Fuel and Time Consumption Rates for Trucks in Freight Service

MALCOLM F. KENT, Transportation Economist, Bureau of Public Roads, Washington, D.C.

The number of times a truck must change its speed in a mile of travel increases with the density of traffic, according to an analysis of data derived from studies conducted in 1957 and 1958 of rural and urban travel in five States—data necessary in the analysis of highway-user benefits.

Using a congestion index, which indicates that speed changes per mile increase uniformly with average daily traffic for different types of highway, together with the rates of fuel and travel time consumed during a change in vehicle speed, the added cost of operating at nonuniform speed could be assessed.

This article also shows that, for the gross vehicle weights observed, smaller and less powerful engines give better fuel economy, but their use carries a penalty of increased time-consumption (lower road speeds) at the higher gross vehicle weights. Trucks with diesel engines were found to travel about 50 percent more miles on a gallon of fuel than trucks with gasoline engines of approximately equivalent power and gross weight characteristics.

ONE OF THE greatest voids in the data available for the analysis of highway-user benefits accruing through the improvement of highway facilities has been reliable fuel- and time-consumption rates of commercial motor vehicles operating in actual service. To help fill this void the Bureau of Public Roads developed a program for obtaining this information. Ohio State University, the Universities of Michigan and Washington, and a transportation consultant from the University of Maryland were engaged to measure fuel consumption and over-all travel time of selected trucks in rural and urban line-haul service and in city pickup and delivery service, under traffic conditions ranging from restricted to free flowing. This study group obtained the cooperation of private, government-owned, and for-hire highway freight carriers. Three of the studies were conducted simultaneously during the summer of 1957, and one during the summer of 1958.

A principal concern of highway planners of a few decades ago was the surfacing of dirt roads. Today, a principal concern is the elimination of frictional factors that impede the free flow of traffic on paved roads. Eliminating stops occasioned by stop signs and traffic lights, the widening of pavements or the adding of more lanes, the designing of highways with easier grades and curves, and the upgrading of other features that cause reduction in normal driving speeds are factors that are now of primary importance.

In addition to improving the safety and efficiency of traffic flow, such improvements result in direct benefits to road users. Savings in motor fuel and time costs are two of the principal benefits that result, and they are directly affected by the elimination of frictional factors that impede the free flow of traffic. The over-all purpose of the studies described in this report was to provide data on fuel consumption and travel time for various vehicle types and traffic conditions, which could be used in the economic analyses of road-user benefits.

SUMMARY OF FINDINGS

Major findings of the studies are summarized in the following paragraphs.

1. The fuel consumption in gallons per mile of motor trucks operating in rural and urban line-haul service increased with the power of the engine for equivalent gross vehicle weights.
2. Operating over identical rural line-haul routes, diesel-powered trucks were found to travel about 50 percent more miles on a gallon of fuel than gasoline-powered trucks of approximately equivalent power and gross vehicle weight. In terms of fuel consumption, this means that diesel-powered trucks consumed about 66 percent of the gallonage used by gasoline-powered trucks.
3. The consumption of gasoline per mile by trucks was 25 to 30 percent higher in urban areas than in rural areas.
4. The average truck speeds, including all stops and slowdowns, were found to be 37 mph in rural line-haul operation, 19 mph in urban line-haul operation, and 11 mph in city pickup and delivery. For free-flowing traffic, the comparative speed for trucks in rural line-haul operation was 40 mph.
5. The usefulness of speed changes per mile as a congestion index was demonstrate by proving that speed changes per mile increased uniformly with average daily traffic for different types of highways. Knowing the number of speed changes saved, the proportion of stops and slowdowns, and the magnitude of each, it is possible to use this index to compute the added cost of fuel and time caused by speed changes, when the extra fuel and time consumed during a speed change are known.
6. The stops on rural highways, made from the average truck speed, represented 11 percent of all deviations from desired speeds, whereas the stops on urban streets represented 45 percent of all deviations from desired speeds.
7. The average number of speed changes per mile was found to be 1.66 for rural line-haul, 4.97 for urban line-haul, and 6.91 for city pickup and delivery operations.

DEFINITION OF TERMS

To avoid misinterpretation of the results, certain terms used in this article are defined.

Fuel consumption.—Gallons of gasoline or diesel fuel consumed per mile of highway travel. The conversion from gallons per mile to miles per gallon can easily be made since one is the reciprocal of the other.

Travel time.—Minutes required to travel 1 mile. Minutes per mile can be converte to miles per hour by dividing 60 by the minutes per mile.

Stop.—Bringing a motor vehicle to a complete stop.

Slowdown.—A reduction in speed of a motor vehicle of more than 3 mph without coming to a stop.

Speed change.—All motor vehicle accelerations and decelerations effecting a speed change of more than 3 mph, including both stops and slowdowns.

Average gross vehicle weight.—The average of the individual gross vehicle weights of several vehicles, all falling within the same class interval of gross vehicle weight.

