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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.

COLLECTION OF DATA

The case-study approach was used in the comparison study, and each study included two abutting or nearby sections of highway which were similar, except for access control. By using this approach, the assumption was made that had the access to the limited-access highway not been controlled, the characteristics (sav-

Form PR-761

ACCIDENT EXPERIENCE RELATED TO CONTROL OF ACCESS

STATE: OHIO

CONTROL OF ACCESS (AASHO definition)	Controlled Access Route (Check one: X Partial)	Comparable Route (Check one: X None)
Section of highway and/or route number	U.S. Rt. 40, Clark County	US Rt. 40, Franklin County
Termini of study	From Springfield to Vienna	Madison County Line to Columbus
Length - miles (nearest .01 mile)	7.4	7.5
Specify rural or urban area	Rural	Rural
Specify type of area as business, residential, industrial, or other	Agricultural and Residential	Industrial and Agricultural
Flat, rolling or mountainous	Rolling	Flat
Number of through traffic lanes	4	4
Number and width of roadways	2 - 24'	2-24'
Width of median	30'	10'-30'
Width of shoulder or parking lane	10'	10'
Annual average daily traffic	7600	11000
Time period	1951	1951
Annual vehicle-miles	20.5 Million	30.2 Million
Percent commercial	18%	19%
Speed limit	50 m.p.h.	50 m.p.h.
Average running speed	50 m.p.h.	50 m.p.h.
Number of intersections signalized	0	1
Number of driveways to roadside businesses	34	70

Figure 1. Route Comparison Form.

VEHICLE OPERATING CHARACTERISTICS
BUREAU OF PUBLIC ROADS TESTS

Employing equipment developed by HRB Committee on Vehicle Characteristics

Test No. 1-N Date June 10, 1954

Route U S Rt 40, Clark County, Springfield to Vienna

Remarks Ohio, Case Study No. 10, Controlled Access

SPEED

Counter No.	1	2	3	4	5	6	7	8	9	10	Total counts
Speed, MPH	0-5	6-8	9-11	12-18	19-23	24-35	36-46	47-56	57-68	69 & up	
Finish	038	125	429	753	003	555	28197	92870	01602	469	
Start	038	125	429	753	003	551	28185	92020	01402	469	
Difference	0	0	0	0	0	4	12	258	200	0	474
% Total											

GASOLINE CONSUMPTION

Counter No.	1	2	3	4	5	6	7	8	9	10	Total counts
Speed, MPH	0-5	6-8	9-11	12-18	19-23	24-35	36-46	47-56	57-68	69 & up	
Finish	763	415	643	515	924	343	1551	56058	10731	101	
Start	763	415	643	515	924	342	1551	55843	10555	101	
Difference	0	0	0	0	0	1	0	215	182	0	404
% Total											

BRAKING

Counter No.	1	2	3	4	5	6	7	8	9	10	Total counts
Deceleration	0-1	2-7	8-10	11-14	15-16	17-19	20-23	24-26	27-29	30 & up	
Finish	15523	69957	009	477	123	443	447	103	668	107	
Start	15053	69953	009	477	123	443	447	103	668	101	
Difference	470	4	0	0	0	0	0	0	0	0	474
% Total											

ENGINE TORQUE

Counter No.	1	2	3	4	5	6	7	8	9	10	Total counts
% Torque	Coast	0-10	11-21	22-32	33-43	44-55	56-66	67-77	78-88	89-100	
Finish	300	435	457	648	364	428	136	979	383	270	
Start	300	405	415	398	239	403	134	979	383	270	
Difference	0	30	42	250	125	25	2	0	0	0	474
% Total											

THROTTLE OPENING

Counter No.	1	2	3	4	5	6	7	8	9	10	Total counts
% Opening	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-100	
Finish	981	440	207	621	001	343	667	150	491	326	
Start	971	415	167	408	882	313	650	135	486	320	
Difference	10	25	40	213	114	30	17	15	5	0	474
% Total											

ODOMETER

Finish	406 28
Start	398 88
Trip Mileage	7.40

CLOCK

Finish	10 17 AM
Start	10 09 AM
Trip Time	8

MASTER COUNTER

Finish	51741
Start	51273
Total Counts	474

Trip Average Speed 54.5 MPH

Trip Average Gas Consumption 19.3 MPG

Figure 2. Field Data Sheet.

ings of time, operating costs, and safety) of this route would be similar to the uncontrolled access section. Twelve case studies were included in the study.

The studies were selected to include examples of two-lane and four-lane highways in urban and rural areas, in flat and rolling topography, with a great variance in volume of traffic, with full and partial control, and from various geographical areas of the United States. The routes were selected with the aid of several state highway departments, the Bureau of Public Roads, and by field inspection. A form developed by the Bureau of Public Roads was used in selecting test sections and is shown in Figure 1. A typical set of data is shown in this figure.

