EFFECT OF SIZE OF GAPS IN LINE ON ACCEPTANCE OF THE LAG AT A STOP SIGN

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THESIS

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INTRODUCTION

Up to the present time, information on the sizes of gaps between vehicles in a traffic stream have not been used in warrants for installing pretimed signals or stop signs. However, research studies have suggested consideration of gap distributions.

The Manual of Uniform Traffic Control Devices[1] states that a comprehensive study should be made before installing a traffic signal. Such a study should be supplemented by data pertaining to the speed and the accident record[2] for the specific intersection. In the section on warrants for pretimed signals,[3] it is stated that the study should also consider the pedestrian volume, minimum vehicular volumes, continuous traffic volume and vehicle-seconds of delay.

Undoubtedly, all these factors should be considered when a decision has to be made, until future research determines that one or more of them could be eliminated, having no particular effect, or that additional factors should be included in the study.

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[1] Bureau of Public Roads, "Manual of Uniform Traffic Control Devices for Streets and Highways," Washington, D.C., 1961.

[2] Ibid., pp. 184

[3] Ibid., pp. 183

The traffic engineer, when faced with the installation of a traffic control device at an intersection, has to be aware of all influencing factors. However, it seems that this is not always the case. For example, the warrants for pretimed traffic signals at an isolated location[4] are based on traffic volume, speed, accidents, pedestrian volume and progressive movement, but there is no mention of gaps. In light of this statement, it seems that the installation of a pretimed traffic signal partially depends on engineering judgment, and further research should be undertaken to provide more facts and a clearer understanding of driver behavior.

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[4]Ibid., pp. 184-185.

THE PROBLEM

The objective of this study is to evaluate the possible effect of size of gaps in line on acceptance of the lag at a two-way stop sign.

Little consideration has been given to this factor, which could be considered very important, as far as acceptance of short gaps is concerned. The driver must, within a short time after he has stopped or reached his lowest speed, decide whether or not he should proceed across the intersection or wait for a longer gap.

Raff[5] developed a criterion in which the percentage of side-street cars delayed is to be used as a stop-sign warrant. He used a value "L" called "critical lag" coupled with the general term "gap" commonly used in many other studies. He defines the lag as follows:

> "A lag is the interval from the arrival of a side-street car at the intersection to the arrival of the next main-street car."

He also defines the "gap" as being "the interval from the arrival of one main-street car at the intersection to the

[5] Morton S. Raff, "A Volume Warrant for Urban Stop Signs," Bureau of Highway Traffic, Yale University.

arrival of the next main-street car.

Following these two definitions, the <u>critical lag</u> "L" is defined as follows:

> "The critical lag is the size lag, which has the property that the number of accepted lags shorter than "L" is the same as the number of rejected lags longer than "L"."

The most important finding[6] of his study was that the critical lag size varies from one location to another. In fact, he states five reasons[7] which might affect the variation in the critical lag:

(1) Traffic volume
(2) Speeds of main-street cars
(3) Sight obstructions
(4) Directional traffic pattern on the side street
(5) Width of the main street

Do any of the factors listed above play an important role in the driver's decision to proceed across the intersection or wait for a longer gap? Raff[8] says, "That the value

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[6]Raff, pp. 26

[7]Ibid., pp. 36

[8]Ibid., pp. 61

of the critical lag is different at different locations has been proved beyond any doubt, but the cause of the variation needs to be explored much more carefully."

The present study is not an attempt to answer all these questions, but it is hoped that it will provide a better understanding of driver behavior at times when a driver has a choice of accepting a gap, or waiting for a longer gap.

The hypothesis which has been investigated in this: "There is a greater probability of drivers rejecting a gap of a size close to that of the 'critical lag,' when the next gap in line is larger." If a driver will accept a short gap only when there is no gap in view which is longer, then this should be taken into account in developing warrants for traffic control which utilize gap distribution information..

