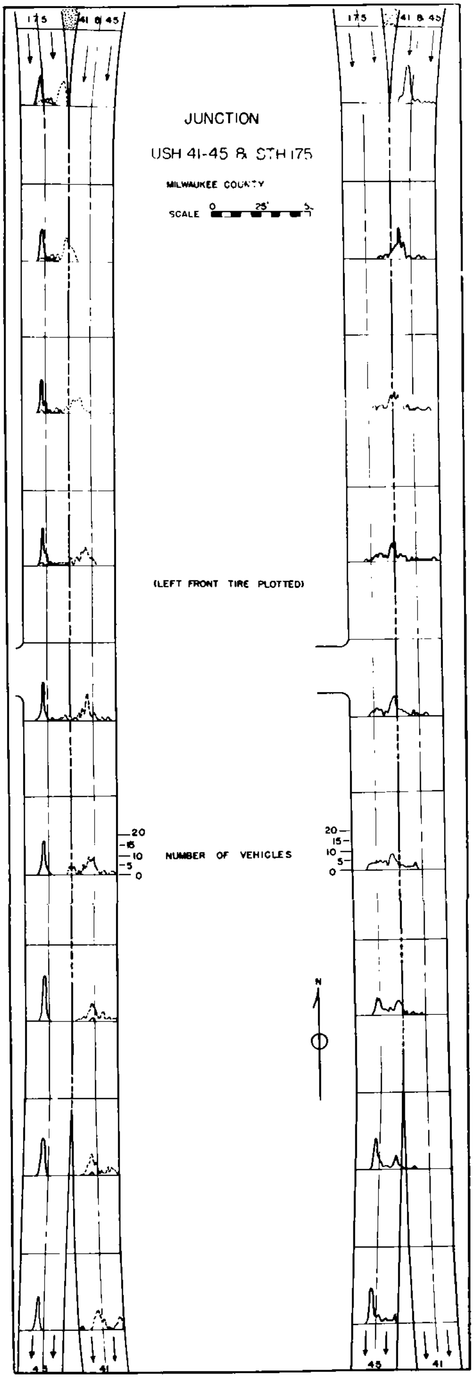

Figure 8. Vehicular path through interchange.

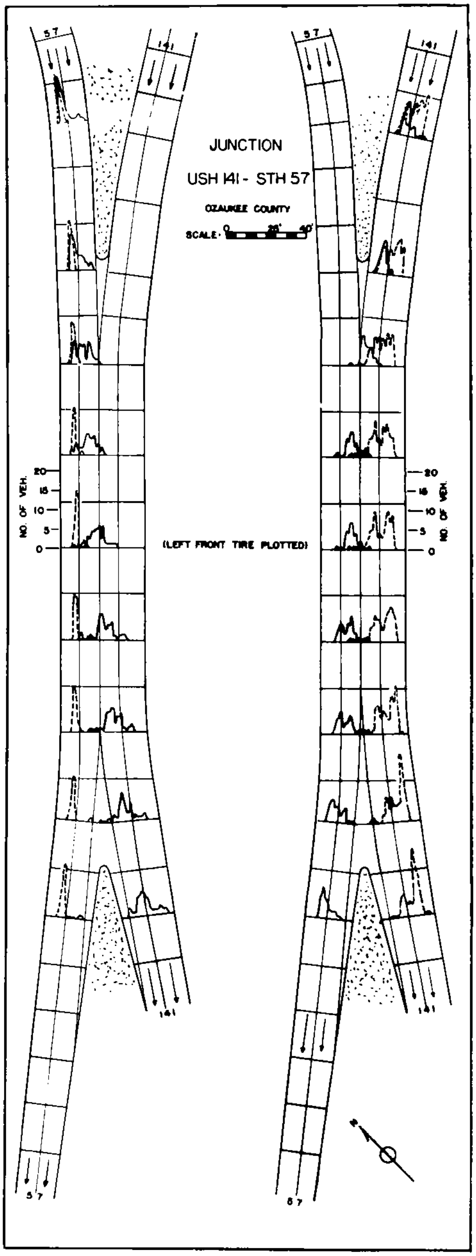

Figure 9. Vehicular path through interchange.

ist's right and choked the right lane of US 141.

Comments: Overhead signs directing traffic to separate into appropriate lanes prior to entering the weaving lane should be installed at Station 11. Lengthening the weaving section at Station 11 would enlarge the conflict area to allow for shifting to be accompanied more gradually and with more freedom of movement. To the extent possible, traffic should be funneled into weaving sections on a tangential or slightly curved alignment. Vehicles negotiating curved sections tend to maintain a constant velocity by drifting toward the outer edge, which reduces the effectiveness of this area for weaving.

The motorist today must know what he wants to do and what he has to do to accomplish his objective *before* he reaches the time for decision. Designs should assist him in this need, not destroy his self-assurance and composure by putting him through complicated interchanges.