Effects of Commercial Roadside Development On Traffic Flow in North Carolina

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This study reveals the magnitude and severity of the problem of commercial roadside development in North Carolina. It attempts to evaluate the effects of this development by means of a study of speed and delay through nine selected test sites.

An attempt was made to define and measure the effect of the various elements which influence traffic operation. Results are based on data collected through the use of two test-car techniques — the average-car method and a newly developed maximum-car method. Various mathematical relationships, which facilitate the prediction of speeds and turning movements along any section of commercially developed highway, were derived and field tested. Such an evaluation may be utilized by highway planners to help determine the desirable degree of access control for proposed facilities or the need for redesign and modification of existing facilities.

● THE heavily traveled highways leading into and around many cities have been reduced in capacity and, in some cases, abondoned as major, traffic-moving facilities because of the congestion and delay brought about by commercial roadside development. A knowledge of the various elements of the congestion and their individual and collective effects on the adjacent traffic stream is necessary to determine needed improvements and solutions to the problem.

Communities generally expand along the traffic arteries which serve them. From the point of view of the businessman, parcels of land adjacent to these major streets and highways make desirable locations for business establishments, but commercial development is not always in the best interest of the motoring public. A section of highway which is bounded by commercial development is frequently plagued by several conditions which are undesirable to the motorist desiring to use the facility as a major thoroughfare. Among these are (a) turning movements of various kinds, (b) delays to vehicular traffic, (c) distractions to the driver, and (d) an increasing accident rate. The accident rate is directly affected by the magnitude of the first conditions.

It is readily apparent that all roads and streets cannot have limited control of access. Decisions must be made concerning which facilities should serve adjacent land use and which should primarily serve the movement of traffic.

The problem of commercial roadside development has been solved in the past by the construction of additional highways which bypass the congestion and accompanying hazards encountered in the fringe areas of many cities. If, however, land use and highway access are not controlled along the new facility, congestion and hazards similar to those on the previous location may seriously impede the highway traveler. If and when this occurs, another bypass may be needed. It is obvious that successive construction of bypasses cannot be considered as an economical or otherwise feasible solution to the problem created by commercial roadside development.

As an outgrowth of a more comprehensive investigation of the effects of commercial roadside development on traffic flow in North Carolina, this report attempts to describe these effects primarily by means of a study of speed and delay through several selected sites. The comprehensive investigation (Highway Research Project ERD-110-B) was transacted within the Highway Research Program conducted by the Department of Civil Engineering at North Carolina State College. It was completed in June 1960, following two years of research in cooperation with the North Carolina State Highway Commission and the U.S. Bureau of Public Roads.

Roadside development at several selected locations in North Carolina was studied, and an attempt was made to define and measure the effect of the various elements of roadside development which influence traffic operation. In particular, the manner and degree to which they affect traffic movement were considered.

Results of this investigation are based on data collected through the use of two test cars. The average speeds of traffic in commercially developed and adjacent undeveloped sections of highway were determined by making successive trips through these sections with an average car. The maximum speeds in the same sections were determined in a similar manner through the use of a maximum car. Other major tools used in this investigation include statistical analyses of elements affecting traffic flow and manual counts of the number of turning movements generated within a commercially developed section of highway.

Investigations of a similar nature may be used in the future by highway engineers who desire to justify such engineering decisions as: (a) the desirable degree of control of access for new facilities, (b) the partial control of access and design of traffic devices for existing facilities encumbered by commercial development, and (c) the desirability of relocating existing highways which have intensive commercial roadside development.

DEFINITIONS

Test car. — Either of the cars used to measure the average speed or the average-maximum speed.

Average speed. — The over-all-average speed of the vehicles in the traffic stream, as measured by the average-car method.

Developed section. — That portion of a test site, approximately one-half mile in length which has commercial roadside development and complete freedom of access.

Undeveloped section. — That portion of a test site, approximately one-half mile in length which has no commercial development or development of such a nature as to cause negligible delay to the traffic stream.

Average car. — A test car driven at a speed which, in the opinion of the driver, is representative of the average speed of the stream of traffic in which the test car is being driven.

Maximum speed. — A speed measured by the maximum-car method which is the average-maximum speed at which a section of highway may be traversed consistent with the maximum-legal speed limit and necessary safety measures.

Maximum car. — A test car whose driver is instructed to drive at a speed as near the maximum-legal speed limit as is consistent with necessary safety measures.

Test site. — A length of highway which contains one developed section and one undeveloped section with a transition section between.

Test. — Fifteen round trips through a site by both the average car and maximum car.

DESIGN OF EXPERIMENT

It was assumed at the beginning of this research endeavor that the average speed of traffic along a section of highway affords one measure of the delay and congestion present on that particular section. However, the average speed of traffic is the collective result of many individual elements which influence drivers. To be included among such elements are (a) the volume of traffic present; (b) the legal speed limit in force on the highway; (c) the geometric design of the facility, including lane width, shoulder width, horizontal and vertical alignment, number of lanes, intersections, and other geometric characteristics; (d) the devices used for traffic control such as signals, markings, and signs; and (e) the degree of abutting commercial, residential, or rural development. Therefore, to use average traffic speed as a measure of the delay and congestion caused by commercial roadside development, it was desirable to eliminate or hold constant, from one test section to another, all elements except roadside development which influence the speed at which the driver will travel.

All of these conditions obviously could not be met. Nevertheless, nine test sections were found which adhered to a preselected definition. A test section was defined as a section of commercially developed two-lane road at least one-half mile in length with a maximum-legal speed limit of 55 mph; medium to heavy traffic volumes; and free from traffic signals, major intersections, or appreciable horizontal or vertical curves.

The general location of all the test sites used in this investigation is shown in Figure 1. A map of the developed section of a typical test site including some of the physical characteristics is shown in Figure 2.

The investigation included the following phases: (a) pilot studies to develop methods

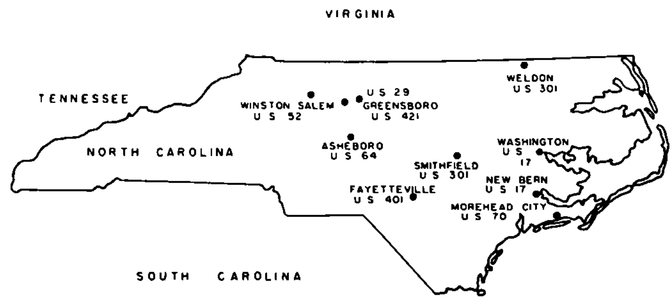

Figure 1. Location of test sites.