The test vehicle was a 1952 two-door Pontiac with a standard gearshift, and the recording apparatus was installed on the test vehicle at General Motors Proving

Grounds in June 1954. The recording apparatus was used during June and July and returned to the proving grounds in August 1954. This apparatus was developed in 1950 under the auspices of the Highway Research Board Committee on Vehicle Characteristics in cooperation with the automotive industry. A report describing this equipment was presented at the thirtieth annual meeting of the Highway Research Board (3). The recording apparatus has 51 counters which automatically record the recording the field data of this study. At the start of each run the 51 counters were read and the values recorded in their appropriate spaces in the form, and at the end of each run the counters were again read and the values recorded in their appropriate spaces. The differences between the start and finish readings were the results of that particular test run. A typical set of values is shown in this figure. The unit of measurement for speed, braking, engine torque, and throttle opening was

Time Period Covered January 1 1954 to December 31 1954 — Page 2 of 2 Pages

ACCIDENT RECORD	Controlled Access Route — Manner of accident							Comparable Route — Manner of accident						
	Rear end or side-swipe 1	Head on or side-swipe 2	Angle collision	Collision with pedestrian	Other collision	Not collision	Total number of accidents	Rear end or side-swipe 1	Head on or side-swipe 2	Angle collision	Collision with pedestrian	Other collision	Not collision	Total number of accidents
All accidents	8	3	1	0	19	14	45	32	1	6	1	33	10	83
Fatal accidents	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Injury accidents	3	0	1	0	6	7	17	10	0	3	1	11	7	32
Property damage accidents	5	3	0	0	13	7	28	22	0	3	0	22	3	50
Persons killed	0	0	0	0	0	0	0	0	2	0	0	0	0	2
[illegible]	5	0	2	0	15	12	34	14	2	4	1	15	9	45
[illegible]							220							275
[illegible]							0							6.3

Figure 3. Accident Reporting Form.

important operating characteristics of the vehicle that might be affected by highway design. These operating characteristics were speed (used to evaluate savings in time), gasoline consumption, deceleration, and acceleration (used to evaluate operating costs).

A special form developed by the Bureau of Public Roads (Figure 2) was used for seconds, while for gasoline consumption the unit of measurement was one thousandths of a gallon of gasoline.

There were between six and ten test runs on each section of the controlled and uncontrolled highways, depending upon the length of the section and consistency of results. Certain statistical tests were made of the field data to determine the

significant differences between the controlled-access sections of each study. Additional statistical tests were made to determine whether or not degree of urbanization and type of access control significantly affected operating characteristics on the highways.

TABLE 1

COMPARATIVE ROUTES IN LIMITED ACCESS FIELD STUDY

STUDY NUMBER	STATE	ROUTE	LOCATION	ACCESS CONTROL	GEOMETRIC DESIGN
1	Connecticut	Connecticut 15	NE of Hartford	Full	4-Lane Divided
	Connecticut	Connecticut 15	SW of Hartford	None	4-Lane "
2	Georgia	Atlanta Expressway	In Atlanta	Full	6-Lane "
	Georgia	Atlanta Bypass	In Atlanta	None	6-Lane "
3	Georgia	US 41	North of Marietta	Partial	4-Lane "
	Georgia	US 41	Around Marietta	None	4-Lane "
4	Indiana	Tri-State Expressway	In Hammond	Full	4-Lane "
	Indiana	US 20	In Gary	None	4-Lane "
5	Louisiana	US 71	Alexandria Bypass	Partial	4-Lane "
	Louisiana	US 190	Baton Rouge Bypass	None	4-Lane "
6	Maine	US 1	Freeport Cutoff	Partial	2-Lane
	Maine	US 201	North of Augusta	None	2-Lane
7	Massachusetts	Massachusetts 128	Around Boston	Full	4-Lane Divided
	Massachusetts	US 9	West of Boston	None	4-Lane "
8	Massachusetts	Massachusetts 128	Around Boston	Partial	4-Lane "
	Massachusetts	US 1	North of Boston	None	6-Lane "
9	Michigan	Michigan 112	West of Detroit	Full	4-Lane "
	Michigan	US 112	West of Detroit	None	4-Lane "
10	Ohio	US 40	East of Springfield	Partial	4-Lane "
	Ohio	US 40	West of Columbus	None	4-Lane "
11	Ohio	US 22	Around Clarksville	Partial	2-Lane
	Ohio	US 22	North of Clarksville	None	2-Lane
12	Rhode Island	Rhode Island 147	So. of Uncontrolled Section	Full	4-Lane Divided
	Rhode Island	Rhode Island 147	South of Woonsocket	None	4-Lane "

In addition to the operating characteristics, accident reports were obtained from the state highway departments for each test section in order to evaluate the differences in safety. The Bureau of Public Roads had previously requested similar information; therefore, the information received by the Bureau is used in this report. The accident reporting form is presented in Figure 3, and a typical set of data is shown in this figure. The results of similar studies were obtained as well as accident experience on toll roads in order to provide a comparison with results of the twelve case studies. The twelve case studies are listed in Table 1.

RESULTS OF THE CASE STUDIES

The data collected in the individual case studies are compared with the data of similar case studies in the following sections, and the data from all the case studies are then combined in order to determine the overall effect of control of access to the road user. The data are evaluated on the basis of travel time, operating costs, and highway safety.

