TABLE N

FUEL CONSUMPTION AND SPEED OF OPERATION ON SECTION OF COLUMBIA PIKE BEFORE AND AFTER INSTALLATION OF TRAFFIC ACTUATED CONTROL EQUIPMENT

Period	Speed			Fuel consumption		
	In-bound	Out-bound	Avg.	In-bound	Out-bound	Avg.
	mph.	mph.	mph.	mpg	mpg.	mpg.
	Before, April 1952					
A M. off-peak	25.4	26 8	26.1	16.7	15.8	16.3
A M peak	20 0	23 8	21.8	13 8	13 7	13 8
P M peak	22.2	19.8	20.9	13.0	12.5	12 8
Avg. peak	21 1	21.8	21 4	13 4	13.1	13 3
	After, August 1952					
A M. off-peak	26 1	25.0	25.5	15 7	15 7	15.7
P M. off-peak	23.9	24.7	24 3	13 4	13 5	13.4
Avg. off-peak	25.0	24.8	24 9	14.6	14 6	14 6
A.M peak	20.9	22.9	21 9	14.2	12 7	13.4
P.M peak	22 3	20.0	21 1	15.0	15.4	15.2
Avg. peak	21 6	21.4	21.5	14 6	14.0	14 2

in the second column headed "individual-grade relation" were based on the rates for individual grades shown in Figure 23.

The fuel measured with the burette was used as a common base for comparative purposes. The percentage of variations from the burette measurement shown in Table 4, indicates that all methods gave results which were within reasonable limits of error. The much simpler rise-and-fall method appears to be as good as, or better than, the two methods which require a solution for each individual grade.

The results obtained with the fuel meter also did not vary appreciably from those measured with the burette.

Analysis of Flow on an Urban Thorofare

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Reading Road has been one of the most-heavily travelled thoroughfares in Ohio, carrying US 25 and US 42, and heavy local traffic. In 1950, a series of major changes in the traffic control was inaugurated, which culminated in the installation of a completely remodeled traffic signal system in the Winter of 1952-53.

This paper presents a description of the changes which were made in the traffic control and a study of the effects of these changes in terms of traffic volumes, capacity, accident records, delays and operating speeds, and on certain operating characteristics of motor vehicles using Reading Road.

The traffic signal system of this 3.85-mile section was remodeled to include two signal faces in each direction on Reading Road, plus pedestrian signals across nearly every crosswalk at signals. Signals were added to one intersection in the group to bring the total number signalized to 24. Signal spacing varies from 250 feet to 1,950 feet, and there is a wide range of spacing between these figures. Many innovations were used to get a reasonable degree of progressive movement, notwithstanding such uneven spacing. The most-outstanding of these was the use of semi-traffic-actuated control units, with a background cycle, at intersections interfering most with progression.

In addition to studies of traffic volumes, capacities, accident records, and speeds and delays, a new method was used in studying the effects of traffic on vehicle-operating characteristics before and after the changes in the traffic signals. These studies were made simultaneously with the conventional speed and delay studies, using a test car equipped with statistical instruments developed by the Highway Research Board Committee on Motor Vehicle Characteristics. These instruments measured vehicle speed, fuel consumption, braking, engine torque, and throttle opening on the car during the 54 test runs made after the traffic signal modernization was completed.

The studies showed that the revisions in traffic control had raised the practical capacity at three critical intersections by an average of 13 percent and that traffic volumes on the road had increased, by 1954, between 10 and 15 percent since 1952.

The studies also showed that, despite the increase in traffic volumes, the average trip during the 1954 studies consumed about 7.5 percent less time than during the 1952 studies and that the accident records showed a 21 percent decrease in accident occurrence at signalized intersections in 1953 as compared with 1952.

Savings have therefore accrued to motorists using the road in time saved, in lower vehicle operating costs, and in reduced accident costs, amounting to at least $140,000 per year, as compared with an installation cost for the system of approximately $85,000.

The studies also indicated that statistical testing equipment of this type should be extremely valuable in the analysis of the effects of traffic flow conditions on vehicle-operating characteristics.

● THE YEAR 1950 was the turning point for traffic signals in Cincinnati. Citizens approved a bond issue of $900,000 for new signals and modernization of existing signals. This, of course, was not adequate money to complete the project, but it was enough to give Cincinnati a taste of standard traffic signalization designed for maximum intersectional capacity and safety. The result of improvements so far has been to show people what can be done to assist traffic and thus bring them into a more cooperative mood toward further signal projects. Of course, the program has been criticized, but this criticism has decreased as greater public understanding was realized.

Traffic signals, themselves, are certainly no cureall for traffic accidents. It has been shown time and again that a traffic signal may increase the number of accidents but usually reduces their severity. Most of you will agree, however, that when traffic signals are properly used they can be one of the most-valuable and most-effective devices for expediting and safeguarding traffic on our antiquated city streets.

From the safety standpoint, traffic signals are only as effective as their ability to be seen. Their effectiveness in carrying volumes of traffic depends upon their timing. Other factors are involved but will not be evaluated in this discussion.

THE PROBLEM

Reading Road was singled out as a prime project early in the program of traffic signal modernization in Cincinnati. The section of Reading Road studied in this paper is 3.85 miles in length (Figure 1) and involved the modernizing of 23 existing signalized intersections and the addition of one newly signalized cross street.

Reading Road is essentially 50 feet wide throughout the section studied and originally had street-car rails in both directions, but street cars have not operated on them for several years. The street passes through apartment developments and strip businesses for its entire length. It carries US 25 and US 42 and State Route 4 joins Reading Road at Paddock Road, thus adding to the amount of through traffic.

The original installation of signals took place over a period of years and was influenced by such factors as neighborhood pressure, as well as traffic considerations; hence, the spacings between signals are irregular. Even without some of the less-essential signals, the spacing would be far from ideal between some of the important cross streets that actually warrant signal installations.

A street with a curb-to-curb width of 50 feet and parking on both sides cannot effectively carry four lanes of moving traffic. Reading Road had peak-hour parking restrictions for inbound traffic in the morning and outbound traffic in the evening, but it will be shown later how this did not fulfill the traffic demand of the street. Use of an offset centerline and

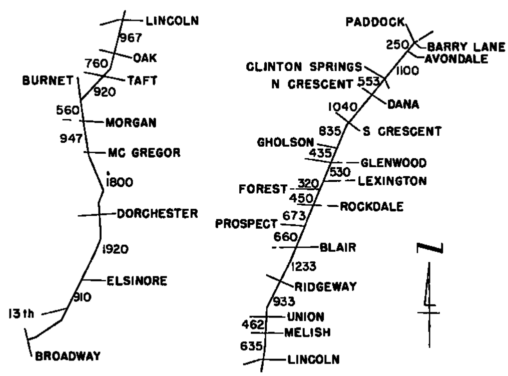


Figure 1. Vicinity map, showing signalized intersections and area studied.