SITE LOCATION

In consideration of the limited manpower available for field observations, and in order to get a larger sample, it was decided to choose only one location for the study.

Two possible locations were investigated. The site chosen has four lanes with two-way traffic on the main street, and two lanes with two-way traffic on the minor street. The main street is Niles Center Road and the minor street Howard Street in Skokie, Illinois.

Since it has been indicated that the main street width (two lanes vs. four lanes) does not have a particular effect on gap acceptance,[9] it was felt that this location was as good as any other. Since it was necessary to choose only one of two intersections for this study, considering the limited time available, this site was the more logical one because the side-street volume was twice as high as at the other location. This permitted obtaining a larger sample in a minimum of time.

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[9] Carl N. Swerdloff, "A Study of Gap Acceptance at a Stop Sign Location." Thesis submitted for the degree of Master of Science, Northwestern University, Evanston, Illinois, 1962.

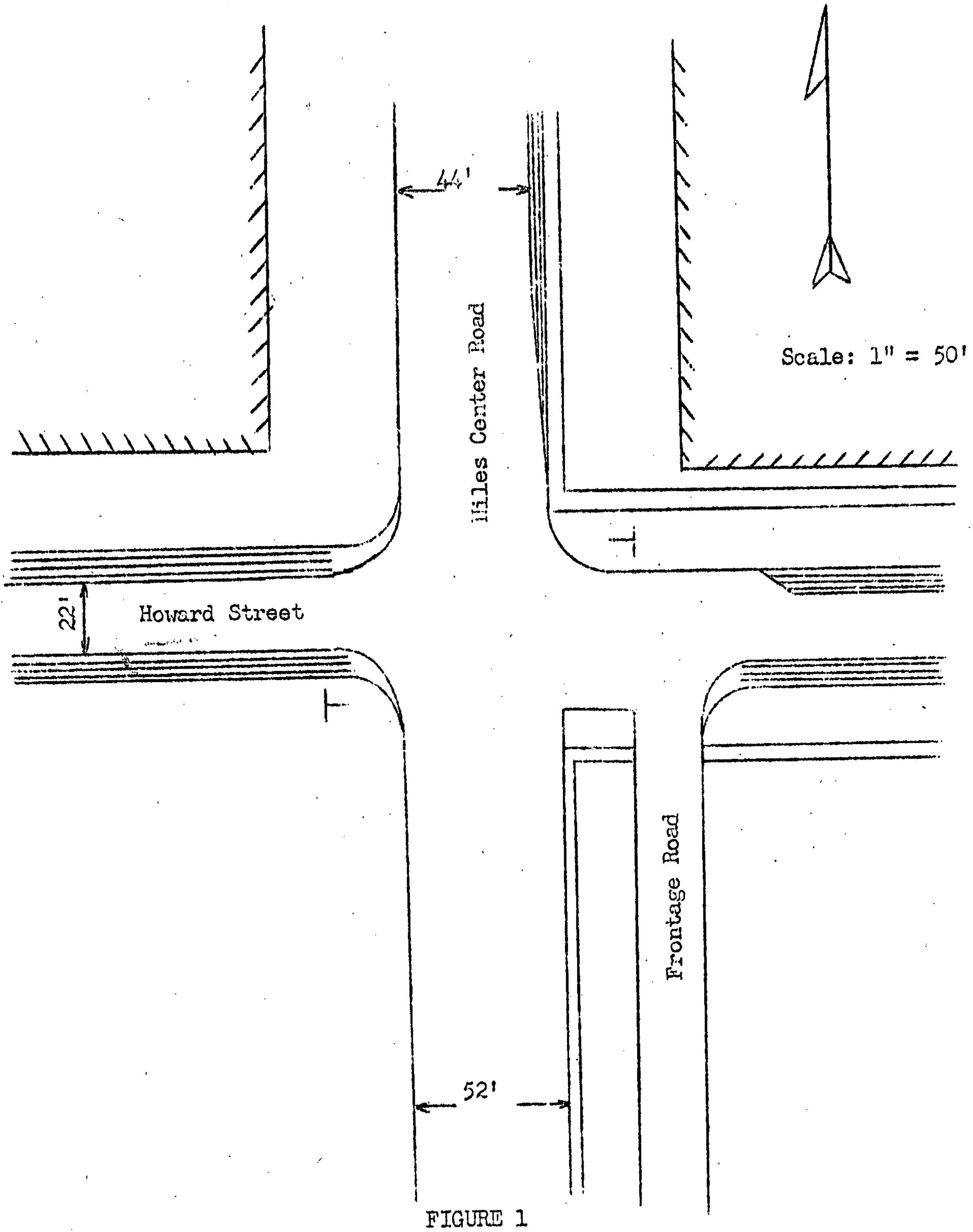


FIGURE 1

Plan of Niles Center Road vs Howard Street

A plan of the intersection is presented in Figure 1. The main street, Niles Center Road, is 44 feet wide on the northern approach and 52 feet on the southern approach. Only two lanes of traffic were permitted on each approach. The existing pavement condition was excellent as were the pavement markings. No parking was permitted anywhere on either side of Niles Center Road. The minor street had a 22 foot travelled way, with 10-foot dirt shoulders on both approaches. The sight distance at both approaches to the intersection was good in both directions.

The traffic volumes during the study period were as follows:

Niles Center Road

Peak (total in both directions): 600-650 veh pr hour