Travel Time

The average speed on the controlled- and uncontrolled-access sections for the 12 case studies is shown in Table 2. The difference in speed between the controlled and uncontrolled access sections for each case study is also given. The speed on the controlled access sections varied from 41.7 mph. to 55.9 mph., with an average for the 12 studies of 48.2 mph. The speed on the uncontrolled access sections varied from 18.5 mph. to 48.9 mph. with an average for the 12 case studies of 38.3 mph. The difference in speed in a particular case study varied from 2.1 mph. in Study 8, to 23.3mph. in Study 2, and the average difference of the studies was 9.9 mph. The average time required to travel a mile on each test section and the savings in time for each case study are also given in Table 2.

The average speeds for the 12 case studies are summarized in Table 3 by type of access control and degree of urbanization. The data in this figure may not be adapted to all highways, because of the relatively small number of test sections. However, the table does give an indication of the approximate average speeds under various highway conditions. The number in parenthesis indicates the number of test sections included in the average speed.

Average speeds on the fully controlled-access highways appear to be only slightly affected by degree of urbanization, whereas average speeds on partially controlled and uncontrolled sections appear to decrease with increased urbanization. In rural areas there appears to be little difference between the average speeds on fully and partially controlled-access highways,

whereas in suburban, and probably more so in urban areas, the average speed on fully controlled-access sections is greater than on partially controlled sections. The difference in average speeds between full-controlled and uncontrolled sections in rural, suburban, and urban areas is 2.5, 10.3, and 20.9 mph., respectively. Assuming these speed differences at the average speeds, there would be a time savings of 0.07, 0.32, and 1.00 minutes per vehicle-mile of travel. In other words, it takes 8, 26, and 79 percent more time, respectively, to travel a mile on the uncontrolled-access highway than on the controlled-access highway.

degree of access control. Assuming these speed differences at the average speeds, there would be a time savings of 0.13 and 0.12 minutes per vehicle-mile of travel. Again using the value of time indicated in the previous paragraph, the monetary time savings on partially controlled access highways in rural and suburban areas would be 0.4 and 0.3 cents per vehicle-mile. If the access to a highway carrying 10,000 vehicles per day was partially controlled, the monetary savings per mile would amount to $13,200 and $12,300 per year.

The case studies not only point out that the average speed on the controlled-access highways is higher, but also that the speed

TABLE 2

AVERAGE SPEED IN MILES PER HOUR ON THE CONTROLLED AND UNCONTROLLED ACCESS SECTIONS FOR THE TWELVE CASE STUDIES

Case Study No.	Controlled Section	Uncontrolled Section	Difference in Speed	Savings in Time (minutes)
1	49.2 (1.22)*	41.3 (1.45)	7.9	0.23
2	41.7 (1.44)	18.5 (3.24)	23.2	1.80
3	45.2 (1.33)	36.6 (1.64)	8.6	0.31
4	53.0 (1.13)	34.2 (1.75)	18.8	0.62
5	42.3 (1.42)	37.4 (1.60)	4.9	0.18
6	50.4 (1.19)	42.7 (1.40)	7.7	0.21
7	48.4 (1.24)	36.7 (1.63)	11.7	0.39
8	41.8 (1.44)	39.7 (1.51)	2.1	0.07
9	49.2 (1.22)	38.8 (1.54)	10.4	0.32
10	54.3 (1.10)	41.7 (1.44)	12.6	0.34
11	55.9 (1.07)	48.9 (1.22)	7.0	0.15
12	46.4 (1.29)	43.2 (1.39)	3.2	0.10
Average	48.2 (1.25)	38.3 (1.57)	9.9	0.32

*Numbers in parantheses are the average time in minutes required to travel one mile on that particular section of highway.

If the value of time for passenger cars and commercial vehicles is taken as $1.35 per hour (2¼ cents per minute) and $3 per hour (5 cents per minute) for a highway carrying 80 percent passenger cars and 20 percent commercial vehicles, the composite value of time would be $1.68 per hour (2.8 cents per minute). The monetary time savings on fully controlled-access highways in rural, suburban, and urban areas would be 0.2 cents, 0.9 cents, and 2.8 cents per vehicle-mile. As a further example, if the access to a highway carrying 10,000 vehicles per day were fully controlled, the monetary time savings per mile would amount to $7,200; $32,800; and $102,000 per year.

The difference in average speeds between partially controlled and uncontrolled sections in rural and suburban areas is 4.6 and 3.4 mph., respectively. The average speed in urban areas on partially controlled-access highways would probably have a great variation, depending upon the

is more uniform over the length of the route. Figure 4 presents the average speed characteristics of the combined 12 studies, and indicates that 90 percent of the travel on the 12 controlled-access sections was at speeds between 36 and 56 mph., while only 74 percent of the travel on the 12 uncontrolled-access sections was between the same speeds. Ten percent of the travel on the uncontrolled access sections was at speeds less than 24 mph.

The uniform speed on the controlled-access highways as compared with the uncontrolled-access highways is important, for uniform speeds generally result in increased safety, increased capacity, and reduced operating costs.

Operating Costs

Gasoline consumption and utilization of brakes were two of the components of operating costs which were obtained for the case studies. Since these are not the only components of operating costs, the overall

operating costs could not be evaluated on a monetary basis.