Figure 2. Reading Road and Melish before improvements.

five lanes will also be shown as the new street laning.

The original Reading Road signal system consisted of one three-light signal head mounted horizontally at the far right of each traffic approach (Figures 2 and 3). These were installed during the late 1920's and 1930's; in general, their physical condition was poor, and in many cases their visibility left much to be desired.

The old system operated on a 46-second cycle and did a fair job of moving light traffic, but it would become very congested under heavy peak hour loads, or even at

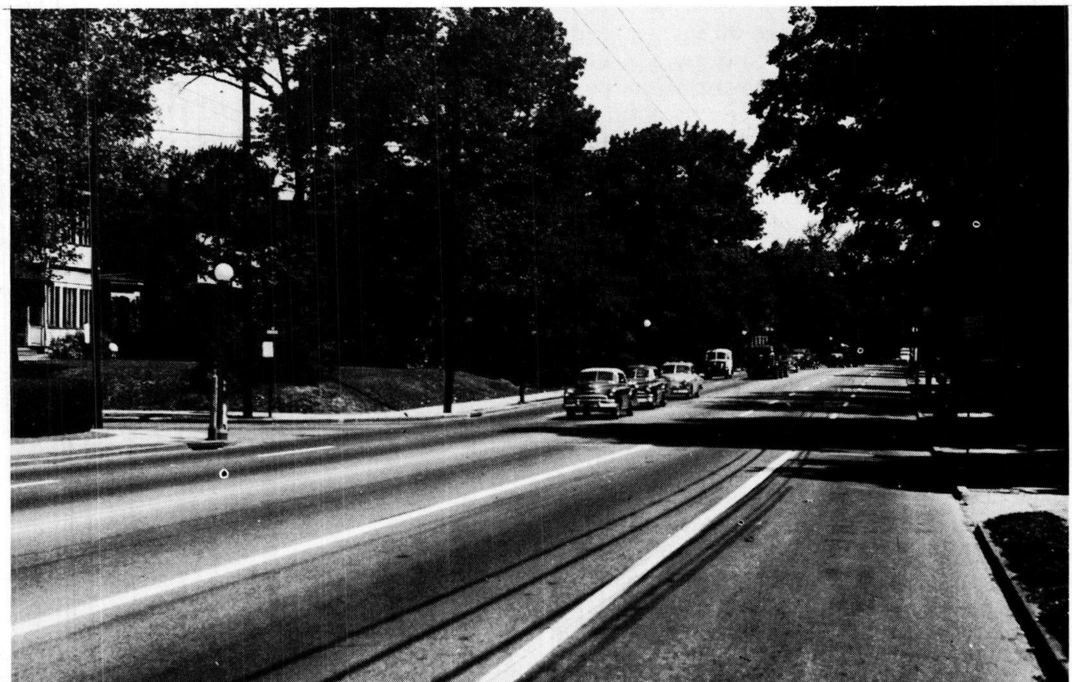


Figure 3. Reading Road and Gholson before improvements.

off-peak hours when several trucks or buses reached close headways. Most of the signalized intersections continually appeared near the top in the list of high accident locations.

It was mandatory that this situation be corrected, since increased vehicle registration demanded greater street capacity. Widening was prohibitively expensive due to heavy business developments on most of this length of Reading Road. Parallel routes are almost nonexistent or too far away. The only way for improvements for the present was to make the best possible use of our existing 50-foot roadway. Ultimately a new expressway will relieve this thorofare, but completion date is not earlier than 1957.

SIGNAL PROJECT DEVELOPMENT

The first step in a traffic-signal-modernization project is to gather data on the street under consideration. The geographical proportions of Reading Road are seen in Figure 1. Distance between signalized intersections vary from 250 feet to 1,920 feet. The overall length of the project is 18,906 feet. A time-space chart for the entire project was laid out at a 200-foot scale on a cross section tracing paper. Many prints from this tracing were used to lay out combinations of signal progression. These prints were 30 inches wide and 10 feet long. The large drawings were used to insure as accurate timing as possible. The method employed in obtaining the proper offsets was the conventional method of using pins and thread to arrive at the proper speed and traffic band widths.

Due to the profusion of signalized intersections, many of them minor cross streets, it became necessary to use all major cross streets on Reading Road in laying out the basic "progression chart." Best results were obtained with a 60-second cycle. When this was completed, the minor cross streets were worked into the basic chart as semi-traffic-actuated signals with a background cycle controlled from the resynchronizing line just as fixed-time controllers. This is accomplished by the use of synchrolizers at each of the eight semiactuated units.

Figure 4 shows a small section of the original progression chart. Union and Lincoln avenues were on the basic chart and Melish Avenue, already a signalized intersection but of a minor nature, had to have its green adjusted to a position that would cause the least interference to Reading Road traffic. As long as no actuation occurs, this section operates as a

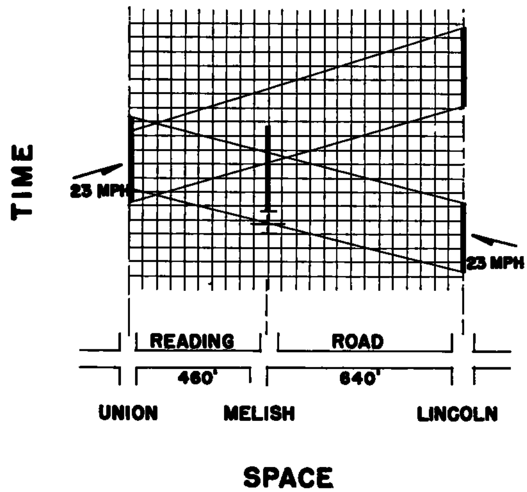


Figure 4. Portion of Reading Road progression chart, Lincoln to Union.

simple ½ cycle offset system. When an actuation does occur, it can be seen that traffic flow in one direction is not interfered with, but the other direction has its band width reduced considerably. If the actuations were to continue indefinitely during peak traffic, considerable congestion would accumulate. A thorough study of traffic counts and characteristics at this and comparable locations disclosed that there would be enough cycles with no