Howard Street

Peak (total in both directions): 330-380 veh pr hour

Commercial vehicle traffic was about 5 percent.

PROCEDURE

The method of gathering data consisted of using a time-lapse camera to collect data at the intersection. The camera was installed about 150 feet from the intersection at a height of approximately 12 feet.

The camera, a modified Keystone 16 mm. motion picture camera, was operated by a small 100 rpm-motor powered from a 110-volt converter which in turn was powered by a 12-volt battery. Pictures were taken at a speed of 100 frames per minute.

The filming was done from June 26th to July 9th between 4:15 - 5:30 p.m., for a total of five hours. It might have been interesting to compare both peak and off-peak results, but due to the fact that the side-street traffic was light during off-peak and the probability of getting a line of vehicles on Niles Center Road was very small also, this procedure was eliminated.

A possible method of obtaining data for off-peak hours would be to use simulation as proposed by Kell.[10] He states, "Almost any traffic situation is capable of simulation and,

[10] James H. Kell, "Analyzing Vehicular Delay at Intersections Through Simulation." University of California, 1962.

as techniques improve, can be rapidly programmed." He has already programmed a digital computer to measure vehicular delay at a stop sign. The possibility of developing a program to study the effect of a line of vehicles on acceptance of the first gap (lag) by the side-street vehicles is quite strong.

The time available not permitting such a consideration here, it is hoped that further research in this direction will be undertaken in the future.

It was decided at the beginning to use the lag as defined by Raff because it is the author's belief that a lag is different from a gap when several time-intervals are considered. Moreover, confusion may be avoided by using the two distinct definitions.