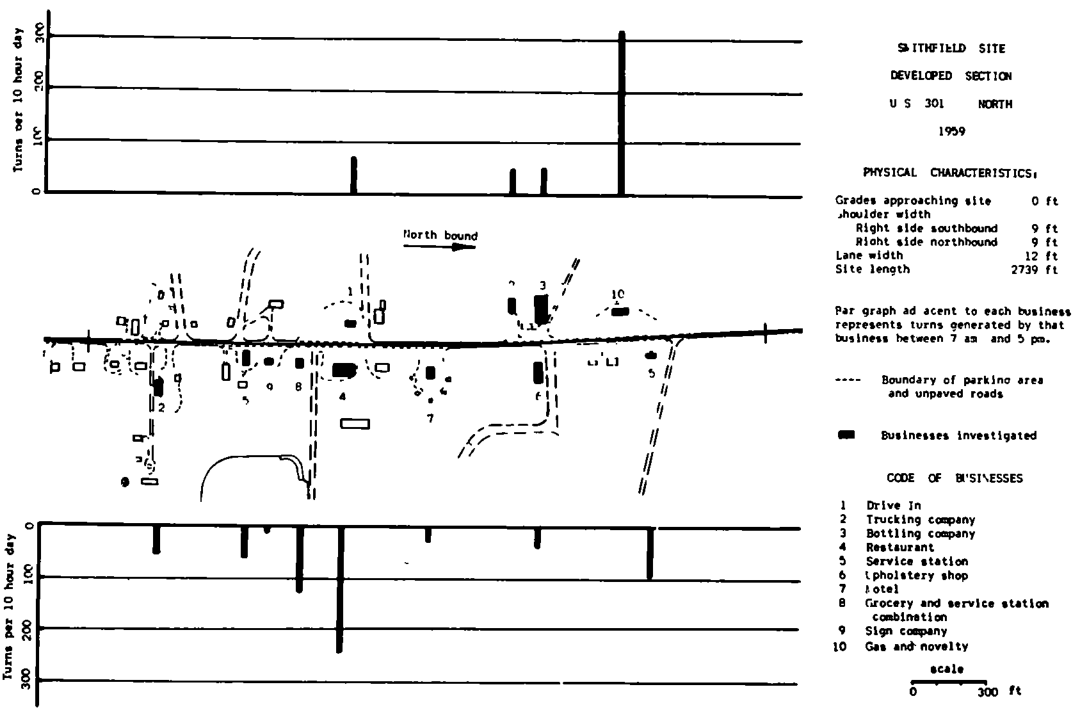

Figure 2. Developed section at Smithfield.

for collecting and analyzing data; (b) a turning movement study to determine the turning movement generation characteristics for various types of businesses; (c) a speed and delay study to analyze the effects of different types of impedances on the traffic stream; (d) an analysis of turning movements versus gross income of various types of roadside businesses; and (e) a road-user cost study to determine the economic losses to the highway user resulting from commercial roadside development. This report includes only the findings pertaining to the turning movement and the speed and delay studies.

SPEED AND DELAY STUDY

Pilot studies conducted at the beginning of this investigation indicated a need for a more detailed study of the elements affecting traffic operation. The degree to which different types of turning movements and other delaying situations affect the speed of the traffic stream was unknown. A vehicle making a left turn from a two-lane road during high traffic volumes probably would create more delay than a number of right turns occurring under the same conditions. However, a driver, under similar conditions, preferring to drive at a speed less than the average or safe and legal speed might delay the traffic stream more than either the left or right turns.

It was noted in the average speed study that commercial roadside development causes a measurable quantity of delay, but data collected by the average-car method did not differentiate between delays caused by physical traffic movements and delays caused by psychological factors. Physical delays are defined as those delays caused

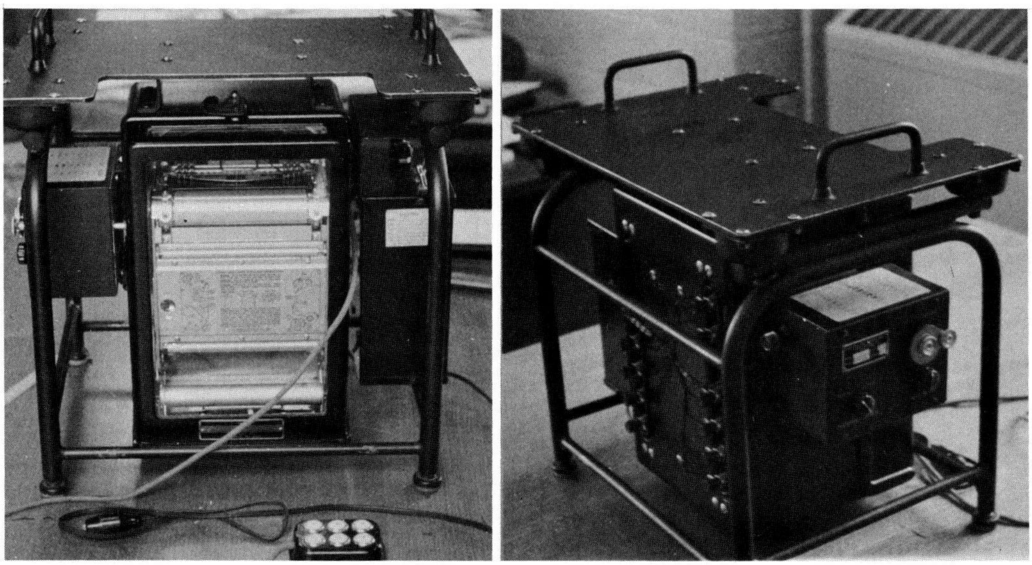

Figure 3. The speed and delay recorder.

directly by the turning movements or other conflicting movements associated with roadside development. Psychological delays are those which are caused by the driver's mental attitude towards congestion or his desire to drive slowly for other reasons. For example, the driver may be anticipating physical traffic movements which may not materialize or he may be searching for a particular business establishment.