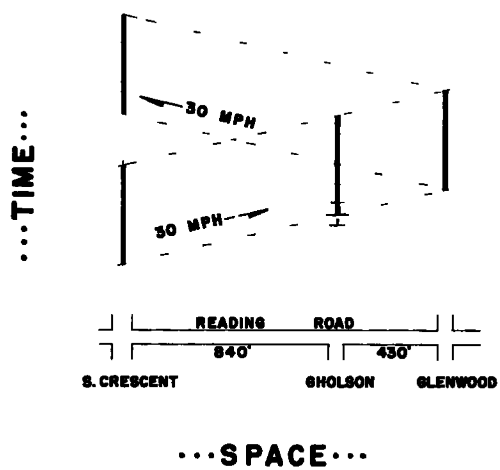


Figure 5. Portion of Reading Road progression chart, Glenwood to South Crescent.

actuation that the congestion could be kept to a minimum.

Figure 5 shows another small section of the progression chart. The conditions here were essentially the same as shown in the previous figure, except that Gholson Avenue intersects Reading Road as a T intersection.

Reading Road at this point is 50 feet wide, curb to curb. An offset centerline allows two southbound lanes, two northbound lanes, and a parking lane which becomes a northbound lane from 4 p. m. to 6 p. m. No parking is allowed in the southbound curb lane at any time.

Figure 6. Reading and Gholson after improvements.

Gholson Avenue is 430 feet north of Glenwood Avenue and 840 feet south of South Crescent Avenue. This again is not conducive to proper progression in both directions with a cycle length that will carry the vehicle volumes. A speed of 30 mph. can be maintained in both directions between Glenwood Avenue and South Crescent Avenue if the signal at Gholson Avenue was removed. The signal could not be removed; so to cause a minimum of interference to Reading Road traffic and still accommodate Gholson Avenue traffic, an unusual combination of signal control was devised.

The signal at Gholson Avenue is semi-actuated with the background cycle and timed so it will progress southbound traffic on Reading Road. The northbound traffic which normally would be interrupted is accommodated in a through lane (Figure 6) which is separated physically from traffic emerging from Gholson Avenue by a half round concrete divider curb. In this way northbound traffic can move at all times, except when it is interrupted by a pedestrian actuation (which stops all Reading Road traffic). Pedestrian movement is light at this intersection so northbound interruptions are few.

Traffic counts were taken on all the cross streets involved and along Reading Road at key locations. From these counts it was determined what the cross-street timing should be and also used to discover what streets could be considered minor enough to receive the semiactuated treatment as previously described.

Analysis of traffic volumes on Reading

Road disclosed that traffic peaks in both directions at about the same time, both morning and afternoon, thus making directional preferential offsets of no value (Figure 7). Offsets that would carry heavy traffic in both directions were mandatory.

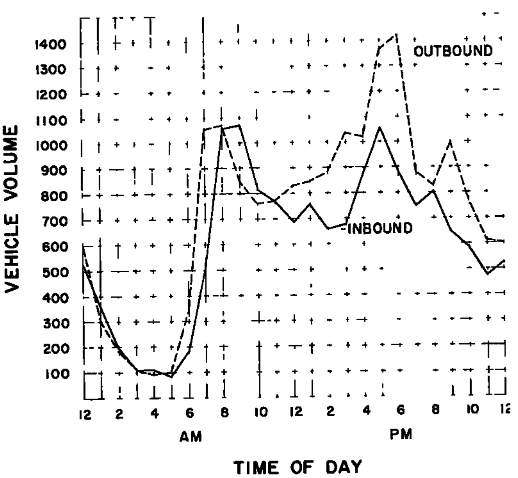


Figure 7. Reading Road traffic volumes, typical hourly distribution.

Signal splits at the fixed-time intersections were calculated by the conventional method but special consideration had to be given the timing of the semiactuated controllers. The conventional isolated signal-timing method no longer applied. Operation with a background cycle meant that the controller, after the expiration of the main street green, was no longer waiting to immediately turn to the side street green upon actuation. This means that the detector placement is no longer a function of the dial setting and speed. To insure a short minimum side street green, it became necessary to place the detectors within 40 to 60 feet of the stop line, thus making it possible to have a green as short as nine seconds. The detector is placed in a position that will allow to pass only the cars ahead of it that can theoretically and normally pass through the minimum green setting. Any additional vehicles will be behind the detector and will receive additional green extensions as they pass over the detector. This will clear any unusually large group of vehicles on the side street with a minimum of delay.

If the detectors were placed the conventional way, the minimum side-street green would, of necessity, be quite long, due to a possible prolonged waiting period until the background cycle would release the signal to permit side street movement. In other words, it would be possible to fill up the long space between detector and the stop line; thus making a long minimum green necessary. The maximum side street green is determined by traffic counts.

Early in the program the decision was made to use double signal indications (Figure 8) on all state and federal routes. One indication is about 5 feet from the right curb and the other is just left of the centerline. From the visibility standpoint this is ideal; a driver can always have one signal head or the other in view at all times. Also, there is little possibility that both signal heads will be lost in a maze of neon signs. A paper (1) on signal visibility has shown that overhead signals in contrast to curb mounted signals can be placed both closer to a motorist's normal line of sight and at an almost constant angle, regardless of street width.

Double signal indications are a tremendous safety factor in case of burnouts. It is seldom that there is a double burnout, leaving an approach to a signalized intersection dark.

In addition to the signal indications for traffic, each of the signalized intersections has at least one crosswalk with "Walk" and "Wait" indications. In areas of heavier pedestrian activity all crosswalks are controlled by pedestrian signals. The pedestrian signals are timed to give a clearance period to the pedestrian so Reading Road will be clear as the platoons of vehicles arrive at the intersection.

The entire project involving the 24 signalized intersections plus the interconnecting control cable was written in contract forms and bids asked. Low bid was $72,100. This amounted to just over $3,000 per intersection for all new signal equipment and the labor for installing it. This price also included the labor of removing the old equipment. Parking signs, paint lines, etc., accounted for approximately $13,000 additional to complete the project for a total of $85,000.

Construction was begun at Thirteenth Street on the south end of the project and proceeded to the north, intersection by intersection. The project was completed, with a minimum of delay to traffic, about three months after it was started.