The average gasoline consumption on the controlled- and uncontrolled-access sections is shown in Table 4. The difference in gasoline consumption between the sections is also given. Although the gasoline consumption on some of the controlled-access highways was better (more miles per gallon) than on comparative uncontrolled sections, nevertheless the combined studies indicated that there was not an appreciable difference in gasoline consumption. In fact, 19.1 mpg. was the average gasoline consumption on the uncontrolled sections as compared with 18.9 mpg. on the controlled sections. This indicates that loss in gasoline mileage due to marginal and intersectional friction may often be less than gasoline mileage lost due to travel at higher speeds. This points out again that time must be of value to motorists, for they will attempt to save time on the controlled sections, even at the expense of increased gasoline consumption.

TABLE 3

AVERAGE SPEED IN MILES PER HOUR BY TYPE OF ACCESS CONTROL AND DEGREE OF URBANIZATION FOR THE TWELVE CASE STUDIES

	Urban	Suburban	Rural
Full Control	47.3 (2)*	49.2 (2)	47.4 (2)
Partial Control	-	42.3 (1)	49.5 (5)
No Control	26.4 (2)	38.9 (7)	44.9 (3)

* Numbers in parentheses indicate the number of test sections included in the average speeds.

The average gasoline consumption is summarized in Table 5 by type of access control and by degree of urbanization. As pointed out in the discussion of average speeds, the size of the sample is rather small, and there appears to be certain relationships that do not seem plausible at first glance. Further investigation revealed that average speed appeared to have as great an influence on gasoline consumption as either access control or degree of urbanization.

The relationship between gasoline consumption and average speed is plotted on Figure 5. The points on the curve were established by averaging the average speeds and their gasoline consumption on the test sections in groups of 30-35, 35-40, 40-45, 45-50, and 50-56 mph. The curve established with the same equipment on a 1951 Pontiac by A. J. Bone (4) is superimposed on the graph. Some of the points on Bone's curve, particularly the points at the higher speeds, were determined by test runs on the test sections given in Study 7 of this report. The other points on Bone's curve were obtained from routes different from those selected by this study and the test vehicles were not the same. This would have some bearing on the differences in the two studies in relationship to gasoline consumption and speed.

The graph indicates that gasoline consumption is dependent upon the speed the vehicle operator desires to drive. If the vehicle operator would drive at the speed of optimum gasoline consumption (30 to 40 mph.) on the average controlled-access sections, the gasoline consumption of the test vehicle would be approximately 20.1 mpg. This choice of speed on the controlled-access highway is the drivers' and generally not dependent upon road and traffic conditions, which do determine the speed on the uncontrolled sections.

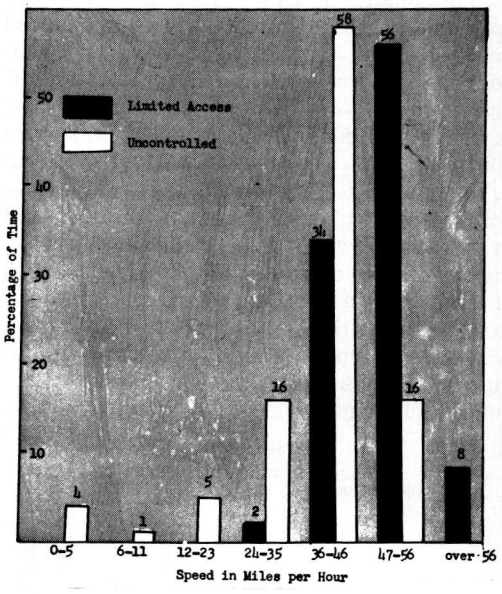

Figure 4. Average Speed Distribution of the Twelve Case Studies.

The conclusion from the gasoline-consumption data is that gasoline consumption could be lower on the controlled-access sections if the vehicle operator would drive 30 to 40 mph. Time savings on the controlled-access sections, of course, would then be reduced. However, under existing driver behavior, gasoline consumption on the rural and suburban sections of highway is not appreciably different. On urban sections of highway, the decrease in miles per

gallon of gasoline consumption is due to greater congestion and traffic friction, rather than the decrease due to above optimum speeds. This results in better gasoline consumption on the controlled-access sections.

on rural, suburban, and urban areas, respectively. Applying the above values to a highway carrying 10,000 vehicles per day, the reduction in length of time of brake application would amount to 172, 1,720 and 5,820 hours per mile per year.

TABLE 4

AVERAGE GASOLINE CONSUMPTION ON THE CONTROLLED AND UNCONTROLLED ACCESS SECTIONS FOR THE TWELVE CASE STUDIES

Case Study No.	Gasoline Consumption (miles per gallon) Controlled Sections	Uncontrolled Sections	Difference
1	19.2	19.0	0.2
2	20.7	16.5	4.2
3	20.3	20.2	0.1
4	17.0	18.9	-1.9
5	19.8	21.4	-1.6
6	17.4	19.0	-1.6
7	19.3	19.3	0.0
8	19.2	19.8	-0.6
9	19.7	20.8	-1.1
10	18.3	18.7	-0.4
11	17.3	17.0	0.3
12	18.3	19.1	-0.8
Average	18.9	19.1	-0.2

The length of time (seconds) of brake application per mile of travel is presented in Table 6 by type of access control and degree or urbanization. Application of brake on full-controlled-access highways is rarely needed, whereas brakes are applied on the average of 0.21, 1.70, and 5.74 seconds for each mile of travel on uncontrolled sections in rural, suburban, and urban areas respectively. In rural areas, the brakes were applied for a greater length of time on partially controlled-access sections than for the fully controlled or uncontrolled sections. This is probably due to higher speeds with an occasional unexpected sudden slowing down or stopping.