Engine cubic-inch displacement.—The cross-sectional area of a cylinder multiplied by the length of piston stroke, which gives the cylinder displacement; multiplied by the number of cylinders.

Net horsepower.—The brake horsepower of the engine, operating with all its norma accessories, that is available at the clutch or its equivalent. It is the gross horsepow minus the horsepower absorbed by fan, compressor, generator, etc. For all practica purposes, net horsepower is assumed to be 90 percent of the gross horsepower.

Total rise and fall.—The arithmetic sum of the vertical rise and fall in feet for any section of highway. The rise in one direction of travel will become the fall in the opposite direction. The total rise and fall is the same regardless of the direction of travel.

Rate of rise and fall. —The total rise and fall for any section of highway in feet divided by the length of section in hundreds of feet. It is not to be confused with the percent of grade. It is equivalent to the average percent of grade only when either the rise or fall is 100 percent of the total rise and fall.

DESCRIPTION OF TEST ROUTES

The four studies were conducted in the general areas of Maryland-District of Columbia-Virginia, Ohio, Michigan, and Washington. The line-haul (intercity) routes with their origins, destinations, route numbers, mileages, and rates of rise and fall are shown in Table 1. The urban extensions of the line-haul routes in Cleveland and Columbus, Ohio, Detroit, Mich., Baltimore, Md., Washington, D.C., Seattle, Wash., and some smaller municipalities were studied separately from rural line-haul operation. These generally followed the numbered routes until diversion was necessary to reach the trucking terminal or delivery warehouse.

TABLE 1

ROUTE TERMINI, ROUTE NUMBERS, DISTANCES, AND RATES OF RISE AND FALL OF RURAL HIGHWAYS TRAVELED BY OBSERVED LINE-HAUL TRUCKS

Termini				Rate of Rise
From	To	Numbered Routes	Mileage[a]	and Fall[b]
Washington, D.C.	Baltimore, Md.	Md. 193, US 1	32.6	1.58
	Richmond, Va.	Va. 350, US 1	95.5	1.42
Columbus, Ohio	Cleveland, Ohio	Ohio 3, 61, US 42	128.4	1.41
	Parkersburg, W. Va.	US 33, 50	108.8	0.63
	Wheeling, W. Va.	US 40	119.9	1.70
Detroit, Mich.	Lansing, Mich.	US 16	80.5	0.59
	Toledo, Ohio	US 25	55.4	0.16
	Three Rivers, Mich.	US 112, 12, Mich. 60	151.7	0.48
Seattle, Wash.	Aberdeen, Wash.	US 99, 410	95.5	1.25
	Bellingham, Wash.	US 99	75.5	1.28
	Centralia, Wash.	US 99	74.7	1.09
	Chehalis, Wash.	US 99	80.7	1.09
	Everett, Wash.	US 99	18.5	1.87
	Longview, Wash.	US 99, 830	120.7	0.95
	Mt. Vernon, Wash.	US 99	53.9	1.24
	Olympia, Wash.	US 99	53.1	1.29
	Portland, Ore.	US 99	161.2	0.93
	Tacoma, Wash.	US 99	23.9	1.59
	Yakima, Wash.	US 10, 97	139.1	1.35

[a]Between municipal boundaries of terminal cities.
[b]In feet per 100 ft of distance.

City pickup and delivery service was studied in Detroit, Columbus, Seattle, and Washington, D.C. All such operations were on irregular routes except for the postal delivery service trucks which followed the same routes each day to the various substations in Columbus. The types of service varied from large tractor-truck semitrailer combinations delivering grocery products from warehouses to retail stores and motor fuel from wholesale storage tanks to retail filling stations, to panel and van-type trucks engaged in package or linen delivery service. Rise and fall rates were estimated for Columbus, Detroit, and Washington, D.C., at approximately 0.5 ft per 100 ft. Rates of rise and fall for routes were recorded for Seattle, and ranged from 1.9 to 2.3 ft per 100 ft. However, the variations in rates of rise and fall among routes were not of sufficient magnitude to cause significant changes in fuel and time consumption.

DESCRIPTION OF TEST VEHICLES

The gasoline- and diesel-powered tractor-truck semitrailer combinations, made available by commercial carriers for line-haul observation, are described in Table 2 according to type, engine displacement, and net brake horsepower. City pickup and delivery gasoline-powered vehicles, consisting of panel and other single-unit trucks and tractor-truck semitrailer van and tank combinations, are similarly described.

Where the size and weight restrictions of the particular state permitted, three vehicles were observed in each state within each of the following weight groups:

Rural and Urban Line-Haul (lb)	City Pickup and Delivery (lb)
20,000 - 29,999	5,000 - 9,999
30,000 - 39,999	10,000 - 19,999
40,000 - 49,999	20,000 - 29,999
50,000 - 59,999	Over 30,000
60,000 - 69,999	

TEST PROCEDURES

After receiving permission from fleet owners to use their vehicles for test purposes, in the course of their normal runs, a fuel meter was placed in the cab of each gasoline-powered truck and connected to the fuel lines of the engine between the tank and the carburetor. The fuel meter could be read by a person sitting next to the driver The fuel tank was filled at the start of each trip and was filled again at the end of the trip; any fuel added en route was, of course, recorded. This over-all record of fuel consumption was used to check the accuracy of the meters.