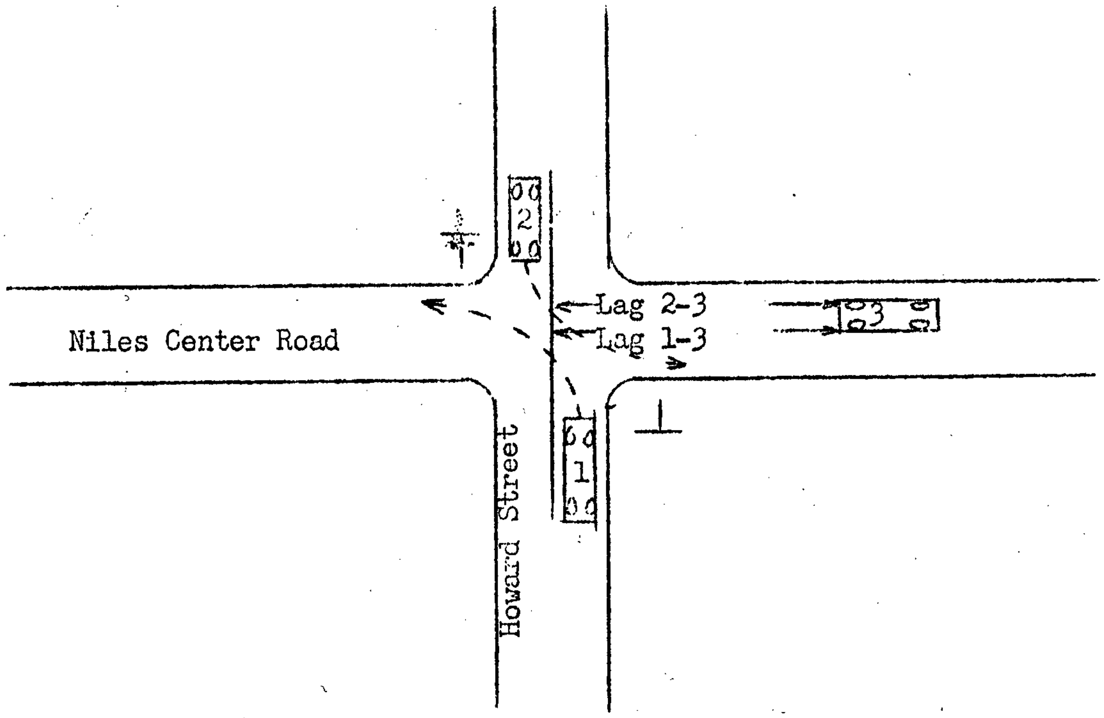
Each time a vehicle came to a stop at the intersection on the minor street, the frame numbers were recorded for the first four cars on the major street. The same procedure was followed whether the car on the side-street proceeded across the intersection or made a left turn. When the vehicle on the minor street came to a stop and yielded to an approaching car on the major street, it was said to have rejected its lag and the subsequent gap, if any. Otherwise, the car was said to have accepted its lag.

Only minor street vehicles which turned left or crossed directly through the intersection were considered.

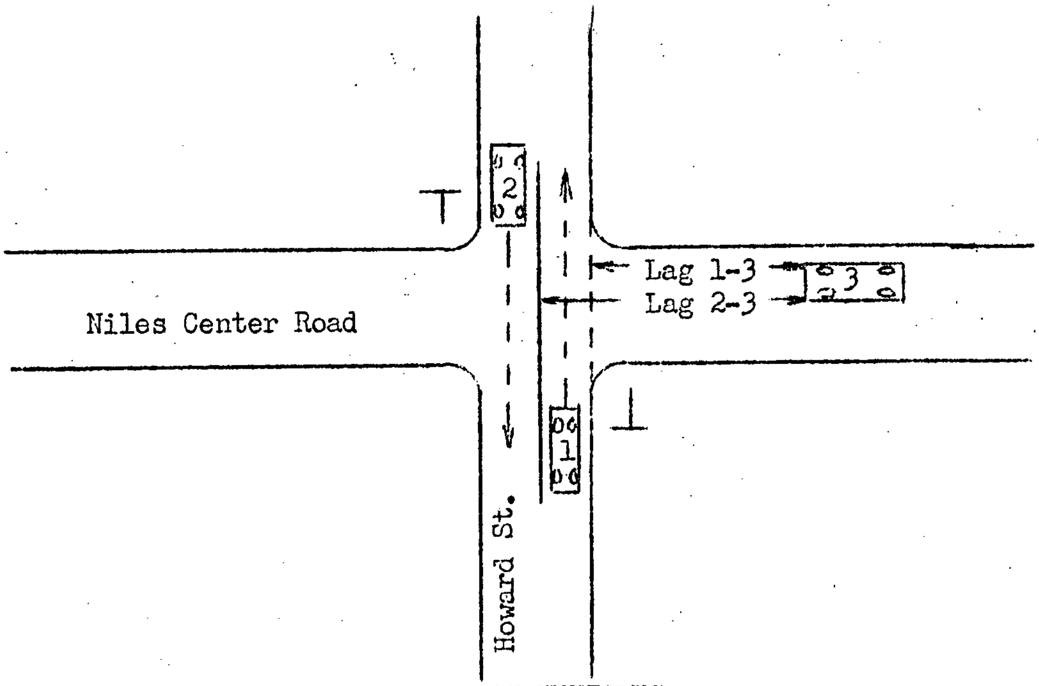
Right-turning vehicles were discounted since it was almost impossible to determine from the camera position whether a main street car was moving in the median or the curb lane. No distinction was made for through vehicles and left-turning vehicles in tabulating the data, both movements being quite similar.