Development of Maximum-Car Technique

A technique, later referred to as the maximum-car method, was developed for measuring the speed reduction resulting from physical impedances only. The speed measured by the maximum-car method is the average-maximum speed at which a section of highway may be traversed consistent with the maximum-legal speed and necessary safety measures. It is believed that a test car driven in this manner is subjected only to physical delays and that delays resulting from psychological factors are reduced to a minimum. It is imperative that the driver of the maximum car understand and be constantly aware of the definition and purpose of the maximum-car-tests. Otherwise, the data collected approaches that collected by the average-car method.

The average-maximum speeds determined by the maximum-car method were considered only as a standard and not as an absolute value. It was realized that drivers not adhering to the definition would produce different average-maximum speeds because of varying reactions to psychological factors. For this reason, the same driver was used during all maximum-car tests conducted during this investigation. Test cars with state emblems or permanent-type license plates tend to arouse suspicion among other drivers, resulting in slower speeds and biased data. Because of this the average car and maximum car used in this and subsequent phases of the investigation had no official markings. Further, in order not to attract the attention of other drivers, the test cars entered the traffic stream from points one-fourth to one-half mile beyond the end of the site.

If data from more than one source are to be compared, it is essential that the data be collected under similar conditions. Variations in the data resulting from changes

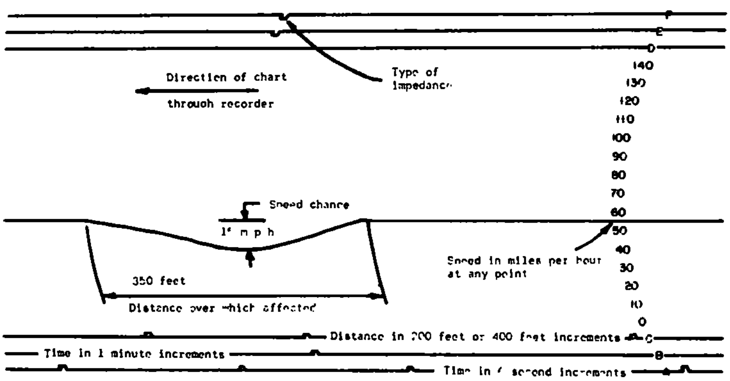

Figure 4. Speed and delay recorder chart with hypothetical speed curve.

in character and volume of traffic were eliminated in this study. This was accomplished by operating the average and maximum cars simultaneously. Thus, 15 round trips through a site resulted in 30 passes through both the developed and undeveloped sections for both the average and maximum cars.

The sample size of 30 passes for each of the cars was selected after consideration of several factors. First, in order that the maximum-car data be comparable to that of the average car, it was necessary that both test cars be subjected to the same traffic stream. Second, the time required to complete 30 passes through both sections is slightly less than two hours. Volume changes and driver fatigue become critical at this point.

Because the problems associated with commercial roadside development are most critical during periods of high traffic volume, tests for this entire investigation were conducted during either the morning, noon, or evening rush hours.

The purpose of the speed and delay study was to determine the relative significance of the various types of turning movements and other delay-causing factors and also to determine the location and average magnitude of these delays.

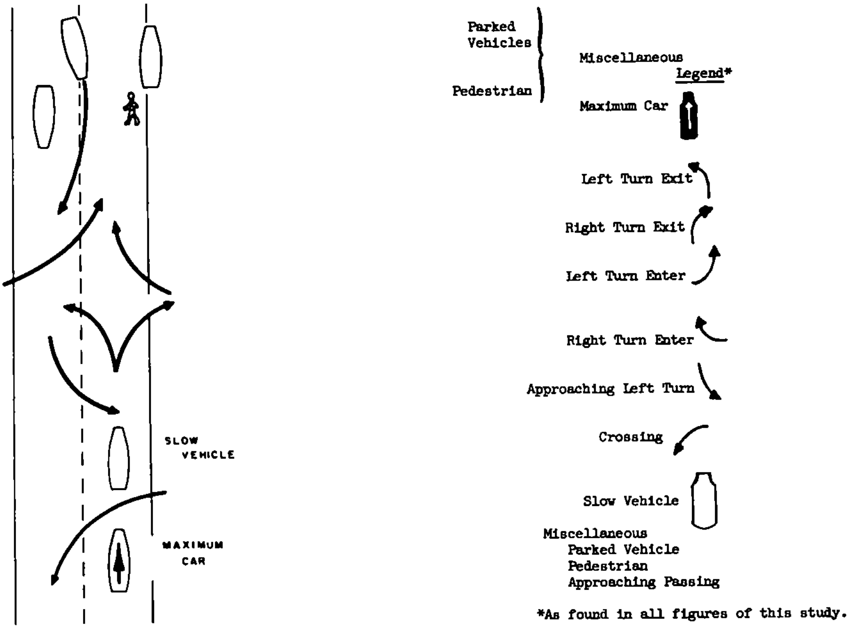

Figure 5. Types of impedances studied and legend used for presenting results.

Recording Instrument

An automatic speed and delay recorder (Fig. 3) was installed in the maximum car for the purpose of collecting extensive data concerning the various types of impedances which affect the speed of the maximum car. The speed and delay recorder registers these data in an accurate and useful form.

A speed and delay recorder is a machine which has a rotating drum over which passes a continuous chart. It is equipped with a speedometer-indicator hand on the end of which is attached an ink pen which records the instantaneous and continuous speed of the test car in which the machine is installed. The recording drum of the machine is turned by a connection with the regular speedometer cable of the test car, so that it rotates at a speed which is proportional to the speed of the test car. The

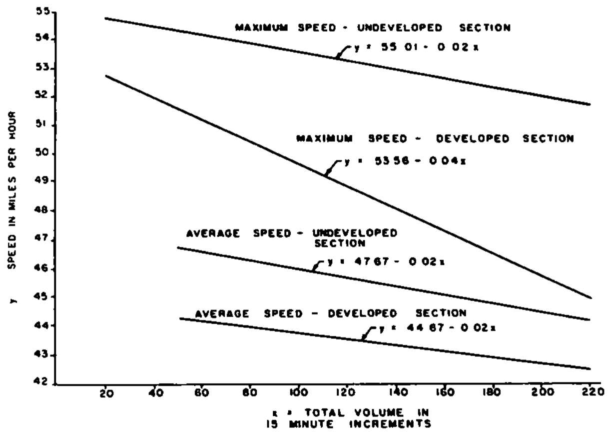

Figure 6. Speed versus volume curves.

recorder is also equipped with six additional pens which mark the chart with an ink blip when any one of them is activated by an electrical impulse. The purpose of three of the six pens is to enable a rider in the maximum car to code various incidents which may take place as a pass is made through the site. Two of the other three pens mark ink blips on the chart at 6-sec and 1-min intervals. The sixth pen is used to indicate either 200- or 400-ft distance increments.