Diesel-engine trucks, in which excess fuel is recirculated from the engine to the fuel tank, required a different type of meter installation. To circumvent the multimetering of the same fuel, a small-volume, constant-level tank was installed in the fuel line between the engine and the main fuel supply tank. The engine fuel pump drew only from this feed tank, to which all excess recirculated fuel was returned. Fuel consumed by the engine was drawn from the feed tank, and a constant level was maintained in the feed tank through a float arrangement and an auxiliary fuel pump supplying additional fuel from the main supply tank through a fuel meter unit. In this manner, the fuel meter recorded only the actual quantity of fuel consumed by the engine.

Before the beginning of the test runs each route to be observed was inventoried to locate control points with relation to major changes in traffic flow and to record mileag between control points, rise and fall (through use of an aneroid barometer), number of traffic signs and signals, and number of lanes. Before the start of each run, the observer recorded the vehicle chassis model and year, unladen weight, payload weight, and gross vehicle weight, engine model size and cubic inches of cylinder displacement, and reported net brake horsepower. The weather and condition of the road were also recorded.

The observer, riding in the cab, recorded on each run the following information as he passed the control points: time of day (hour and minute), fuel meter reading (hundredths of a gallon), and odometer reading (tenths of a mile). The magnitude of each speed change of ± 3 mph or more within each section was recorded during the trip. Trips were made at all hours of the day and night, with no change from normal operations being made on account of the study. Drivers were not to change their normal driving habits, and drove at speeds representative of other traffic .

TABLE 2

CHARACTERISTICS OF COMMERCIAL MOTOR VEHICLES

Number of Vehicles	Number of Axles and Body Types[a]	Engine Displacement, cu. in.	Net Brake Hp of Engine[b]	Engine Rpm
Line-haul gasoline:				
1	3-S2-2 van	302	172	3,600
3	3-S2 van	331	128	3,200
1	2-S2 van	377	126	2,800
12	2-S1 van	386	130	2,800
8	3-S1 van	406	156	2,750
4	3-S2 van	450	146	2,600
2	3-S2 van	461	197	3,200
3	2-S2 van	501	165	2,800
1	3-2 van	531	178	2,880
1	3-S2 van	549	230	3,200
4	3-S2 van	590	225	2,800
Line-haul, diesel:				
5	3-S2 van	743	200	2,100
City pickup and delivery gasoline:				
2	2 panel	214	73	3,200
1	2 panel	223	126	4,000
1	2 panel	235	123	4,000
1	2 van	220	89	2,800
5	2 van	228	90	3,000
5	2 van	248	115	3,400
1	2 van	260	90	2,500
1	2 van	261	135	4,000
1	2 van	263	105	3,400
3	2 van	271	114	2,800
2	2 van	272	167	4,400
1	2 van	282	103	3,200
2	2 van	320	103	3,000
1	2 van	386	163	3,000
2	2-S1 van	372	139	3,200
2	2-S1 van	386	145	3,000
3	2-S1 van	406	175	3,200
1	2-S2 van	383	150	2,800
2	2-S2 van	450	150	2,800
1	2-S2 van	505	175	2,800
2	2-S2 tank	464	170	2,800

[a] Each digit indicates the number of axles of a vehicle or of a unit of a vehicle combination. A single digit, or the first digit of a group symbol, represents a single-unit truck or, if followed by an S, represents a truck-tractor. The S designation represents a semitrailer. A digit, without an S preceding it, in the second or third position of a group symbol represents a full trailer.

[b] Average 140 hp for engine sizes 302-406 cu in., average 171 hp for sizes 450-549.

ANALYSIS PROCEDURES

When the fieldwork had been completed, the first step in the analysis procedure was to list the consumption of fuel, travel time, and mileages traveled on each section for each trip, segregating rural from urban data. Speed changes were similarly listed for each section and trip, with stops being shown separately from slowdowns in the Ohio and Washington data. Gallons per mile, minutes per mile, and speed changes per mile were computed separately for line-haul rural trips, for line-haul urban trips, and for city pickup and delivery trips.

Rate of Rise and Fall

Rise and fall was considered a variable with respect to fuel consumption rates and travel time. No significant variations were found, however, in either parameter for the rather narrow range of rates of rise and fall studied. As shown in Table 1, rates of rise and fall for the rural highways studied ranged from 0.16 for the route between Detroit and Toledo, to 1.87 for the route between Seattle and Everett. Of the total mileage studied, 40.6 percent had a rate of rise and fall below 1.0, 47.7 percent had rates from 1.0 to 1.5, and 11.7 percent had rates from 1.51 to 1.87. The average rate of rise and fall for all rural sections studied was 1.22. The results reported for this study reflect the average values for all highway sections without regard to variations in rise and fall.