A lag for a left-turning vehicle entering from the minor street was measured from an arbitrary line traced in the middle of the intersection and parallel to the minor street. For the cars proceeding through the intersection, the lag was measured from the same line for near-side cars and from another arbitrary line denoting the extension of the minor street travelway across the major street, for far-side cars. Figure 2 shows how these lags were measured for each particular movement.

Less than 5 percent of the data was rejected because a non-confirming or congestion situation existed at the intersection.



LEFT-TURNING VEHICLES



THROUGH VEHICLES

FIGURE 2

Procedure for Gap Measurements

DATA PRESENTATION

Tables 1 - 5 present the results for the intersection studied. Table 1 represents the whole picture of lags accepted and rejected while Tables 2 - 4 show the distribution of gaps in line for the most critical lag sizes during peak hour. Table 5 shows the cumulative number of accepted and rejected lags to compute the critical lag at the intersection.

TABLE 1

NUMBER OF LAGS ACCEPTED OR REJECTED BY MINOR-STREET TRAFFIC IN ENTERING A FOUR-LANE FLOW PAST A STOP SIGN IN PEAK HOUR

Niles Center Road and Howard Street, Skokie

June, 1962

Lag Size (Seconds)	Minor-Street Traffic-Through & Left			Proportion of Acceptance
	Accepted	Rejected	Total (N)	
0- 1.2	1	121	122	0.008
1.3- 2.4	4	149	153	0.026
2.5- 3.6	30	174	204	0.147
3.7- 4.8	101	101	202	0.500
4.9- 6.0	141	45	186	0.759
6.1- 7.2	103	26	129	0.798
7.3- 8.4	72	4	76	0.947
8.5- 9.6	52	1	53	0.981
9.7-10.8	55	0	55	1.00
10.9-12.0	55	0	55	1.00
12.1-13.2	37	0	37	1.00
13.3-14.4	28	0	28	1.00
14.5	117	0	117	1.00

TABLE 2

DISTRIBUTION OF GAPS IN LINE
FOR PEAK HOUR CONDITION

Lag size 3.7-4.8 seconds

	Number of Lags Accepted	Number of Lags Rejected			Total
		Reject a Longer 1st Gap	Wait for Other Gaps		
			For 1st Gap	For 2nd or 3rd	
*First gap same or smaller than lag	71	-	2	75	148
First gap longer than lag	30	5	19	-	54
Total	101	5	21	75	202
First 2 gaps same or smaller than lag	41	-	1	47	89
One of first 2 gaps longer than lag	60	5	20	28	113
Total	101	5	21	75	202
First 3 gaps same or smaller than lag	25	-	1	24	50
One of first 3 gaps longer than lag	76	5	20	51	152
Total	101	5	21	75	202