TABLE 5

AVERAGE GASOLINE CONSUMPTION BY TYPE OF ACCESS CONTROL AND DEGREE OF URBANIZATION

	Urban	Suburban	Rural
Full Control	18.8 (2)*	19.4 (2)	18.8 (2)
Partial Control	-	19.8 (1)	18.5 (5)
No Control	17.7 (2)	19.9 (7)	18.4 (3)

* Numbers in parentheses indicate the number of test sections included in the average gasoline consumption.

The utilization of the brakes is reduced when access is fully controlled by 0.17, 1.70 and 5.74 seconds per mile of travel

TABLE 6

AVERAGE LENGTH OF TIME OF BRAKE APPLICATION PER MILE BY TYPE OF ACCESS CONTROL AND DEGREE OF URBANIZATION FOR THE TWELVE CASE STUDIES

	Urban	Suburban	Rural
Full Control	0.00 (2)*	0.00 (2)	0.04 (2)
Partial Control	-	0.00 (1)	0.42 (5)
No Control	5.74 (2)	1.70 (7)	0.21 (3)

* The unit of duration of brake application is seconds per mile and the numbers in parentheses indicate the number of test sections included in the average brake application.

Highway Safety (Twelve Case Studies)

The accident and fatality rates are shown in Table 7. Most of these rates cover only a one-year period. The average accident rates for the controlled-and uncontrolled-access sections were 136 and 327 accidents per 100 million vehicle-miles, respectively. The average fatality

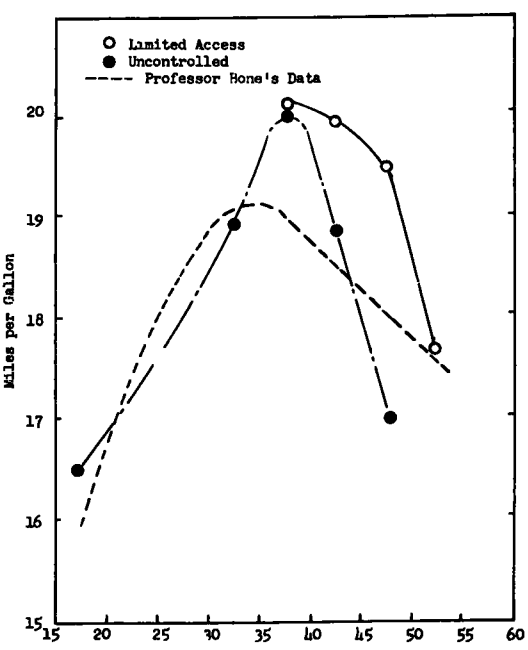

Figure 5. Gasoline Consumption Related to Speed.

rate for the controlled and uncontrolled sections was 3.2 and 7.4 fatalities per 100 million vehicle-miles, respectively. There were 2.4 times as many accidents per 100 million vehicle-miles on the uncontrolled sections as the controlled sections and 2.3 times as many fatalities per 100 million vehicle-miles. If the above accident and fatality rates were long-run averages for all roads of the two types, controlling the access on a 6.5 mile stretch of highway carrying 10,000 vehicles per day would be expected to save one life and reduce the number of accidents by 45 each year. However, each of the rates given in Table 7 is subject to year-to-year variation. The table gives an estimate of the standard error for each observed accident and fatality rate. It is practically certain that corresponding rates over a longer period of time would fall within two standard errors of the rates reported in Table 7.

TABLE 7

ACCIDENT AND FATALITY RATES ON THE CONTROLLED AND UNCONTROLLED ACCESS SECTIONS FOR THE TWELVE CASE STUDIES

Case Study No.	Data for Year	Accident Rate				Fatality Rate			
		Controlled		Uncontrolled		Controlled		Uncontrolled	
		Rate*	ESE**	Rate	ESE	Rate	ESE	Rate	ESE
1	1946-52	150	15	300	16	0.9	1.1	8.1	2.7
2	1953	151	26	435	38	4.4	2.5	0.0	-
3	1953	165	24	333	25	3.4	3.4	0.0	-
4	1953	465	68	457	57	20.0	14.2	7.1	7.1
5	1953	320	39	648	55	0.0	-	6.2	5.4
6	1953	176	44	133	42	0.0	-	0.0	-
7	1952	46	5	364	18	1.1	.8	2.1	1.5
8	1952	278	31	428	28	3.4	3.4	3.6	2.5
9	1952	115	11	383	29	6.7	2.7	15.0	5.7
10	1951-52	232	33	273	30	2.5	3.5	9.8	5.7
11	1951-52	156	46	450	125	3.2	6.6	0.0	-
12	1953	103	33	167	37	10.3	10.2	0.0	-
Average***		136		327		3.2		7.4	

* The units of the values under rate represent accidents or fatalities per 100 million vehicle-miles.
** ESE = Estimated Standard Error.
*** Weighted on basis of vehicle-miles.