Capacity studies showed that the revision in traffic control had raised the practical capacity (2) of Reading Road at three critical intersections on Reading Road by an average of 13 percent. At many intersections the practical capacity was raised as much as 30 percent. A typical intersection is Reading Road and Elsinore Place, where the practical capacity increase was 17.7 percent. Reading Road, here, had a practical capacity of 1,580 vehicles per hour, and after the improvement the practical capacity was increased to 1,860 vehicles per hour.

RESULTS AND COMPARISONS

General Considerations

In attempting to evaluate a traffic engineering improvement, a basis for comparison must first be established. Using, as a guide, the definition of traffic engineering, criteria were set up, and studies of conditions before and after the improvements on Reading Road were made as follows: (1) roadway capacity and traffic volumes actually carried; (2) safety, as reflected in accident records; (3) convenience, as reflected in freedom from delays, running speeds, and travel time; and (4) economy, reflected in three major economic factors of traffic operations: (a) costs due to accidents, (b) vehicle-operating costs, (c) monetary costs of delays and lost time in traffic.

In this study of traffic conditions, a relatively new and still largely experimental method was used in measuring certain aspects of both convenience and economy. This method involved the use of statistical testing equipment developed by the Highway Research Board's Committee on Vehicle Characteristics.

These studies had as objectives, first, to determine the effects of the modernized traffic signal system installed on Reading Road, and second, to investigate the use of the statistical testing equipment in studying the effects of traffic flow on vehicle-operating characteristics.

Capacity and Traffic Volumes

As stated earlier, the revised lane lin-

Figure 8. Reading and Melish after improvement.

ing and modernized signal system increased the capacity at the signalized intersections on Reading Road by amounts up to 30 percent.

Meanwhile, traffic volumes on Reading Road, as throughout Cincinnati and all over the country, have increased tremendously in the years since World War II. The traffic survey reports of 1948 and 1952, published by the Ohio Highway Planning Survey, showed that the average daily vehicle mileage travelled on Reading Road, between Broadway and Paddock Road, increased from 77,450 in 1948 to 85,700 in 1952. Traffic-volume studies by the Division of Traffic Engineering of the City of Cincinnati in 1954 showed the average daily vehicle mileage to exceed 105,000 vehicle-miles per day. Table 1 shows the actual traffic volumes reported in various sections of Reading Road by the three studies. Table 2 shows the mileage figures for the same sections.

TABLE 1

TRAFFIC VOLUMES ON READING ROAD

Section	Traffic Volumes 1948	1952	1954
Broadway to Elsinore	27,190	28,580	31,585
Elsinore to Taft	19,590	21,380	25,652
Taft to Rockdale	17,300	19,420	25,439
Rockdale to Paddock	20,440	23,340	30,061

TABLE 2

VEHICLE-MILEAGE ON READING ROAD

Length	Section	Vehicle-Mileage 1948	1952	1954
0.46 mi.	Broadway to Elsinore	12,500	13,150	14,550
1.18 mi.	Elsinore to Taft	23,100	25,200	30,250
1.20 mi.	Taft to Rockdale	20,800	23,300	30,600
1.03 mi.	Rockdale to Paddock	21,050	24,050	31,000

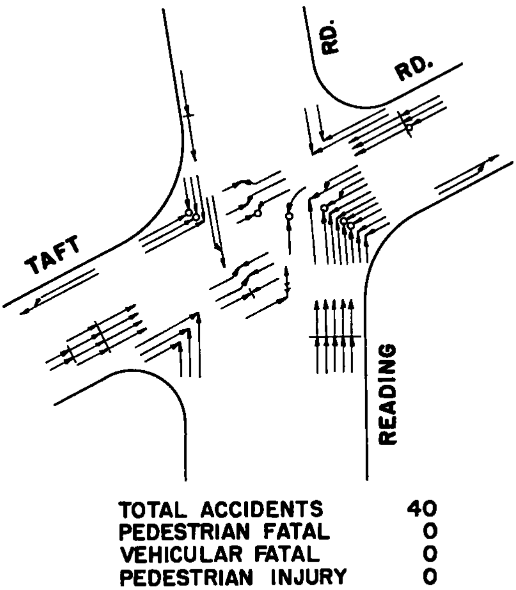
These studies indicate that traffic volumes on Reading Road increased between 10 and 15 percent between 1952 and 1954, and that the average daily traffic volume on most of the section covered in this paper in 1954 was approximately 27,000 vehicles. There are some short portions which carry greater volumes than this due to east-west cross traffic having to jog over Reading Road.

Accident Records

The total number of accidents reported in this section decreased 3.5 percent (from 749 in 1952 to 723 in 1953). However, accidents at locations other than at signalized intersections increased from 301 in 1952 to 369 in 1953, while the accidents at signalized intersections decreased from 448 in 1952 to 354 in 1953, a decrease of 21.0 percent.

The record of personal injuries and fatal accidents showed a similar change. In 1952, there were 96 injury accidents and four fatal accidents (including two at signalized intersections), while in 1953, there were 94 injury accidents and only one fatal accident, that one being midblock. Here again, injury and fatal accidents at other than signalized intersections increased from 36 to 44, while injury and fatal accidents at signalized intersections decreased from 64 to 51, or 20.3 percent.

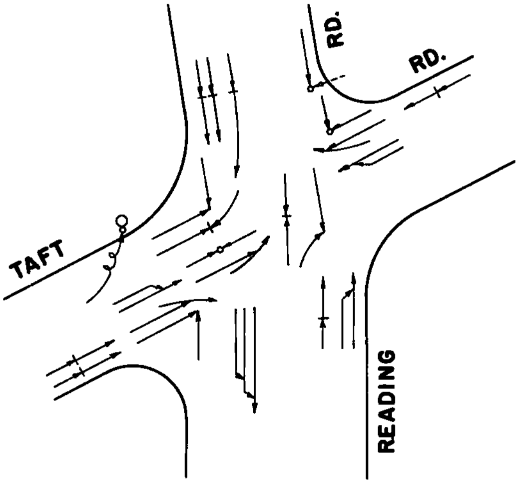
There is no readily apparent reason why the accidents at locations other than signalized intersections on Reading Road should have increased at a rate considerably greater than the city-wide increase for such accidents. However, it is of interest to note that the percentage of accidents occurring at the signalized intersections on Reading Road decreased from 59.8 percent of the total number of accidents in 1952, to 49.0 percent in 1953.