A short section of the chart used in the speed and delay recorder is shown in Figure 4. The hypothetical speed curve shown in Figure 4 reflects the speed change induced by a delay-causing turn. The impedance causing this delay was coded on the two lines, D and F. Lines D, E, and F are the lines on which are coded the various types of

TABLE 1

RESULTS OF LEAST SQUARES ANALYSIS FOR SPEED VERSUS VOLUME

Test Car		Intercept	Slope	90% Confidence Limits on Y'		Standard Deviation,	Correlation
Type	Section	a	b	at $X = \bar{X}$	at $X = \bar{X} \pm 40$	$s_{Y/X}$	Coefficient
Avg.	Developed	44.67	-0.02	0.16	0.22	1.13	-0.43
Avg.	Undeveloped	47.67	-0.02	0.56	0.77	3.33	-0.22
Max.	Developed	53.56	-0.04	0.37	0.50	3.68	-0.43
Max.	Undeveloped	55.01	-0.02	0.08	0.11	0.46	-0.91

impedances. On lines C, A, and B are marked the 200- or 400-ft increments, the 6-sec intervals, and the 1-min intervals, respectively. The distance scale on line C is a constant scale of 1 in. of chart equal to 100 ft traveled by the test car. The chart moves through the recorder at a variable speed; thus, the time scale on lines A and B is variable.

The speed and delay recorder was used to record the following data:

1. Type of impedance.
2. Speed change from the maximum-legal speed.
3. Speed change from the previous speed of the test car.
4. The distance over which the speed of the maximum car was affected by the impedance.
5. The seconds of delay to the maximum car caused by the impedance.

These data can be read directly from the speed and delay recorder chart (Fig. 4)

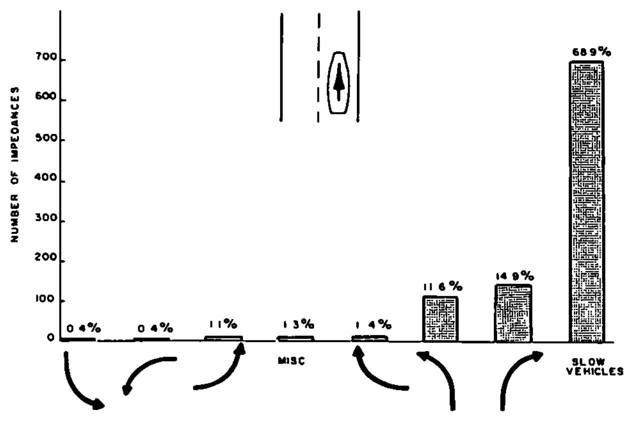

Figure 7. Frequency of occurrence of different types of impedances.

with the exception of the seconds of delay to the maximum car. This requires a simple calculation. First, the travel time, in seconds, is computed for the distance over which the speed of the maximum car was affected, had the impedance not occurred. Second the actual travel time over the same distance, in seconds, is scaled directly from the chart. The difference between these two travel times is the seconds of delay caused by the impedance.

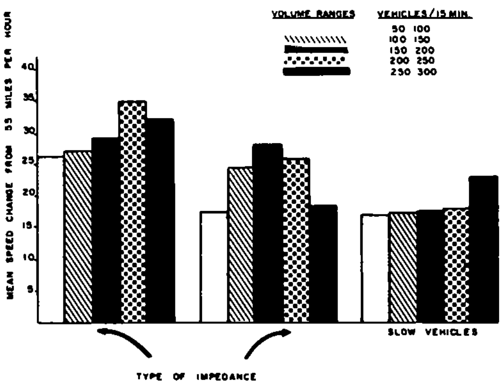

Figure 8. Speed change from 55 mph by type of impedance.

During this study these data were collected for eight types of impedances. These impedances are shown individually in Figure 5. The maximum car is shown traveling in the indicated direction at the bottom of the figure preceded by a slow vehicle impeding the maximum car. In front of the slow vehicle are shown six directional arrows indicating the six kinds of turning movements which can possibly affect the speed of

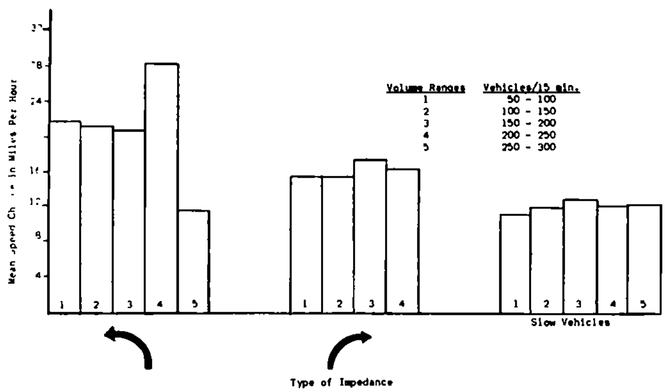

Figure 9. Speed change in miles per hour by type of impedance (for maximum car).

the maximum car. The eighth type of impedance, miscellaneous, is shown at the top of Figure 5. Any occurrence which affected the speed of the maximum car, except the first seven mentioned, was coded onto the recorder chart as miscellaneous. The three miscellaneous occurrences shown in Figure 5 are (a) a passing maneuver taking place in a direction opposed to the direction of the maximum car, (b) a parked vehicle, and

(c) a pedestrian. The legend shown in Figure 5 was used in all figures and tables of this study to facilitate the presentation of data and results.

Data collected during this study, in addition to the data collected by the speed and delay recorder, consisted of the directional roadway traffic volume in 15-min intervals and the average and maximim speeds. These speeds which were obtained by the average and maximum cars, respectively, were measured on the basis of the same 15-min intervals.