These rates serve as the basis for all comparisons and factual statements which are made in the remainder of this paper, and so any conclusions are relative to only the roads which were in the case studies and the years for which the accident data was obtained.

Table 8 summarizes the accident and fatality rates by type of access control and degree of urbanization. The accident rate decreases with an increase in control of access with the exception of partially controlled highways in rural areas. The accident rate for the uncontrolled access sections in rural areas for this study appears to be low when compared with data collected by the Bureau of Public Roads, which will be presented later in this report.

The small number of test sections included in the case studies to measure relatively small occurrences, such as highway fatalities, is insufficient to draw any definite conclusions as to the effect of access control and degree of urbanization. Later in this section additional data will be presented to determine the relationship of fatalities to type of access control and degree of urbanization.

Even on the best-designed, full-controlled-access highways—where marginal, intersectional, medial, and internal frictions are almost eliminated—accidents and loss of lives continue to occur. The question is obviously what kind of accidents and fatalities still occur and what causes them. In order to make this analysis, accidents on the test sections were combined as related to access control. Then the accidents and fatalities were summarized on the basis of 100 million vehicle-miles, as shown in Table 9. Sixty percent of the accidents on the fully controlled sections were of the rear-end or side-swipe type, 20 percent of the noncollision type, and 12 percent of the total were other collision. Sixty percent of the fatalities on the full-controlled-access sections occurred in rear-end or side-swipe accidents.

Another approach to the accident problem is to determine the percent difference of accidents as access is controlled and a summary of this analysis is shown in

Table 10. The greatest difference in accidents and fatalities on partially and fully controlled sections is for angle collisions and collisions with pedestrians. The smallest difference as access control increased is in rear-end or side-swipe and noncollision accidents.

In order to understand better the causes of accidents and fatalities on fully controlled highways, motor-vehicle reports were obtained from the Rhode Island Department of Public Works for the fully controlled access highway of Study 12. The following is the description of several of the accidents on the full-controlled-access highway:

1. "Vehicle 1, the truck, was parked on the highway. The driver had stopped to rearrange his load. Vehicle 2, car, ran into rear of truck." Result - one fatality.

2. "Driver lost control of car at curve north of Old Louisquisset Pike - Driver says car kept going to left - doesn't know what happened." Result - one person injured.

3. "Car 1 was passing a truck which had stopped in its lane to allow some birds to cross road. Car 2 following car 1 hit car 1 when car 1 saw birds and slowed down." Result - one injured person.

4. "Vehicle 1, the bus, was passing car 2. The right rear of the bus hit left front fender and side of car 2." Result - two injured persons.

5. "Car 1 following car 2 going south on Louisquisset. Car 2 slowed down suddenly and was hit in rear by 1 - weather very rainy." Result - four injured persons.

After reading the description of these accidents, improving the highways by controlling the access will not eliminate all the accidents and fatalities. Controlling the access will greatly reduce them, but the driver can still involve himself and others in accidents even on the best highways.

Highway Safety (Connecticut Study)

A study of accidents and fatalities on fully controlled, partially controlled and uncontrolled access highways was made (5) in Connecticut in 1953, and a summary of the study is presented in Table 11. The accident and fatality rates have been arranged in order to compare these rates with the accident and fatality rates of the 12 case studies shown in Table 8. The accident rates, as presented in the Connecticut study, in all cases are substantially greater than those obtained in the 12 studies, particularly on the uncontrolled-access highways. This is also true for the fatality rates, except in the case of fully controlled-access highways in urban areas.

Highway Safety (Bureau of Public Roads Study)

In October 1953 the Bureau of Public Roads distributed a memorandum (6) which was a summary of a preliminary study pertaining to accidents and fatalities as related to access control, and the tentative results of this study are presented in Table 12. The data represent over 1,000 miles of highways and over 12 billion vehicle-miles. The accident rates and fatalities in the Bureau of Public Roads study are also greater than those obtained in the case studies, and once again particularly on the uncontrolled-access sections.

TABLE 8

ACCIDENT AND FATALITY RATES BY TYPE OF ACCESS CONTROL AND DEGREE OF URBANIZATION FOR THE TWELVE CASE STUDIES

	Accidents**		
	Urban	Suburban	Rural
Full Control	247 (2)*	141 (2)	49 (2)
Partial Control	-	320 (1)	200 (5)
No Control	443 (2)	330 (7)	236 (3)
	Fatalities**		
	Urban	Suburban	Rural
Full Control	9.2 (2)*	2.5 (2)	1.6 (2)
Partial Control	-	0.0 (1)	9.0 (5)
No Control	2.3 (2)	6.9 (7)	0.0 (3)

* The values in the tables are the number of accidents and fatalities per 100 million vehicle-miles and the numbers in parentheses indicate the number of test sections included in the average speeds.