*First gap is the gap immediately following the first main-street vehicle

TABLE 3

DISTRIBUTION OF GAPS IN LINE
FOR PEAK HOUR CONDITION

Lag size 4.9-6.0 seconds

	Number of Lags Accepted	Number of Lags Rejected			Total
		Reject a Longer 1st Gap	Wait for Other Gaps		
			For 1st Gap	For 2nd or 3rd	
First gap same or smaller than lag	109	-	3	33	145
First gap longer than lag	32	3	6	-	41
Total	141	3	9	33	186
First 2 gaps same or smaller than lag	78	0	1	4	108
One of 1st 2 gaps longer than lag	63	3	8	4	78
Total	141	3	9	33	186
First 3 gaps same or smaller than lag	48	0	1	18	67
One of 1st 3 gaps longer than lag	93	3	8	15	119
Total	141	3	9	33	186

TABLE 4

DISTRIBUTION OF GAP IN LINE
FOR PEAK HOUR CONDITION

Lag size 6.1-7.2 seconds

	Number of Lags Accepted	Number of Lags Rejected			Total
		Reject a Longer 1st Gap	Wait for Other Gaps		
			For 1st Gap	For 2nd or 3rd	
First gap same or smaller than lag	74	-	2	22	98
First gap longer than lag	29	-	2	-	31
Total	103	-	4	22	129
First 2 gaps same or smaller than lag	62	-	1	19	82
One of 1st 2 gaps longer than lag	41	-	3	3	47
Total	103	-	4	22	129
First 3 gaps same or smaller than lag	33	-	1	14	48
One of 1st 3 gaps longer than lag	70	-	3	8	81
Total	103	-	4	22	129

TABLE 5

CUMULATIVE NUMBER OF ACCEPTED AND
REJECTED LAGS AT NILES CENTER ROAD AND HOWARD STREET

Lag Size (Seconds)	Number Accepted	Number Rejected	Cumulative Accepted	Cumulative Rejected
0- 1.2	1	121	1	621
1.3- 2.4	4	149	5	500
2.5- 3.6	30	174	35	351
3.7- 4.8	101	101	136	177
4.9- 6.0	141	45	277	76
6.1- 7.2	103	26	380	31
7.3- 8.4	72	4	452	5
8.9- 9.6	52	1	504	1
9.7-10.8	55	0	559	0
10.9-12.0	55	0	614	0
12.1-13.2	37	0	651	0
13.3-14.4	28	0	679	0
14.5	117	0	796	0

RESULTS AND DISCUSSION

When tabulating the data for the major-street traffic a decision had to be made whether to choose a single line of vehicles from one direction only, or to consider cars from both directions. A check was made to seek a possible difference in the trend. The conclusion was that omitting cars from one direction and taking the line from the other direction only would be unrealistic and would not give a true picture of the situation. Accordingly, cars coming from both directions were tabulated as though they were in one line at all times.

Swerdloff[11] states that the gap size immediately following a lag acceptance might be a factor on driver behavior. This does not seem to be the case from the current study. The calculations presented in the Appendix reveal that no difference in lag acceptance was found even when the gap or gaps immediately following were smaller than the lag accepted or rejected. Thus, we must reject the hypothesis that the percent of lags of a certain size accepted, "p_1", by the side-street driver will be greater than the percent

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[11]Swerdloff, pp. 56

of lags of the same size accepted, "p_2," when followed by a gap or gaps in line smaller than the same size. Then $p_1 \leq p_2$. The results of these calculations are displayed in Table 6.

These results are in accordance with Raff's statement[12] when he says that the main-street volume does not have an appreciable effect on the critical lag. This is because the critical lag for a particular intersection seems to remain constant even if we consider the sizes of following gap or gaps.