TOTAL ACCIDENTS	40
PEDESTRIAN FATAL	0
VEHICULAR FATAL	0
PEDESTRIAN INJURY	0
VEHICULAR INJURY	8
PROPERTY DAMAGE	32

Figure 9. Reading and Taft collision diagram before signal improvements.

One surprising development was the fact that although the total number of reported accidents at signalized intersections decreased, the number of pedestrian accidents increased from 17 to 23. This increase occurred in spite of the fact that the revised signal system included pedestrian signals for at least one crosswalk across Reading Road at every signalized intersection andat all crosswalks in areas of greater pedestrian activity. Analysis of the individual accidents showed a considerable increase in pedestrian signal violations in 1953 as compared with 1952. However, records for the first 10 months of 1954 showed only one accident caused by a pedestrian violation and the pedestrian accident record appears to show a downward trend, so the difficulty may have been largely due to unfamiliarity of the pedestrians with the new system.

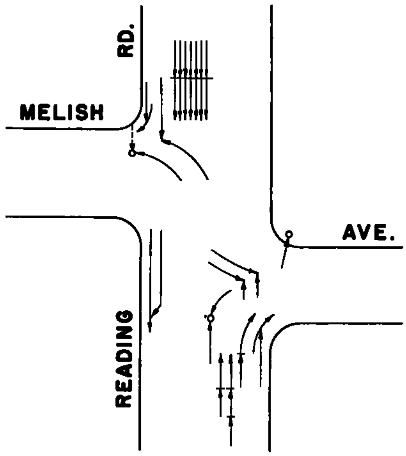


TOTAL ACCIDENTS	23
PEDESTRIAN FATAL	0
VEHICULAR FATAL	0
PEDESTRIAN INJURY	1
VEHICULAR INJURY	3
PROPERTY DAMAGE	19

Figure 10. Reading and Taft collision diagram after signal improvements.

Many of the signalized intersections on Reading Road showed slight changes in their accident records. A few of the locations, however, showed major improvements. Two examples of intersections which showed notable decreases in reported accidents from 1952 to 1953 were: Reading and Wm. H. Taft, from 40 to 23 accidents; and Reading and Melish, from 19 to 6 accidents. Figures 9, 10, 11, and 12 show collision diagrams of these two intersections for 1952 and 1953, or before and after the signal improvements.

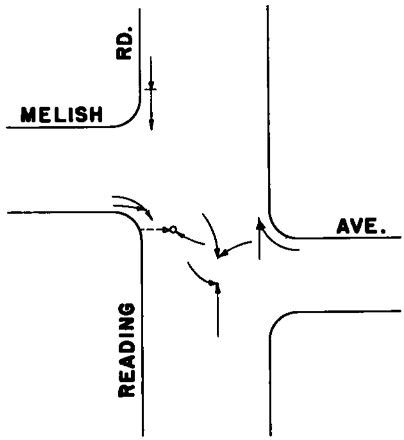
Only two intersections showed major increases in accident occurrence. These were Reading, Dorchester, and Florence,



TOTAL ACCIDENTS	19
PEDESTRIAN FATAL	0
VEHICULAR FATAL	0
PEDESTRIAN INJURY	1
VEHICULAR INJURY	1
PROPERTY DAMAGE	17

Figure 11. Reading and Melish collision diagram before signal improvements.

where accidents increased from 20 to 36, and Reading and Gholson, where accidents increased from 9 to 30. Detailed accident analyses have been made of these two locations to determine the causes for the increases, and corrective measures have been taken. Records for the first 10 months of 1954 indicate that these measures have been beneficial, as the inter-



TOTAL ACCIDENTS	6
PEDESTRIAN FATAL	0
VEHICULAR FATAL	0
PEDESTRIAN INJURY	1
VEHICULAR INJURY	0
PROPERTY DAMAGE	5

Figure 12. Reading and Melish collision diagram after signal improvements.

sections showed 16 and 17 accidents reported, respectively, for the 10-month period. The accident records also indicate that the improvement shown at most of the other signalized intersections from 1952 to 1953 has continued during 1954.

Characteristics of Traffic Flow and Vehicle Operation

Moving-car speed-and-delay studies were made on Reading Road in October, 1952, immediately prior to the installation of the revised signal system, and again in April, 1954, approximately a year after the completion of the revised system. The latter studies also included studies of vehicle operating characteristics which were made with the statistical testing equipment developed by the HRB Committee on Vehicle Characteristics.

The statistical testing equipment was described in detail by Carmichael and Haley (3). These instruments measure speed, fuel consumption, deceleration, engine torque, and throttle opening, and record their data in the form of numbers on banks of electrical counters, which are mounted inside the car. All the instruments except the fuel meter, which registers each 0.001 gallon of gasoline consumed, register once each second. On each unit the total number of counts recorded on all the dials in that unit represents the number of seconds the equipment is in operation. As a check, the equipment also includes a separate counter dial which records the total number of seconds of operation.

Speed-and-delay data on Reading Road obtained by means of the so-called average-car method, in which the driver attempts to maintain a speed typical, in his opinion, of the traffic flow, were used in these studies. We have found a rigid application of the so-called floating-car method, in which the driver attempts to follow the general rule of passing as many vehicles as pass the test car, impractical on congested urban thoroughfares. The computed results of the average-car speed-and-delay studies include average travel time, average operating (or overall) speed, average running speed, and causes, locations, and average durations of delays incurred by the test car.

In combining the speed-and-delay studies and the vehicle-operating-characteristics studies on Reading Road, the two types of tests were made simultaneously. The statistical testing equipment was started at the starting point of the speed-and-delay test, and turned off at the end point of the test. The timer on the testing equipment then gave an excellent check on the elapsed time recorded on the speed-and-delay test, and the data from the two types of tests represented exactly the same traffic and operating conditions.

In both the before and the after studies, the tests were divided into three time groups for a typical day; the morning peak hours, from 7 a.m. to 9 a.m.; the off-peak hours, from 9 a.m. to 4 p.m.; and the evening peak hours from 4 p.m. to 6 p.m. At least eight test runs were made in each group and in each direction. These hourly groupings were based on the peak-hour parking restrictions on Reading Road, and approximately 65 percent of the average daily traffic on Reading Road occurs during this 11-hour period. On Figure 7, showing a typical hourly distribution of traffic volumes at one point on Reading Road, the shaded area indicates the portion of the average daily traffic represented by the 11-hour period.