** See Table 7 for an indication of limitations of data and the resulting standard errors.

An overall comparison of the accident rates and fatality rates included in each study by type of access control and degree of urbanization for the 12 case studies, the Connecticut study, and the Bureau of Public Roads study is presented in Tables 13 and 14.

Table 13 indicates that the combined accident rates of the case studies are lower than the accident rates obtained in the Connecticut and Bureau of Public Roads studies, except on fully controlled-access highways in urban areas. This suggests that the controlled and uncontrolled-access sections of highway in the 12 case studies may be better designed than sections included in the other two studies.

The Connecticut and Bureau of Public Roads studies indicate there is a greater reduction in accidents by access control in urban areas than in rural areas. The accident rates reported in the Connecticut study are higher on full-controlled-access sections and lower on uncontrolled-access sections than the accident rates as reported by the Bureau of Public Roads. Therefore the BPR study shows a greater reduction in accident rates by access control than the Connecticut study.

All three studies indicate that accident rates are 1½ to 6 times greater on uncontrolled-access highways than on controlled-access highways.

TABLE 9

TYPES OF HIGHWAY ACCIDENTS AS RELATED TO ACCESS CONTROL

Accident Record		Manner of Accident: Rear-end or sideswipe	Head-on or sideswipe	Angle Collision	Collision with Ped.	Other Collision	Non-Collision	Total Accidents
All Accidents	F	82	4	6	1	16	27	136
	P	92	9	55	6	66	81	309
	N	197	12	108	12	73	34	436
Fatal Accidents	F	2			1	1		4
	P	2		3				5
	N	1		1	4	1		7
Injury Accidents	F	33		1		5	16	55
	P	27	2	12	6	19	34	100
	N	66	3	32	5	25	16	147
Property Damage	F	46	4	5		11	11	77
	P	64	8	38		47	47	204
	N	131	9	75		48	18	281
Persons Killed	F	3			1	1		5
	P	1		8				9
	N	2		1	4	2		9
Persons Injured	F	70		1		6	20	97
	P	48	2	23	16	36	62	187
	N	112	9	67	7	38	23	256

F indicates Full Control
P indicates Partial Control
N indicates No Control

All values in table are the number of accidents per 100 million vehicle-miles, and accidents of case studies 3, 6, 7, and 8 are not included.

The results of Table 14 indicate that the combined fatality rates of the 12 case studies are lower than the fatality rates obtained in the Connecticut and Bureau of Public Roads studies, except on full-controlled-access highways in urban areas. This again suggests that the controlled- and uncontrolled-access sections

TABLE 10

REDUCTION OF ACCIDENTS AND FATALITIES BY ACCESS CONTROL

Accident Record		Manner of Accident: Rear-end or sideswipe	Head-on or sideswipe	Angle Collision	Collision with Ped.	Other Collision	Non-Collision	Total Accidents
		%	%	%	%	%	%	%
All Accidents	F	58	67	94	92	78	21	69
	P	53	25	49	50	10	*	29
Fatal Accidents	F	*		100	75	0		43
	P	*		*	100	100		29
Injury Accidents	F	50	100	97	100	80	0	63
	P	59	33	62	*	24	*	32
Property Damage Accidents	F	65	56	93		77	39	73
	P	51	11	49		2	*	27
Persons Killed	F	*		100	75	50		44
	P	50		*	100	100		6
Persons Injured	F	37	100	99	100	84	7	72
	P	57	78	65	*	53	*	27

F indicates Full Control
P indicates Partial Control
* Actually an increase

of highway in the 12 case studies may be better designed than sections included in the other two studies.

The Connecticut data suggests that fatality rates decrease with an increase in access control, while the Bureau of Public Roads data suggest that partial-controlled-access highways may have a higher fatality rate than uncontrolled-access highways.

TABLE 11

ACCIDENT EXPERIENCE RELATED TO CONTROL OF ACCESS IN CONNECTICUT

	Accidents	
	Urban	Rural
Full Control	261	221
Partial Control	180	250
No Control	725	313

FATALITY EXPERIENCE RELATED TO CONTROL OF ACCESS IN CONNECTICUT

	Fatalities	
	Urban	Rural
Full Control	1.9	3.0
Partial Control	0.0	5.9
No Control	5.7	6.7

The values in the tables are the number of accidents and fatalities per 100 million vehicle-miles.

The Connecticut and Bureau of Public Roads studies show that fatality rates are generally higher on rural sections of highway than on urban sections and that fatality rates are lowest on fully controlled-access highways.

Highway Safety (Toll Roads)

As of September 1954, there were 1,153 miles of toll roads in operation, 1,439 miles under construction, 2,708 miles authorized or ready to begin construction, and 2,640 miles in investigational or preliminary planning stage (7). With the growth of the number of miles of toll roads, it is of special interest to compare the accident and fatality rates of some of the existing toll roads with similar rates of fully controlled-access highways which are under public control. The accident and fatality rates (8, 9) on the New Jersey, Oklahoma, and Pennsylvania Turnpikes are shown in Table 15. Assuming that the toll roads have similar characteristics to the rural fully controlled-access-highways under public control, the accident rates on the toll roads are quite favorable. In fact, in general they appear to be slightly less than the accident rates on the comparable publicly owned highways. However, the fatality rates, as reported by all three studies, are less than the fatality rates of the three toll roads. There may be other factors, such as speed, which may have caused the discrepancy between the accident and fatality rates on the toll roads and the publicly owned roads.