Vehicle Weight Groupings

It was not possible to set up a precise schedule of vehicles and gross vehicle weights to be observed, since the demand for commercial freight in normal operations did not permit the selection of a specified gross vehicle weight. It was hoped that the plan to observe a minimum of three vehicles for each of several weight-class intervals would result in an even distribution within the class interval. This, however, was not the case and it was necessary to form new gross vehicle weight groupings in the analyses. The most significant groupings for the line-haul and pickup and delivery vehicles, together with the number of trips and total miles observed in each grouping, are shown in Table 3. It is evident that sizable mileages were logged in each type of service and that a reliable base exists for the development of fuel consumption and travel time rates.

Engine Size Groupings

The gasoline-powered vehicles observed on line-haul operations were grouped, for purposes of analyses, into three engine displacement size groups consisting of 302-406 cu in., 450-549 cu in., and 590 cu in. Vehicles with 743-cu in. displacement diesel engines were also studied as a group. The net horsepower for the four groups of engine displacement were determined to be 140 horsepower for the 302-406-cu in. size group, 171 horsepower for the 450-549-cu in. size group, 225 horsepower for the 590-cu in. size group, and 200 for the 743-cu in. diesel engine.

A grouping of city pickup and delivery vehicles by power characteristics was considered but found impractical for the purposes of analysis because of the irregularity of the service, which resulted in wide variations in the speed of operation, number of deliveries, stops per mile, idling time, and the rate of discharge of cargo.

AVERAGE FUEL CONSUMPTION RATES

A summary of the average rates of fuel consumption is shown in Table 4. Two fuel consumption values are shown for each group of vehicles with similar power characteristics. One is the actual rate and the other is the computed rate (Fig. 1) as straight line relationships, which were derived from the actual average values. The rates of rise and fall were 1.18 ft per 100 ft for the 302-406-cu in. group, 1.20 ft per 100 ft for the 450-549-cu in. group, 1.29 ft per 100 ft for the 590-cu in. group, and 1.22 ft per 100 ft for the 732-cu in. diesel engine. The variation in rise and fall appeared to be rather insignificant and therefore a valid comparison of the motor-fuel consumption rates for the several groupings of vehicles is practical.

TABLE 3

NUMBER OF TRIPS AND TOTAL MILES OBSERVED FOR GASOLINE- AND DIESEL-POWERED MOTOR VEHICLES

Weight Class (lb)	Average Gross Vehicle Weight	Gasoline Vehicles		Diesel Vehicles	
		Number of Trips	Total Miles Observed	Number of Trips	Total Miles Observed
Line-haul vehicles:					
17,000-18,999	17,000	15	1,111	-	-
19,000-23,999	21,300	55	3,085	-	-
24,000-29,999	27,000	25	2,398	1	60
30,000-37,999	34,500	123	11,740	6	545
38,000-47,999	42,000	98	8,906	12	1,641
48,000-53,999	51,200	64	5,381	8	668
54,000-61,999	59,500	42	3,520	9	1,125
62,000 and over	67,900	31	2,111	12	1,503
Total	-	453	38,252	48	5,542
City pickup and delivery vehicles:					
4,400- 4,999	4,600	13	231	-	-
5,000- 8,999	6,000	25	1,172	-	-
9,000-12,999	10,500	89	1,775	-	-
13,000-16,999	14,500	51	603	-	-
17,000-20,999	18,500	6	67	-	-
21,000-24,999	22,500	1	33	-	-
25,000-30,499	27,500	80	480	-	-
30,500-36,999	33,300	18	232	-	-
37,000-39,999	38,500	3	81	-	-
40,000-45,999	42,100	5	171	-	-
51,000-51,999	51,300	3	154	-	-
54,000-59,999	57,000	40	64	-	-
62,000-69,999	66,000	32	70	-	-
Total	-	366	5,133	-	-

It may be noted that the vehicles with the larger power plants used appreciably more gasoline for a given average weight. For instance, Figure 1 shows that gasoline-powered vehicles in the lowest engine power group with an average GVW (gross vehicle weight) of 40,000 lb had a fuel-consumption rate of 0.202 gal. per mi. This compares with 0.233 gal per mi for vehicles in the medium power group, which represents a 15 percent increase; and with 0.262 gal per mi for vehicles in the largest gasoline-engine power group, a 30 percent increase.