The studies showed that the average operating time or travel time on Reading Road had decreased and the average operating speed (or overall speed) had increased in both directions and in each time grouping in the 1954 studies as compared with the 1952 studies. The increases in average operating speeds ranged from 0.4 mph. to 2.1 mph. and the decreases in average operating times ranged from 7 seconds to 68 seconds.

The average time saving in 1954 during the 11-hour period covered by the tests was 53.1 seconds per trip between Broadway and Paddock, or about 7.5 percent from the 1952 studies. This represented an average increase in operating speed from 19.5 mph. in the 1952 studies, to 21.1 mph. in the 1954 studies. These average figures are obtained by weighing the average operating times of the tests from each time group, according to the traffic volumes which they represent.

Aside from the definite, but unmeasurable, cost of congestion or lost time in traffic in driver fatigue, nerve strain, and inconvenience, there has been considerable discussion in recent years as to the monetary value of the lost time. It is not the purpose of this paper to enter this discussion, but rather to use a single conservative value of purposes of comparative study on Reading Road. W. R. Bellis (4) stated that assigned values for time lost have ranged from 1 to 4 cents per vehicle-minute, with 2 cents per vehicle-minute, or $1.20 per vehicle-hour, being a probable reasonable figure. A. J. Bone (5) used a value of $1 per hour in his travel-time studies in Boston in 1951. It appears, therefore, that a figure of $1.20 per hour, or 2 cents per minute, would be a conservative figure, and a simple one to use in this study.

Considering an average daily traffic volume of 27,000 vehicles, the traffic volumes represented by the Reading Road studies amounted to approximately 17,500 vehicles daily in 1954. On the basis of a time saving of 53.1 seconds per trip, the studies showed a saving of 257.64 vehicle-hours per day, or 94,035 vehicle-hours per year. At $1.20 per hour, this amounts to a monetary saving of $309.17 per day, or approximately $113,000 per year. These savings represent only those realized by traffic during the 11-hour period represented by these studies. Although no attempt was made to evaluate them, it is highly probable that savings have also been realized by the motorists using Reading Road during other hours of the day.

All of the data obtained from the statistical testing equipment is in the form of numbers, and therefore, can be plotted on

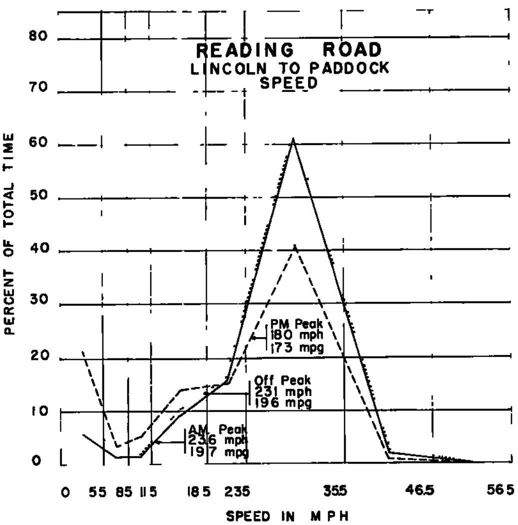


Figure 13. Time versus speed for Reading Road, Lincoln to Paddock.

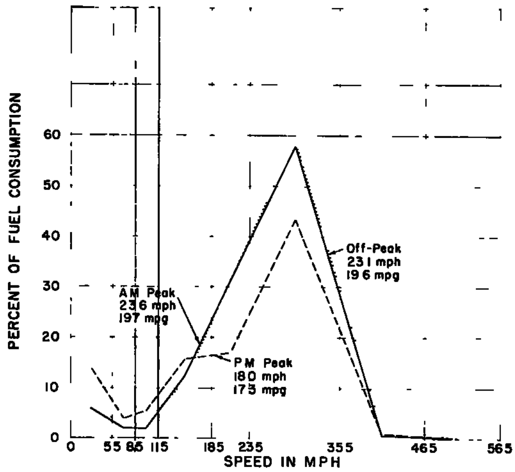


Figure 14. Fuel consumption versus speed for Reading Road, Lincoln to Paddock.

charts or graphs. Figure 13 shows typical curves obtained from the speed meter, and Figure 14 shows typical curves obtained from the fuel meter. The speed meter registers not only the amount of fuel consumed, but the amount used in each speed range. It would seem apparent that on both these charts, the most-satisfactory and most-economical driving conditions are represented by curves showing high peaks in the speed ranges in which vehicles normally cruise under urban conditions, and which show low values in the lower speed ranges which represent reduced speeds and actual delays. This is shown clearly in these two charts; the curves for the evening peak hour tests, in which much-lower operating speeds and fuel economy were recorded, show much less time and fuel consumed at cruising speeds, and much-more time and fuel consumed at very low speeds, than do the other test periods.

Figure 15 shows typical curves of deceleration characteristics, showing the percentage of time spent in various ranges of deceleration rates. In general, it is probably true that the most-satisfactory and most-economical operating conditions would be represented by the curve in the lowest position on the chart, although higher operating speeds may result in the occasional occurrence of higher rates of deceleration.

Figures 16 and 17 show typical charts of the devices measuring engine torque and throttle opening. Although these curves

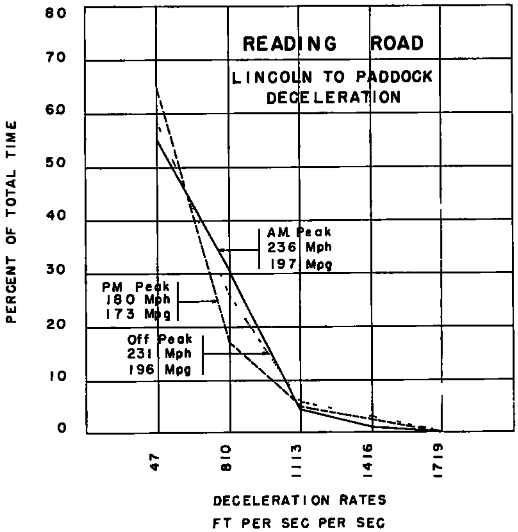


Figure 15. Time versus deceleration for Reading Road, Lincoln to Paddock.

do vary with operating conditions, as yet no definite relationships have been established.

One of the major purposes of this study was to determine whether there are any relationships between the traffic-flow characteristics of a given roadway, as shown by the speed-and-delay studies, and the operating characteristics of a vehicle using the roadway. The results of the studies show that several general relationships do exist.