TABLE 12

TENTATIVE RESULTS OF BUREAU OF PUBLIC ROADS STUDY RELATING ACCIDENT EXPERIENCE TO CONTROL OF ACCESS

	Accidents	
	Urban	Rural
Full Control	146	210
Partial Control	790	227
No Control	966	407
	Fatalities	
	Urban	Rural
Full Control	2.3	3.0
Partial Control	5.3	10.4
No Control	3.0	8.9

The values in the tables are the number of accidents and fatalities per 100 million vehicle-miles.

TABLE 13

COMPARISON OF ACCIDENT RATES AS RELATED TO ACCESS CONTROL

Type of Access Control	Urban	Rural
Full Access Control		
Twelve Case Studies	247	49
Connecticut Study	261	221
Bureau of Public Roads Study	146	210
Partial Access Control		
Twelve Case Studies	-	200
Connecticut Study	180	250
Bureau of Public Roads Study	790	227
No Access Control		
Twelve Case Studies	443	236
Connecticut Study	725	313
Bureau of Public Roads Study	966	407

The values in the table represent the number of accidents per 100 million vehicle-miles of travel.

TABLE 14

COMPARISON OF FATALITY RATES AS RELATED TO ACCESS CONTROL

Type of Access Control	Urban	Rural
Full Acess Control		
Twelve Case Studies	9.2	1.6
Connecticut Study	1.9	3.0
Bureau of Public Roads Study	2.3	3.0
Partial Access Control		
Twelve Case Studies		9.0
Connecticut Study	0.0	5.9
Bureau of Public Roads Study	5.3	10.4
No Access Control		
Twelve Case Studies	2.3	0.0
Connecticut Study	5.7	6.7
Bureau of Public Roads Study	3.0	8.9

The values in the table represent the number of fatalities per 100 million vehicle-miles of travel.

SUMMARY OF RESULTS

Results obtained from the 12 case studies of comparing controlled-access facilities with uncontrolled-access facilities:

1. The average speed on the fully controlled and partially controlled sections was higher in all 12 case studies than the average speed on comparable uncontrolled sections. The average speed on the combined twelve controlled sections was 48.2 mph., while the average speed on the com-

bined 12 uncontrolled sections was 38.3 mph., resulting in a difference between the two average speeds of 9.9 mph.

TABLE 15

ACCIDENT AND FATALITY RATES ON CERTAIN TOLL ROADS

	Accident Rate			Fatality Rate		
Year	New Jersey	Oklahoma	Pennsylvania	New Jersey	Oklahoma	Pennsylvania
1940			260			9.4
1941			218			10.7
1942			231			10.9
1943			244			8.0
1944			239			14.5
1945			166			11.2
1946			135			9.8
1947			137			5.8
1948			157			7.3
1949			157			10.0
1950			200			12.4
1951			126			8.5
1952	93		103	6.1		7.3
1953	67	94	136	4.1	3.8	7.3
Average	80	94	179	5.1	3.8	9.5

The values in the table represent the number of accidents and fatalities per 100 million vehicle-miles.

2. The average time savings on fully controlled-access highways as compared with uncontrolled-access highways in rural, suburban, and urban areas are 0.07, 0.32, and 1.00 minutes per vehicle-mile of travel, or on a monetary basis are 0.2, 0.9, and 2.8 cents per vehicle-mile of travel.

3. The average time savings on partially controlled-access highways as compared with uncontrolled-access highways in rural and suburban areas are 0.13 and 0.12 minutes per vehicle-mile of travel, or on a monetary basis are 0.4 and 0.3 cents per vehicle-mile of travel.

4. The average gasoline consumption on the combined sections was 18.9 mpg. as compared with 19.1 mpg. on the combined sections. Gasoline consumption did not appear to be as affected by access control or by degree of urbanization as it was by average speed.

5. The brakes were used 0.17, 1.70, and 5.74 seconds more per vehicle-mile of travel on the uncontrolled-access sections than on the full-controlled-access sections in rural, suburban, and urban areas, respectively.

6. For the period of time covered by the accident data there were 2.4 times as many accidents and 2.3 times as many fatalities per vehicle-mile of travel on the uncontrolled-access sections than on the comparable controlled-access sections.

CONCLUSIONS

The data of this study indicate that fully and partially controlled-access highways carrying substantial volumes of through traffic result in: (1) a significant savings in time and a significant reduction in gasoline consumption in urban areas; (2) a significant savings in time but no significant reduction in gasoline consumption in suburban areas; (3) no significant savings in time nor significant reduction in gasoline consumption in rural areas; and (4) a significant decrease in the accident rate in urban, suburban, and rural areas.

In view of the limitations of the fatality data and the resulting standard errors, no conclusion concerning a comparison of fatality rates can be made.

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