Conduct of Study

The average- and maximum-car methods were employed simultaneously during the

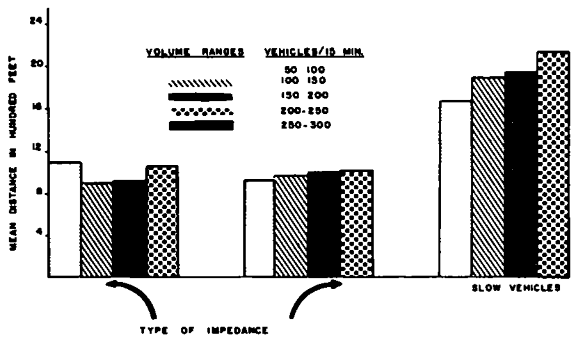

Figure 10. Distance impeded by type of impedance.

speed and delay study. Data were collected during the months of March and April 1959, at each of eight sites. Approximately 30 passes were made through each site with each of the test cars during the two most prominent peak-traffic periods. The same procedure was followed during the subsequent summer months. These procedures resulted in approximately 900 passes, or lines of data, for each of the test cars. These passes were divided equally between each direction of travel at the sites. In addition, approxi-

TABLE 2

RESULTS OF LEAST SQUARES ANALYSIS FOR SPEED VERSUS IMPEDANCE ENCOUNTERED BY TYPE

Impedance and Test Car Type	Intercept a	Slope b	90% Confidence Limits on Y' at $X = \bar{X}$	90% Confidence Limits on Y' at $X = \bar{X} \pm C$	Correlation Coefficient
Maximum-car speed versus number of turns per 30 runs	51.43	-0.30	0.80	c = 3 1.00	-0.43
Maximum-car speed versus number of slow vehicles per 30 runs	55.08	-0.37	0.73	c = 10 0.79	-0.67
Average-car speed versus number of turns per 30 runs	44.29	-0.18	-	-	+0.14
Average-car speed versus number of slow vehicles per 30 runs	34.98	0.00	-	-	0.00

mately 500 additional passes of supplemental maximum-car data were collected during the late summer months of 1959.

Analysis of Data

The data collected during the speed and delay study were treated by a least squares analysis of speed versus roadway traffic volume and speed versus frequency of occurrence of specific types of impedances. An application of confidence limits to determine the reliability of the least squares equations was also made. A detailed explanation of the technique is included in the Appendix.

Findings

Speed Versus Volume. — The results of the four least squares speed versus volume equations are given in Table 1. The equation for the maximum car in the undeveloped

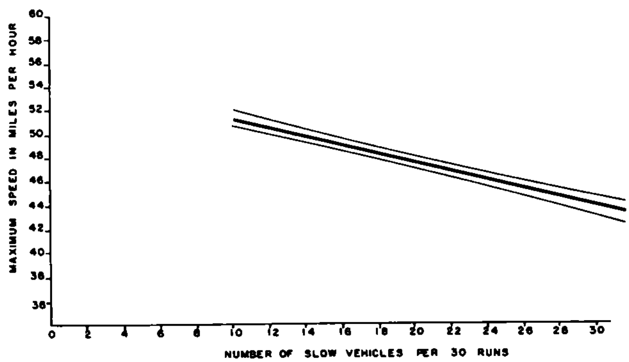

Figure 11. Effect of slow vehicles on maximum speed.

section has an intercept of 55.01 mph. This is most significant because the theoretical value for the intercept is 55 mph, the maximum-legal speed. When observing the value for each of the intercepts, it should be realized that these speeds occur only when the roadway traffic volume is equal to zero, and therefore do not represent average speeds for either test car.

It is notable that the slope is the same in each case except for the maximum car in the developed section. This might be explained in terms of the fact that the theoretical

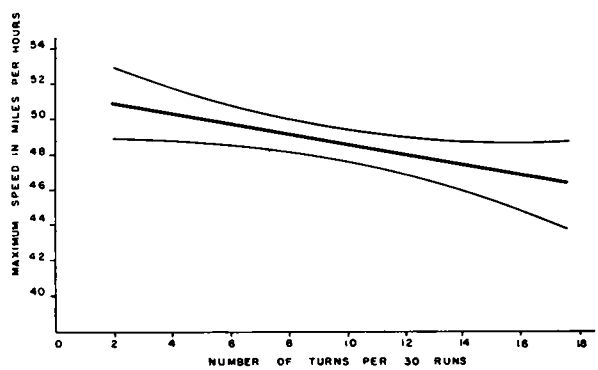

Figure 12. Effect of number of turns on maximum speed.

intercept, a, for both maximum-car equations is 55 mph. But because maximum speeds in the developed sections are lower than those in the undeveloped sections, the slope, b, must be greater for the equation representing maximum speed in the developed section.

The confidence limits given in Table 1 exhibit a great deal of variation from test car to test car and section to section. This is readily explained in terms of the residual standard deviation of Y with respect to X. Confidence limits are directly proportional to the standard deviation.

As an example, the equation for the speed of the average car in the developed section is $Y = 44.67 - 0.02X$, in which X is a measured 15-min traffic volume and Y is the resulting average speed. These equations, of course, are applicable for all undeveloped sections of any highway and for all other developed sections of highways similar to those studied in this investigation.

The correlation coefficients of Table 1 illustrate the degree of linear relationship between the Y and X variables, speed and volume. The equations are shown in Figure 6.

Analysis of Impedances. — This analysis is concerned with the maximum car only and with the delay-causing impedances encountered by the maximum car while collecting data for the speed and delay study. The maximum car encountered approximately 1,000 impedances of the eight types studied. These are shown in Figure 7. This figure indicates the distribution of these impedances both by percentage and by absolute number. It may be seen readily that more than two-thirds of the impedances encountered consisted of slow vehicles. The two other major impeders, right and left turns off the highway from the direction of the maximum car, are individually quite significant. The other five impedance types, however, are not significant, either individually or collectively. They combine to yield only 4.6 percent of the total impedances encountered. In much of the following analysis and discussion, the five minor impedance types are not considered because the quantity of data does not permit reliable analysis.