One of the most-significant of these relationships is that of fuel consumption to

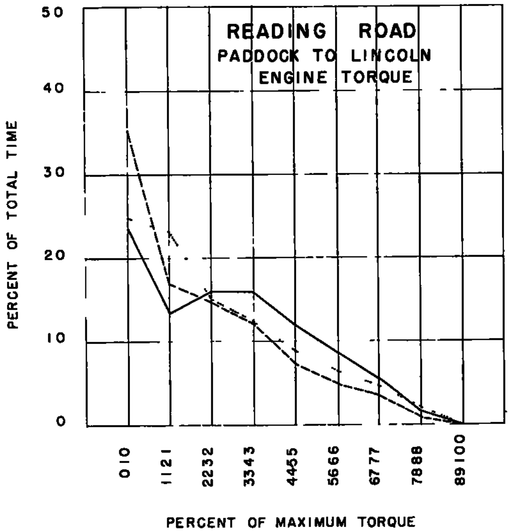


Figure 16. Time versus engine torque for Reading Road, Paddock to Lincoln.

total delay time (time in which the vehicle is at a full stop in traffic) on each test run. For a given test vehicle, operating on a given roadway, and within a normal range of urban operating speeds, the fuel consumption increases directly as the total delay time. Figure 18 illustrates this relationship on one section of Reading Road. On the Reading Road studies, in both 1952 and 1954, a 1952 Ford 6 two-door sedan was used. During the 1954 studies it was found that on Reading Road this vehicle was using between 0.0165 gal. and 0.020 gal. additional fuel for each 60 seconds of delay in traffic. By using this information it was possible to arrive at approximate fuel-consumption figures for the 1952 studies when the statistical testing equipment was not available.

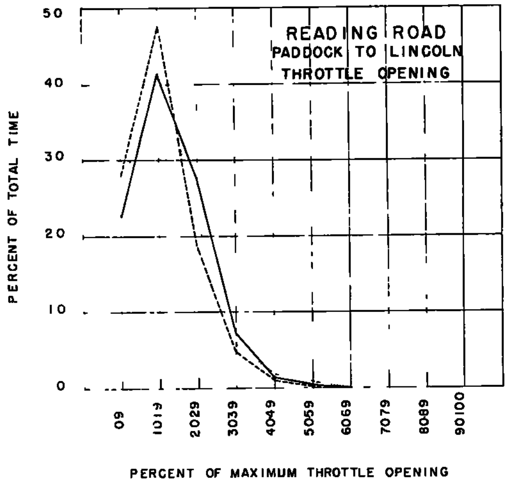


Figure 17. Time versus throttle opening for Reading Road, Paddock to Lincoln.

Figures are frequently given for a specific decrease in fuel economy with a given number of stops per mile. These studies did not show any such definite relationship, except that, in general, when there are a greater number of stops on a test run there is more total delay time which, in turn, affects fuel economy.

The studies showed a general relationship between the average operating speed, and the fuel economy. However, individual tests showed large variations in this relationship, as shown in Figure 19, and it appears likely that in the range of speeds encountered in urban driving, the relationship is due more to the effects of the delay time which affects the average operating speed rather than the speed itself.

Other general relationships which the studies showed are inverse ones between the average operating speed and fuel economy, and the amount of braking. Sufficient data were not obtained to establish numerical values for these relationships, but it appears definite that an increase in operating speed and fuel economy is usually accompanied by a decrease in the time spent in braking. Figure 20 illustrates this for one section of Reading Road, showing the average time per mile spent in braking the vehicle (braking is assumed to be deceleration at a rate greater than 4 ft. per sec. per sec.), during the different time groups. In this example, during the evening peak hours, when the operating speed was 5.1 to 5.6 mph. slower, and the fuel economy 2.3 to 2.4 mpg. less than during the morning peak and off-peak hours, the time spent in braking was 45 percent greater. This is an important relationship because braking is an important factor in vehicle-maintenance costs of all types, affecting tire wear, brake life, and wear and tear on nearly all mechanical parts of the vehicle.

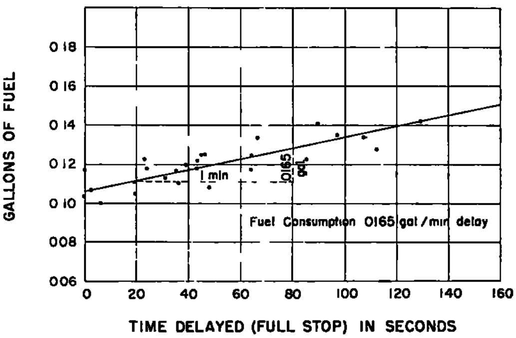


Figure 18. Fuel consumption versus delay for Reading Road, Paddock to Lincoln.

The relationships which these studies showed to exist indicate that statistical equipment of this type can be of great value in studying the effects of traffic flow on vehicle-operating characteristics. This type of study can be used in analyzing the efficiency of and effects of changes in traffic-control systems, in route evaluation, in comparisons of traffic flow on different thoroughfares at different times, under different traffic volume conditions, or other variables. A particular advantage is the fact that in the measurement of fuel consumption, a direct measurement is made of one of the largest single components in vehicle-operating expense. This permits a simpler analysis of the economic benefits or detriments of changes in traffic conditions than heretofore possible.

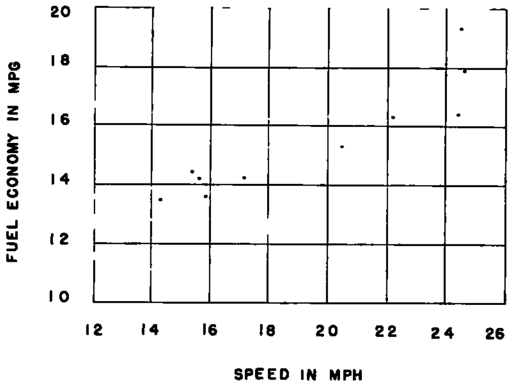


Figure 19. Fuel economy versus operating speed for Reading Road, Paddock to Lincoln.