From Figure 3, the critical lag for Niles Center Road and Howard Street was found to be 5.1 seconds. The intersection "D" studied by Raff[13] seems to have the same characteristics as Niles Center Road and Howard Street. His calculations yielded a critical lag of 6.0 seconds. Considering the five factors previously listed, the one which is primarily responsible for the variation in critical lag might be the speed as a whole at the location. The five factors mentioned were:

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[12] Raff, pp. 37

[13] Raff, pp. 21

TABLE 6

RESULTS COMPARING THE EFFECT OF GAPS FOLLOWING AT NILES CENTER ROAD

PEAK HOUR DATA

Lag Size (Seconds)	Number of Gaps Following	p_1(%)	p_2(%)
3.7-4.8	1	48.0	55.6
" "	2	46.1	53.1
" "	3	50.0	50.0
4.9-6.0	1	75.2	78.1
" "	2	72.2	81.8
" "	3	71.7	78.8
6.1-7.2	1	75.5	93.5
" "	2	75.7	87.2
" "	3	68.8	86.4

p_1 = Percent of lags of size "i" seconds accepted when followed by a gap or gaps in line smaller than the lag within this size.

p_2 = Percent of lags of size "i" seconds accepted when followed by a gap or gaps in line greater than the lag within this size.

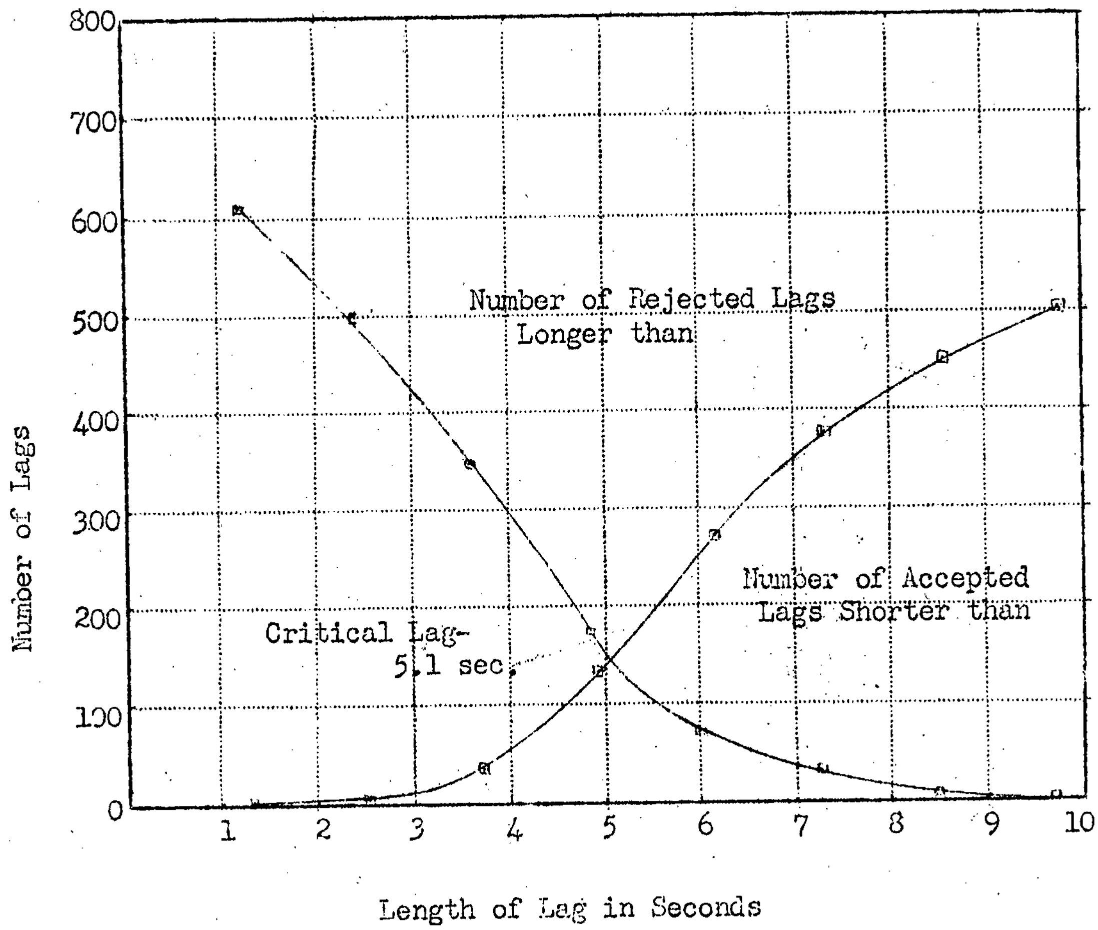

FIGURE 3

Determination of Critical Lag
for Data in Table 5.

(1) Traffic volume

(2) Speeds of main-street cars

(3) Sight obstructions

(4) Directional traffic pattern on the side-street

(5) Width of the main street

The traffic volume factor has already been eliminated in view of the results obtained. Because the sight distance was excellent in all directions at the intersection, it is doubtful that this could be the major factor responsible for variation.

Since the traffic on Howard Street is two-way, it is inconceivable that the directional traffic pattern has an effect on critical lag, although the directional traffic was 60-40 almost all the time during peak-hour. While Raff found that the results of his data were confusing in that there was no consistent effect on the values of critical lag as main street width increased, Swerdloff[14] did find that not only was there no steady direction in the results but also no valid relationship existed between the two factors (main street width and critical lag).

These results suggest that the remaining factor affecting the situation was the overall speed on the major

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14 Swerdloff, pp. 55