Also, the fuel-consumption rate increased with gross vehicle weight. In the medium power group, for instance, a vehicle weighing 20,000 lb consumed approximately 0.181 gal per mi, while a vehicle weighing 60,000 lb consumed 0.285 gal per mi. However, despite the fuel-consumption rate increase with gross vehicle weight increase, there was a decrease in the fuel consumption per 10,000 lb of gross vehicle weight. For example, in the medium power group a 20,000-lb vehicle consumed 0.181 gal per mi or 0.091 gal per mi per 10,000 lb, while a 60,000-lb vehicle which consumed 0.285 gal per mi actually consumed only 0.048 gal per mi per 10,000 lb, indicating that as gross

TABLE 4

SUMMARY OF FUEL-CONSUMPTION RATES FOR LINE-HAUL TRUCKS OPERATING OVER RURAL HIGHWAY[a]

Gross Vehicle Weight (lb)	Fuel-Consumption Rates (gal/mi)							
	302-400 Cu In. Gasoline (140 hp)		450-549 Cu In. Gasoline (171 hp)		500 Cu In. Gasoline (225 hp)		743 Cu In. Diesel (200 hp)	
	Actual	Computed[b]	Actual	Computed[b]	Actual	Computed[b]	Actual	Computed[b]
17,000	0.150	0.154	0.152	0.173	-	-	-	-
21,300	0.163	0.163	0.189	0.185	-	-	-	-
27,000	0.170	0.175	0.210	0.200	0.243	0.241	0.146	0.153
34,500	0.196	0.191	0.229	0.219	0.247	0.253	0.176	0.162
42,000	0.214	0.207	0.246	0.239	0.278	0.266	0.176	0.171
51,200	0.233	0.226	0.256	0.263	0.273	0.280	0.164	0.182
59,500	0.233	0.244	0.289	0.285	0.287	0.294	0.189	0.193
67,900	-	-	0.298	0.307	0.314	0.307	0.212	0.203

[a]Average rate of rise and fall, 1.2 ft per 100 ft.
[b]Computed rates are based on the following formulas: 302-406 cu in., 0.1177+0.00212W; 450-549 cu in., 0.1288+0.00262; 590 cu in., 0.1975+0.00162W; and 743 cu in., 0.1194+ 0.001229W. (W=GVW in thousands of pounds.)

vehicle weight is increased the fuel economy per unit of gross weight is improved.

Gasoline and Diesel Fuel Comparison

For the same gross vehicle weight averages, the diesel-powered vehicles consumed considerably less fuel than the gasoline-powered vehicles with approximately the same power characteristics. For example a vehicle with a 590-cu in. gasoline engine and an average GVW of 60,000 lb consumed approximately 0.294 gal per mi, while a vehicle with a 743-cu in. diesel engine and a similar weight consumed 0.193 gal per mi. In this case the diesel consumption rate was 66 percent of the gasoline consumption rate. However, the foregoing comparison does not represent results obtained over identical routes.

A comparison of gasoline and diesel fuel consumption rates for vehicles traveling over identical routes was possible from the data obtained in the State of Washington. The diesel-powered combination units traveled a total of 5,542 mi on 48 trips. Twenty-eight of these trips, totaling a distance of 3,617 mi, were traveled over the same routes used by gasoline-powered trucks on 32 trips, totaling 3,966 mi. By grouping gross vehicle weights into class intervals, it was possible to obtain average consumption values that were directly comparable with respect to rise and fall rates and gross vehicle weight. Of the vehicles

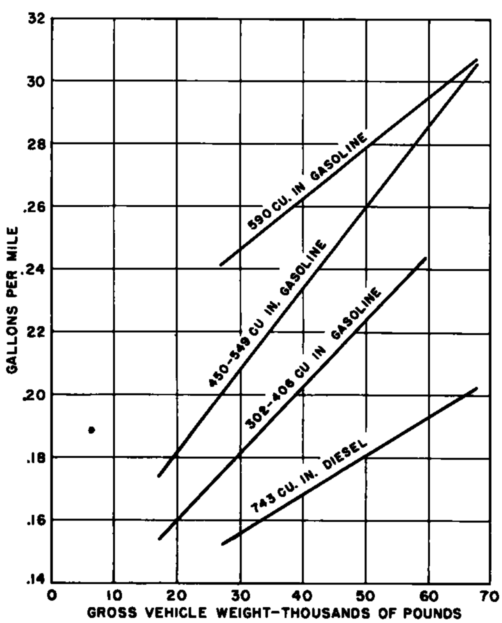


Figure 1. Motor-fuel consumption rates of rural line-haul trucks by size of engine for 1.2 rate of rise and fall.

vith gasoline engines, 21 trips were made by vehicles with engines of 461-cu in. displacement, 3 with engines of 450-cu in. displacement, and 8 with engines of 590-cu in. lisplacement. For the 32 trips, the average net horsepower of the vehicles with gasoline engines was 199 hp, as compared with the 200-hp diesel engines. The results are summarized in Table 5 and the relationships derived from the average rates of fuel consumption are shown in Figure 2.