Figure 8 is a distribution in terms of impedance type, roadway traffic volume, and the average change in speed from 55 mph induced by various combinations of these two conditions. The illustrated increase in speed change with higher traffic volumes, up to a point, resulted from the increased difficulty encountered by the driver endeavoring to turn. The speed change induced by slow vehicles continues to increase with increasing volume because of the inverse relationship between speed and volume (Fig. 6). The size of the speed change induced by turns tended to decrease at the higher volume ranges. This might have been caused by the accumulation of very large slugs of traffic in which case a turning vehicle from near the front of the slug would induce a smaller speed change in the vehicles near the rear of the slug.

In Figure 9, the mean speed change induced in the maximum car is measured from the speed of the maximum car before the effect of the impedance. The magnitude of the speed changes in this instance is smaller than in Figure 8 because, in most cases, the maximum car was traveling at a speed less than 55 mph. A turning movement may slow the maximum car to a stop. Therefore, the speed changes induced by turns are larger than those induced by slow vehicles. The speed changes induced by turns tend to decrease in the high volume ranges because the maximum car is already moving at a low rate of speed.

It is significant that slow vehicles affect the speed of the maximum car over almost twice as much distance as do the turns (Fig. 10). A slow vehicle may continue through the entire length of the test section. The impedances, right turns and slow vehicles, tend to affect the maximum car over longer distances as the traffic volume increases because opposing vehicles make passing difficult for the maximum-car driver. The same tendency associated with the left turns results from the increased difficulty in turning across the opposing traffic stream.

As shown in Figure 10, there was not a great deal of difference between the mean seconds of delay caused by slow vehicles and that caused by left turns. Of greater significance, as shown in Figure 5, is the fact that six times as many slow vehicles impeded the maximum car as did left turns. The seconds of delay caused by right turns was less than that caused by left turns, yet, the two have almost equal significance because right turns occurred somewhat more frequently than left turns. The longer delay associated with high volume ranges resulted from the difficulty encountered by the maximum car trying to pass and by the impeding vehicle trying to turn. It should be noted that slow vehicles cause about the same time delay as turns, but they occur more frequently and thus are more significant.

Speed Versus Impedance. — The average speeds of the maximum and average cars were both analyzed by the least squares method in terms of number of turns encountered and number of slow vehicles encountered by the maximum car during 30 passes through the developed section. The results are given in Table 2. The correlation coefficients for the average-car analyses indicate no linear relationship in one case and practically no relationship in the other case. These coefficients might be explained in terms of the speed of the average car being determined by the average speed of the traffic stream which in turn might be the result of psychological factors rather than actual impedances. Because no relationships existed, the average-car analyses were not completed.

In the case of the maximum-car analyses, the correlation coefficients indicate a rather high degree of linear relationship. The confidence intervals are quite narrow, but only one of the intercepts given in Table 2 approaches the theoretical value of 55 mph.

It must be realized in studying the results in Table 2 that these constants do not relate a completely true picture because the analysis of speed versus slow vehicles was affected to an unknown degree by the turns encountered by the maximum car. The same is true in the reverse order concerning the analysis of speed versus the number of turns.

The equations for these analyses may be written in the same manner as previously shown for the analyses of speed versus volume.

The equations and confidence intervals for the foregoing are shown in Figures 11 and 12. The curves are shown only for the range over which the data were collected.

Conclusions

Based on the findings of this speed and delay study, the following conclusions are drawn:

1. The least squares analyses for speed versus volume indicate that the average speeds of both the maximum and average cars can be predicted, in terms of roadway traffic volume, with a high degree of confidence.
2. Slow vehicles are by far the most significant of the eight impedance types studied.
3. Left turns and right turns from the highway and in the direction of the test car are individually significant as impedances.
4. The remaining five types of impedances are insignificant, both individually and collectively.
5. There is a definite, inverse relationship between the speed of the maximum car and the number of slow vehicles encountered by the maximum car.
6. There is a definite, inverse relationship between the speed of the maximum car and the number of turns encountered by the maximum car.

FIELD TESTING OF DERIVED RELATIONSHIPS

Various mathematical relationships were derived and presented in the preceding section. The purpose in developing these relationships was to permit prediction of the speed and turning movement characteristics of any section of highway. Any section for which predictions are to be made would necessarily be required to have physical characteristics similar to those on which the relationships are based.

Unless the derived relationships are field tested in some practical manner, their validity may be subject to question. The purpose of this section is to relate the manner in which the relationships were tested and the results of the test.

Summary of Relationships and Method of Testing

For predicting average speeds in the sections indicated, the following equations were presented previously:

Developed section: $Y = 44.67 - 0.02X$
Undeveloped section: $Y = 47.67 - 0.02X$.

Similar equations for the maximum-car speeds are as follows:

Developed section: $Y = 53.56 - 0.04X$
Undeveloped section: $Y = 55.01 - 0.02X$.

The X and Y variables in these four equations are, respectively, average speed and roadway traffic volume in 15-min increments.

The equations for predicting turning movements for the indicated business types were not previously discussed in this report, but are as follows:

Service stations: $Y\ .\ 0.77X_1 + 0.01X_2$
Restaurants: $Y = 1.15X_1 + 0.01X_2$
Cafes and drive-in cafes: $Y = 2.13X_1 + 0.01X_2$
Grocery and grocery-service station combinations: $Y = 1.04X_1 + 0.01X_2$
Supermarkets and large open-air markets: $Y = 2.42X_1 + 0.02X_2$
Furniture and restaurant equipment stores: $Y = 0.04X_1 + 0.01X_2$
Miscellaneous: $Y = 0.66X_1 + 0.01X_2$.

The Y, X_1, and X_2 variables in these seven equations are, respectively, turning movements, dollar income, and roadway traffic volume (all for a 10-hr period between 7:00 AM and 5:00 PM).