street and the minor street. In fact, it was noted that more than 60 percent of the traffic had as its origin or distribution an expressway located close by. It is possible that drivers accustomed to driving at high speeds are more prone to take chances. More research in this direction might produce some interesting results.

Conclusions

The conclusion indicated by the results of the present study is:

> For a given lag size, the probability of acceptance is not greater when there is a line of vehicles on the main street than when there is only one car visible to the side-street driver.

The present study was an attempt to discover whether there are differences in sizes of lags accepted when the gaps following are small. In consideration of the limited time available for field observations, only one intersection was studied. In term of the results obtained, it is hoped that further research on an expanded scale might follow a similar procedure and correlate the results for more than one intersection. An approach using simulation techniques should not be disregarded.

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APPENDIX

Calculations showing the percentage of acceptance of lags when followed by a gap or a series of gaps.

Notation:

p_1 = Percent of lags of size "i" seconds accepted when followed by a gap or gaps in line smaller than the lag within this size.

p_2 = Percent of lags of size "i" seconds accepted when followed by a gap or gaps in line greater than the lag within this size.

Lag size: 3.7 - 4.8 seconds

1 Gap following:	p_1	=	71/148	=	0.480
	p_2	=	30/54	=	0.556
2 Gaps following:	p_1	=	41/89	=	0.461
	p_2	=	60/113	=	0.531
3 Gaps following:	p_1	=	25/50	=	0.50
	p_2	=	76/152	=	0.50

Lag size: 4.9 - 6.0 seconds

1 Gap following:	p_1	=	109/145	=	0.752
	p_2	=	32/41	=	0.781
2 Gaps following:	p_1	=	78/108	=	0.722
	p_2	=	63/77	=	0.818
3 Gaps following:	p_1	=	48/67	=	0.717
	p_2	=	93/118	=	0.788

Lag size: 6.1 - 7.2 seconds

1 Gap following:	p_1	=	74/98	=	0.755
	p_2	=	29/31	=	0.935
2 Gaps following:	p_1	=	62/82	=	0.757
	p_2	=	41/47	=	0.872
3 Gaps following:	p_1	=	33/48	=	0.688
	p_2	=	70/81	=	0.864

Therefore, the hypothesis that $p_1 > p_2$ is rejected since in no case is this inequality verified. It is concluded that the side-street driver is not willing to accept a shorter lag even when there is a line of vehicles on the major street.