TABLE 5

GASOLINE AND DIESEL FUEL CONSUMPTION RATES FOR LINE-HAUL TRUCKS TRAVELING OVER THE SAME RURAL ROUTES[a]

Gross Vehicle Weight (lb)	Number of Trips	Total Miles Traveled	Total Gallons Consumed	Consumption Mi/Gal Actual	Consumption Mi/Gal Comp.[b]	Consumption Mi/Gal Actual	Consumption Mi/Gal Comp.[c]
Gasoline:							
30,400	1	63	14.34	4.393	4.452	0.228	0.221
36,800	2	284	66.77	4.253	4.224	0.235	0.237
46,800	7	993	254.89	3.896	3.867	0.257	0.263
57,900	14	1,831	529.23	3.460	3.472	0.289	0.292
62,500	1	142	42.45	3.345	3.308	0.299	0.303
68,300	7	653	213.25	3.062	3.101	0.327	0.318
Total or avg	32	3,966	1,120.93	3.538	-	0.283	-
Diesel:							
32,600	1	65	9.15	7.104	6.723	0.141	0.158
41,500	7	923	163.89	5.632	6.229	0.178	0.168
51,600	6	618	105.17	5.876	5.668	0.170	0.179
58,100	8	1,146	219.87	5.212	5.306	0.192	0.187
69,900	6	865	182.15	4.749	4.651	0.211	0.200
Total or avg	28	3,617	680.23	5.317	-	0.188	-

[a]Average rate of rise and fall, 1.17 ft per 100 ft. [b]Computed miles-per-gallon rates are based on the following formulas: gasoline, 5.53486-0.03563W; diesel, 8.5345-0.0556W. [c]Computed gallons-per-mile rates are based on the following formulas: gasoline, 0.14217+0.00258W; diesel, 0.12106+0.00113W. (W=GVW in thousands of pounds.)

For a GVW of 70,000 lb (Fig. 2) the gasoline consumption rate was 0.322 gal per mi, or 3.11 mi per gal; and the diesel consumption rate was 0.200 gal per mi, or 5.00 mi per gal. In effect the diesel-powered vehicles traveled about 53 percent more miles per gallon of fuel than did the gasoline-powered vehicles. A similar comparison for a GVW of 50,000 lb indicated that the diesel-powered vehicles traveled about 52 percent more miles per gallon of fuel than gasoline-powered vehicles. A comparison of the average rate for all gasoline-powered vehicles for all 32 trips with that for all diesel-powered trips shows that 51 percent more mileage was obtained by diesel-powered vehicles on the same gallonage of fuel. This relative value is based on the

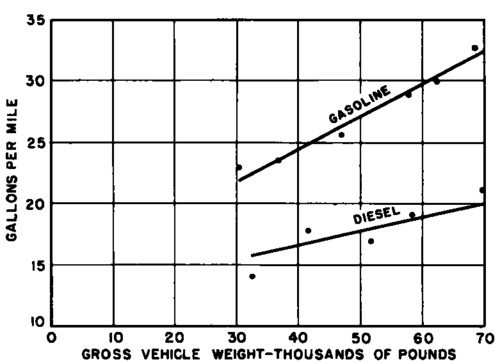


Figure 2. Comparison of gasoline and diesel fuel consumption rates of rural line-haul trucks operating over the same routes.

total miles traveled and total gallons consumed (Table 5). The average diesel consumption rate of 0.188 gal per mi was 66 percent of the average gasoline consumptio rate of 0.283 (Fig. 1).

Rural and Urban Comparison

The fuel consumption rates for all gasoline- and diesel-powered trucks observed in line-haul rural and urban travel are shown in Table 6. The computed rates, obtained from the straight-line relationships shown in Figure 3, were derived from the averag actual rates. The fuel consumption rates for gasoline-powered vehicles in urban trav appear to be considerably greater than the gasoline consumption rates in rural travel. The fuel consumption percentage differences in rural and urban travel range from a 25 percent difference for a GVW of 20,000 lb to a 32 percent difference for a GVW of 70,000 lb.

TABLE 6

GASOLINE AND DIESEL FUEL CONSUMPTION RATES FOR RURAL AND URBAN LINE-HAUL OPERATIONS

Gross Vehicle Weight (lb)	Fuel Consumption Rates (gal per mi)							
	Gasoline Vehicle				Diesel Vehicle			
	Rural		Urban		Rural		Urban	
	Actual	Comp.[a]	Actual	Comp.[a]	Actual	Comp.[a]	Actual	Comp
17,000	0.150	0.152	0.175	0.189	-	-	-	-
21,300	0.166	0.165	0.218	0.207	-	-	-	-
27,000	0.184	0.182	0.232	0.230	-	-	-	-
34,500	0.206	0.204	0.263	0.261	0.176	0.167	0.147	0.14
42,000	0.229	0.227	0.291	0.292	0.176	0.174	0.179	0.16
51,200	0.243	0.254	0.332	0.330	0.164	0.184	0.180	0.19
59,500	0.280	0.279	0.365	0.364	0.189	0.192	0.225	0.22
67,900	0.308	0.304	0.395	0.399	0.212	0.200	0.255	0.25