Because the turning-movement equations may be used only to predict the total number of turns for the entire 10-hr period, the frequency distributions in Figures 7 through 10 are used to predict the number of turns for specific periods, such as the

TABLE 3

PREDICTIONS FOR THE WASHINGTON SITE

Time	Section Type	Maximum Speed (mph)		Average Speed (mph)	
		Predicted	Actual	Predicted	Actual
7:00 - 8:00 AM	Developed	49.2	49.5	-	-
	Undeveloped	53.0	53.6	-	-
7:10 - 9:10 AM	Developed	-	-	43.0	40.4
	Undeveloped	-	-	46.1	45.0
12:00 - 1:00 PM	Developed	49.0	46.5	-	-
	Undeveloped	52.9	51.8	-	-
3:10 - 4:10 PM	Developed	47.9	47.7	-	-
	Undeveloped	52.1	49.7	-	-
3:10 - 5:10 PM	Developed	-	-	42.2	40.6
	Undeveloped	-	-	45.3	46.4

Business	Turning Movement	
	Predicted	Actual
Esso service station	87 ± 26	97
Etna gas	117 ± 26	160
Sinclair service station	98 ± 26	115
Ayers Restaurant	224 ± 71	181
Franks Restaurant	60 ± 71	115
Mobley's Tire Company	70 ± 30	67
Clearview Television	58 ± 14	27

lunch hour period. For example, if the frequency distribution for a particular type of business indicates that the period between 11:30 AM and 12:30 PM generates 19.5 percent of the total number of turns occurring during the 10-hr period, then 19.5 percent of the value arrived at by the equation represents the number of turns to be expected between 11:30 AM and 12:30 PM.

An important phase of this test was the selection of a typical test site. It was desirable to locate a test site which included all seven of the business types studied previously. Further, it was necessary that the site not contain any major intersections or traffic signals. In short, the site needed to be in general conformity with the test site definition.

After investigating a number of possible locations, a site on US 17, south of Washington, North Carolina, was chosen. The developed section of this site has three businesses of the service station type, two businesses of the restaurant type, one business of the furniture and restaurant equipment type, and one business of the miscellaneous type. The furniture and restaurant equipment type of business is a television sales and service store. It was classified in this manner because of the non-impulse-type buyers which patronize the business. The miscellaneous-type business is an automobile-tire recapping and vulcanizing business. The operations of both of the latter-type businesses were rather limited in scope. Each of these businesses employed only two persons. It is unfortunate that the site did not contain businesses of each of the seven types. It is most difficult, however, to find a site having all the business types.

The data necessary for computing all the desired predictions consisted only of: (a) the total roadway traffic volume between the hours of 7:00 AM and 5:00 PM, and

TABLE 4

PREDICTED AND ACTUAL NUMBER OF TURNS FOR SHORT TIME PERIODS

Business	Time	Predicted No. of Turns for 10 Hours	Percent	Predicted	Actual
Esso station	8:30 - 8:45	87	3.0	3	0
	12:00 - 1:00	87	14.0	12	10
	3:00 - 4:00	87	6.0	5	3
Sinclair station	8:30 - 8:45	117	3.0	4	0
	12:00 - 1:00	117	14.0	16	14
	3:30 - 4:00	117	6.0	7	6
Etna gas	8:30 - 8:45	98	3.0	3	7
	12:00 - 1:00	98	14.0	14	9
	3:00 - 4:00	98	6.0	6	14
Ayer's Restaurant	10:30 - 10:45	224	3.0	7	1
	12:00 - 1:00	224	18.4	41	41
	3:00 - 3:30	224	5.8	13	4
Frank's Restaurant	10:30 - 10:45	60	3.0	2	3
	12:00 - 1:00	60	18.4	11	11
	3:00 - 3:30	60	5.8	3	5
Mobley's Tire Company	10:00 - 10:30	70	10.0	7	6
	12:00 - 1:00	70	11.5	8	9
	4:45 - 5:00	70	5.6	4	1
Clearview Television	10:00 - 10:30	197	10.0	20	1
	12:00 - 1:00	197	11.5	23	1
	4:45 - 5:00	197	5.6	11	0

(b) the total dollar income for each business for the same period of time. Because the predictions were being made for a particular day, it was necessary to determine the actual values on that day. Therefore, the following data were all collected on the same day:

1. Total roadway traffic volume, in 15-min intervals, between the hours of 7:00 AM and 5:00 PM.
2. Total dollar income for each business in the developed section for the same time period.
3. Average speeds by the average- and maximum-car methods for both the developed and undeveloped sections during the peak traffic periods of the day.

All the tests were conducted and the data collected in a manner similar to that employed in previous studies of this investigation.

Findings

The effects tabulated in this section are presented in terms of the Washington test site versus the average of results for all the other test sites studied during this investigation.

The predicted and actual values of speeds and turning movements are given in Table 3. In some cases the difference between predicted and actual speed was greater than the confidence limit as computed and tabulated in the previous section. This resulted from the fact that the actual speeds given in Table 3 are in each case based on the average speed of 30 passes through the site. The roadway traffic volume during the required 1- to 2-hr periods varied from one 15-min period to the next. The predicted speeds of Table 3, however, were computed from the speed versus volume equations which were based on average speeds and roadway traffic volumes for 15-min periods only. The volume variation during this short period was rather small. There-

TABLE 5

PERCENTAGE OCCURRENCE BY TYPE OF IMPEDANCE

Type Impedance	Washington Data (%)	Average Data[a] (%)
Slow vehicles	77.7	68.9
	5.6	14.9
	13.0	11.6
	0.0	1.4
Miscellaneous	0.0	1.3
	3.7	1.1
	0.0	0.4
	0 0	0 4
 Maximum car	100 0	100.0

[a]Source Figure 7 of text.

TABLE 6

SPEED AND DELAY DATA AT WASHINGTON VERSUS THE AVERAGE FOR ALL SITES

						Slow Vehicles	
Characteristic	Ranges of Volumes per 15 Min	Washington	Average	Washington	Average	Washington	Average
Mean speed change	50 - 100	-	21.5[a]	-	15.0[a]	10.9	11.0[a]
	100 - 150	-	21.0	39.0	15.0	11.4	12.0
	150 - 200	12.0	20.5	14.0	17.0	12.5	13.5
Mean speed change from 55 mph	50 - 100	-	26.5	-	17.5	20.7	18.0
	100 - 150	35.5	27.0	39 0	24.0	22.6	18.3
	150 - 200	34.0	29.0	30.0	28.0	19.5	19.0
Mean seconds of delay	50 - 100	-	7.5	-	3.8	6.6	7.0
	100 - 150	4.5	7.0	10.0	5.8	6.4	8.5
	150 - 200	10.5	7.0	15.0	6.0	6.0	9.0
Mean length of impedance	50 - 100	-	11.0	-	8.2	16.3	17.0
	100 - 150	15.0	8.5	23.8	9.0	16.5	19.0
	150 - 200	18.6	9.0	23.8	9.8	17.1	19.5

[a]Source: Figures 7-10 of text.

fore, the actual speed cannot be expected to lie exactly within the confidence interval of the predicted speed. The difference between actual and predicted speeds ranges between 0.2 and 2.6 mph. Considering these points, this is deemed adequate.