Since most studies of this type are comparisons of two (or more) different operating conditions, it is obviously desirable to use the equipment for all portions of the studies, since the comparisons of operating characteristics can then be made directly. However, by means of the relationships between the traffic flow, or speed-and-delay data, and the operating characteristics, it is possible when the equipment is available for only a portion of the studies to obtain estimated data for the remainder of the studies, as was done for the 1952 Reading Road studies. It is possible that further research with equipment of this type may develop these studies to sufficient accuracy to permit estimates to be made of fuel consumption and

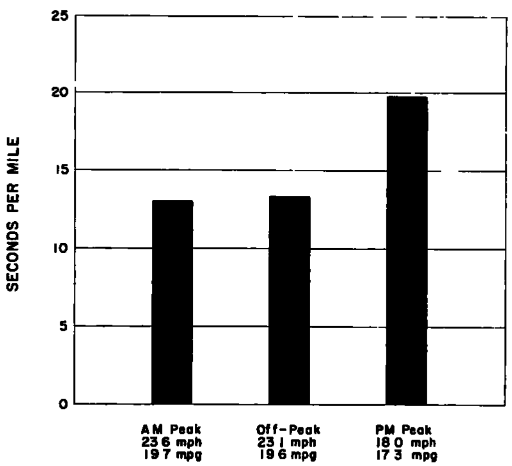


Figure 20. Braking time for Reading Road, Lincoln to Paddock.

changes in fuel consumption due to changes in traffic flow conditions, without the actual use of the equipment.

The relationship between delay time and extra fuel consumption, as shown in the 1954 studies using the statistical testing equipment, was used to estimate the change in fuel consumption per vehicle on Reading Road as compared to 1952. The studies showed that despite the increase in traffic volumes since 1952, substantial savings in fuel were realized by the motorists using the thoroughfare in 1954. The savings per individual vehicle were quite small (generally less than 0.025 gallon per trip between Broadway and Paddock), but the 17,500 vehicles using Reading Road during the 7-a.m.-to-6-p.m. test period on an average day used at least 180.8 gallons per day less fuel than would have been used by the same number of vehicles operating under 1952 traffic conditions.

This is believed to be a conservative figure because (1) the 1952 Ford 6 test car is believed to have at least average or better economy; (2) no consideration was given to extra fuel used by the 15 percent commercial traffic (trucks and buses) on Reading Road; (3) it is probable that savings in fuel were also realized by traffic using the thoroughfare during hours outside the 11-hour test period.

Using an estimated average gasoline price for Greater Cincinnati of 28 cents per gallon, the 180.8 gallons of gasoline per day would be a saving of $50.62 per day or on a yearly basis, a saving of approximately $18,500 per year.

SUMMARY

The first portion of this paper described the traffic control conditions on Reading Road prior to 1952 and the complete remodeling and modernization of the traffic signal system which took place in the winter of 1952-1953. The second portion of the paper described studies of statistics, speed-and-delay (or traffic-flow) characteristics, and vehicle-operating characteristics which were conducted in October 1952 and in April 1954.

These studies had as their objectives, first, to determine the effects on traffic operation of a modernized traffic-signal system which was installed between the time of the two studies; and second, to investigate the use of the statistical testing equipment in measuring the effects of traffic-flow characteristics on vehicle-operating characteristics. From the studies the following conclusions were reached.

1. Although traffic volumes on Reading Road between Broadway and Paddock has increased from 10 to 15 percent in 1954 as compared with 1952, traffic-flow characteristics have improved due to revisions in the traffic control system, so as to provide substantial savings to motorists using Reading Road in the form of a reduction in losses due to accidents, reduced fuel consumption, and time saved due to higher average operating speeds and less delay time in traffic. The total savings, on a monetary basis, amounted to at least $140,000 per year. The original cost of the modernized traffic-control system was approximately $85,000, so the savings in one year alone are greater than the first cost of the modernized system.

2. Statistical testing equipment, of the type developed by the Committee on Vehicle Characteristics of the Highway Research Board, should be extremely valuable in the analysis of the effects of traffic-flow characteristics on vehicle operating characteristics. The value of the equipment lies both in its use in making direct comparisons of vehicle operating characteristics under different traffic flow conditions and in its use in discovering general relationships between traffic flow conditions and vehicle operating characteristics.

City street capacity is increasing slowly, if at all, but traffic volumes have been growing tremendously. It has become mandatory that emphasis must be placed on positive traffic control that will, in every possible way, assist the movement of traffic. Adequate traffic flow information and proper signalization are only steps in this direction, but they should be exploited to the limit on existing facilities.

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Economics of Operation on Limited-Access Highways

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● MANY miles of the highway system of the United States are inadequate for present and future traffic needs, not necessarily because these highways are structurally deficient but primarily because they are geometrically and functionally inadequate. This geometric or functional inadequacy is caused by intersectional, medial, internal, and marginal interferences which contribute to an increase in highway accidents, and increase in the operating cost of motor vehicles, an increase in travel time, a reduction in highway capacity, and a decrease in the value of the highway investment.

In general, highways serve through traffic, provide access to abutting property, facilitate the needs of the general public, and contribute to the needs of national defense. These functions often create geometric inadequacies through conflict of use. For example, traffic on a highway that serves abutting property has the characteristics of low to moderate speed and of frequent turning movements. These do not blend with the characteristics of through traffic of high speeds and few turning movements. Therefore, in this era of specialization, it may be economical to construct separate highways for specific types of traffic.

Forty states have attempted to minimize highway interference by constructing sections of highways for which the prime purpose is to serve through traffic. These sections are often designated as freeways, expressways, parkways, limited-access highways, or controlled-access highways. A limited-access highway or a controlled-access highway is a "highway or street especially designed for through traffic, and over, from, or to which owners or occupants of abutting land or other persons have no right or easement or only a restricted right or easement of access, light, air, or view by reason of the fact that their property abuts upon such limited access facility or for any other reason" (1).

The design of limited-access highways varies from state to state. Some general features include: (1) restriction of access, (2) median strips, (3) multi-lanes, (4) wide right-of-way, (5) strict control of vertical and horizontal alignment, (6) land service roads, (7) elimination of highway intersections at grade, (8) elimination of railroad crossings at grade, and (9) prohibition of billboards and commercial signs (1).

Early English law provided for right of access to public roads to be enjoyed by all, and the term "highway" referred to a route to which the public at large had the right of access (2). The transition to limited-access highways has been deterred because of the historical background of public access to all highways. In recent years, however, there has been a tendency to shift from full public access to restricted access on certain portions of the present highway system.

Studies have been made of certain limited-access highways, of the legal aspects of limited-access highways, and of certain design characteristics and are reported in the literature. Little study, however, has been made of the economics of operation on limited-access highways.

PURPOSE

The purpose of this study is to evaluate certain benefits of several limited-access highways by making a comparison of some of the effects of limited and non-limited-access highways.