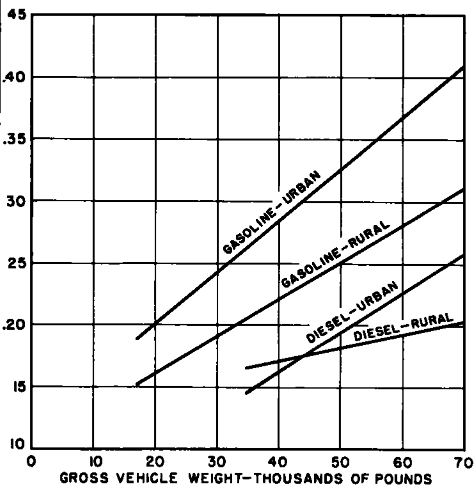
[a]Computed rates are based on the following formulas: gasoline, rural, 0.10115+0.00299W gasoline, urban, 0.11865+0.00413W; diesel, rural, 0.13180+0.00101W; diesel, urban, 0.03924+0.00310W. (W=GVW in thousands of pounds.)

A comparison of the rural and urban fuel consumption rates for diesel-powered trucks observed in line-haul service, however, shows that there was little percentage difference where the GVW was from 40,000 to 50,000 lb, but where the GVW approach 70,000 lb there was a 27 percent higher consumption rate in urban travel.

Again, Figure 3 shows the fuel consumption advantage of the diesel engine.

City Pickup and Delivery Vehicles

City pickup and delivery motor-vehicle gasoline consumption rates are shown in Figure 4 for two different rates of rise and fall. The straightline values were derived from actual average values. In Seattle, where the rate of rise and fall averaged 2.1 f per 100 ft, the gasoline consumption was 18 percent higher at 10,000-lb GVW and 14 percent higher at 40,000-lb GVW than the consumption rate in the other three cities where the rise and fall was about 0.5 ft per 100 ft. It will be noted that gasoline consumption increased as gross vehicle weights increased, as was the case for line-haul operation. It may also be noted that the consumption rates approximate closely the values shown in Figure 3 for gasoline-powered vehicles in urban line-haul service. Consumption rates for wholesale motor-fuel delivery vehicles are shown separately in Figure 4 as they were not considered for this study as multi-stop city delivery vehicles.



igure 3. Comparison of rural and urban otor-fuel consumption rates of line-haul trucks.

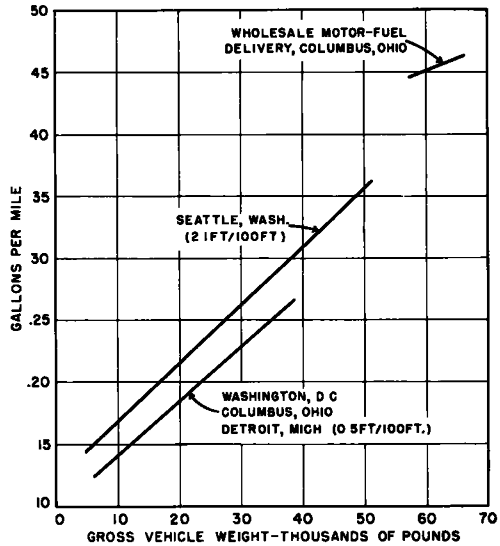


Figure 4. Motor-fuel consumption rates at different rates of rise and fall for city delivery vehicles.

omparison with Previous Studies

Fuel-consumption rates obtained in his study have been compared with results found in two previous studies—a 1937 Oregon tudy (1), and a 1948 Pennsylvania study (2). The comparison of these consumption ates are given in Table 7 and shown graphically in Figure 5. For comparative pur-oses, the average consumption rates found in the 1958 study, rather than the rates ound for the individual groupings of vehicles, were used. Considering the entire gross ehicle weight range, the consumption rates obtained in the 1958 study were found to e approximately 10 percent higher than corresponding data reported in the Pennsylvania

TABLE 7

COMPARISON OF MOTOR-FUEL CONSUMPTION RATES OF THREE STUDIES OF TRUCKS OPERATING OVER RURAL HIGHWAYS[a]

Average Gross Vehicle Weight (lb)	Motor-Fuel Consumption (gal/mi): 1958 Five-State Study: Gasoline Vehicles: Engine Displacement (cu in.) 302-406	450-549	590	Average	Diesel Veh	1937 Oregon Study: Gasoline Veh	Diesel Veh	1948 Pennsylvania Study: Gasoline Veh
20,000	0.160	0.181	-	0.161	-	-	-	0.135
30,000	0.181	0.207	0.246	0.191	0.156	0.203	0.128	0.170
40,000	0.202	0.234	0.262	0.221	0.169	0.251	0.157	0.200
50,000	0.224	0.260	0.279	0.251	0.181	0.295	0.183	0.228
60,000	0.245	0.286	0.295	0.281	0.193	-	-	0.255
70,000	-	0.312	0.311	0.311	0.205	-	-	0.282

ate of rise and fall for Oregon data was 1.0; for the other study data it was 1.2.