The actual and predicted number of turns for each of the seven businesses in the Washington test site are given in the lower portion of Table 3. The confidence intervals were computed for the average Y, number of turns, not the predicted Y. Yet, in only two cases did the confidence interval not include the actual value. The Clearview Television Store, a furniture and restaurant equipment type of business, had an actual value outside the confidence interval. This business deals with non-impulse buyers of expensive items resulting in a high degree of dollar income variation from day to day. This fact makes predictions difficult. The error in prediction for the Etna Gas Station was possibly a result of random variation outside the 90 percent probability level on which the confidence interval is based.

The predicted and actual number of turns for various time periods during the 10-hr test period are given in Table 4. The values in the percent column were obtained from frequency distributions not shown. Except for the noon-hour time period, the periods in the time column were chosen at random. The values tabulated give some indication of the validity and utility of the frequency distributions. In the majority of instances, the difference between actual and predicted values was quite small in magnitude. However, the predictions having a large error indicate the difficulty arising from the large variation of the number of turns, during a short-time (15-min) period as opposed to a smaller variation when considering a time period of perhaps an hour.

A tabulation of the eight types of impedances studied, and the percentage each contributes to the total number of impedances is presented in Table 5. In general, the Washington data follow the trend established by the averages of all the sites. This is readily understood when considered in light of the fact that the Washington data represent only a small fraction of the sample size on which the average values are based.

Table 6 gives the Washington speed and delay data and the average of data from all the sites studied. Only the three major impedance types are considered along with their four characteristics as measured by the speed and delay recorder and the maximum car. Again the Washington data represent a very small sample size as seen from the blank spaces in the table in which cases no impedances occurred under the indicated conditions. It is evident, however, that the Washington data follow the trend of the average data.

Conclusions

Based on the data collected during this investigation, the statistical analyses conducted, and the field testing of the results of the analyses, the following conclusions are drawn:

1. The equations of average and maximum speeds for developed and undeveloped sections are adequate for predicting these speeds.
2. The seven turning-movement equations can be used to predict within a reasonable degree of accuracy the number of turns to be expected at any of the seven types of businesses.
3. Using the time-frequency distributions of turns for each business type, the number of turns can be estimated for time periods as short as one hour.
4. The percentage distribution of occurrence of the eight types of impedances and the speed and delay characteristics for each type are essentially the same for any developed section of highway similar to the sections studied during this investigation.

REFERENCES

1. Greenshields, B.D., "Quality of Traffic Transmission." HRB Proc., 34:508-522 (1955).
2. Hader, R.J., "Introduction to Statistics for Engineers." North Carolina State College, Raleigh (1956).
3. Hader, R.J., and Grandage, H.E., "Simple and Multiple Regression Analysis." Proc., Symposium on Design of Industrial Experiments, 1:109-137. Inst. of Statistics of the Consolidated Univ. of North Carolina, Raleigh (1956).
4. May, A.D., Jr., "A Friction Concept of Traffic Flow." HRB Proc., 38:493-510 (1959).
5. May, A.D., Jr., and Kaneko, E.T., "Comparative Study of Two Vehicle Operating Characteristics Instruments." HRB Proc., 37:375-395 (1958).
6. Mueller, E.G., "Recent Speed and Delay Instruments." Traffic Engineering, 25:100-105 (1954).

Appendix

THE LEAST SQUARES METHOD OF ANALYSIS

For the speed versus volume relationships, four equations were fitted for the four combinations of average speed in developed and undeveloped sections and maximum speeds in the same sections. This least squares analysis is based on the primary assumption that the speeds of the average and maximum cars vary linearly with the independent variable, roadway-traffic volume. Based on this assumption, the following model equation may be written:

$$Y = A + BX$$

in which

Y = the mean speed of the test car based on a 15-min increment of roadway traffic volume,
X = the roadway traffic volume during a 15-min interval,
A = the intercept or the value of Y when X is equal to zero, and
B = a constant which is the slope of the speed-volume curve.

The least squares analysis computes estimates of the true parameters, A and B, such that the sum of the squares of the vertical distances from the line ($Y = A + BX$) will be a minimum. The estimates of A and B are designated by a and b, respectively. By completion of the least squares analysis the following equations may be written:

$$Y' = a + bX'$$

in which

$$b = \frac{\Sigma (X-\bar{X})\ (Y-\bar{Y})}{\Sigma (X-\bar{X})^2}$$

$$a = \bar{Y} - b\bar{X}$$

$$R = \sqrt{\frac{\Sigma (X-\bar{X})\ (Y-Y)}{\Sigma (X-\bar{X})^2\ \ \Sigma (Y-\bar{Y})^2}}$$

in which

Y' = the resulting predicted value of speed,
X = the observed 15-min roadway traffic volume,
Y = the average value for speed measured during the 15 min for which roadway traffic volume was measured,
$\bar{Y}$ = $\frac{\Sigma Y}{N}$,
R = correlation coefficient,
$\bar{X}$ = $\frac{\Sigma X}{N}$, and
N = the number of observations or 15-min intervals for which X and Y were measured.

Two other least squares analyses were conducted on the speed and delay data. In both analyses, the model equation is identical with that of the speed versus volume analysis previously discussed. In the first analysis, the dependent and independent variables have the following meaning: Y = the average speed of the maximum car, and X = the number of slow vehicles encountered by the maximum car during 30 passes through the developed section. In the second of the two analyses, the dependent and independent variables have the following meaning: Y = the average speed of the maximum car, and X = the number of delay-causing turns encountered by the maximum car during 30 passes through the developed section.

The procedure and equations used in the speed versus volume analysis apply equally well for these two analyses. It is necessary to adjust only the meanings of the terms in those equations to fit the meanings given these dependent and independent variables.