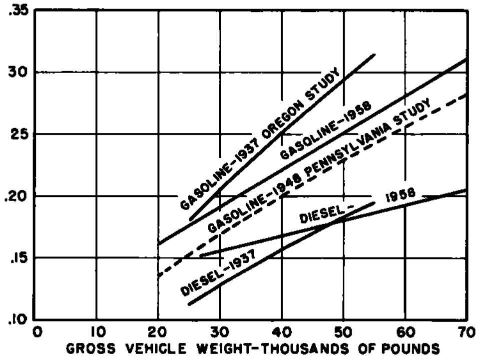


Figure 5. Comparison of data from 3 reports on motor-fuel consumption rates of line-haul trucks.

study, which were obtained by controlled tests on new vehicles. The higher motor-fuel consumption rates in commercial oper ation as compared with the controlled test operation can be ascribed partly to a great er prevalence of speed changes in commercial operation than had been encounter ed in the test truck operation, and partly to the fact that the commercial truck engines were not kept to the high degree of performance efficiency as the controlled test trucks, which were regularly maintained by factory mechanics.

It appears that the results in the Pennsylvania study, which covered a much wide range of gross vehicle weights and rates o rise and fall, may be increased by 10 percent and used to represent the fuel characteristics of vehicles now in actual commercial service.

Gasoline consumption rates in the 1937 Oregon study and the 1958 study were quite similar in the lower gross vehicle weights but the Oregon study gasoline consumption rates were higher by nearly 20 percent for the gross vehicle weights at 50,000 lb. Diesel-fuel consumption figures in the Oregon study were lower than the 1958 study diesel consumption rates by as much as 30 percent in the lower weight ranges but were almost identical for gross vehicle weights at 50,000 lb.

AVERAGE TIME CONSUMPTION RATES

The travel time consumption rate of commercial motortrucks in rural line-haul ope ation was analyzed in two different ways. The first analysis was made to determine th travel time of vehicles for all trips, without considering rise and fall or traffic frictio This analysis was made in a manner similar to that used for determining the fuel-consumption rates. Actual and computed travel time consumption rates are given in Tabl 8. In Figure 6, straight lines are used to relate travel time and gross vehicle weight for each of the engine characteristic groups. It is seen that vehicles with engine displacement size of 302-406 cu in., which traveled at a rate of 1.59 min per mi with a GVW of 30,000 lb, traveled at 1.85 min per mi when the GVW was 60,000 lb. Vehicle in the 450-549-cu in. engine size group traveled 1.46 and 1.72 min per mi at corresponding weights. The straightline relationships for these two engine groups were approximately parallel, indicating a constant rate of increase in travel time consumed

TABLE 8

RATES OF TRAVEL TIME CONSUMPTION FOR TRUCKS IN RURAL LINE-HAUL SERVICE IN FIVE STATES, 1957-58[a]

Gross Vehicle Weight (lb)	Time-Consumption Rates (min/mi)								
	302-406 cu in., Gasoline (140 hp) Engine		450-549 cu in., Gasoline (171 hp) Engine		590 cu in., Gasoline (225 hp) Engine		Gasoline Engine Average–	743 cu in., Diesel (200 hp) Engine	
	Actual	Computed[b]	Actual	Computed[b]	Actual	Computed[b]	Actual	Actual	Computed[b]
17,000	1.434	1.478	-	-	-	-	1.434	-	-
21,300	1.506	1.514	-	-	-	-	1.506	-	-
27,000	1.649	1.563	1.467	1.436	1.606	1.593	1.592	-	-
34,500	1.619	1.627	1.520	1.501	1.590	1.626	1.596	1.636	1.567
42,000	1.687	1.691	1.526	1.566	1.662	1.659	1.620	1.460	1.571
51,200	1.728	1.769	1.626	1.645	1.738	1.699	1.692	1.616	1.576
59,500	1.859	1.840	1.660	1.717	1.724	1.735	1.696	1.569	1.580
67,900	-	-	1.859	1.790	1.761	1.771	1.797	1.598	1.585
Average	1.638	-	1.586	-	1.696	-	1.625	1.559	-

[a]Average rate of rise and fall, 1.2 ft per 100 ft.
[b]Computed rates are based on the following formulas: 302-406 cu in., 1.333+0.008516W; 450-549 cu in., 1.203+0.008642W; 590 cu in., 1.476+0.004347W; and 743 cu in., 1.549+0.000526W. (W-GVW in thousands of pounds.)

with increase in gross vehicle weights.

The vehicles with 743-cu in. diesel engines maintained a much more constant speed with respect to gross vehicle weights than those with the larger gasoline engines, showing an increase of only 0.02 min per mi from 30,000- to 60,000-GVW.

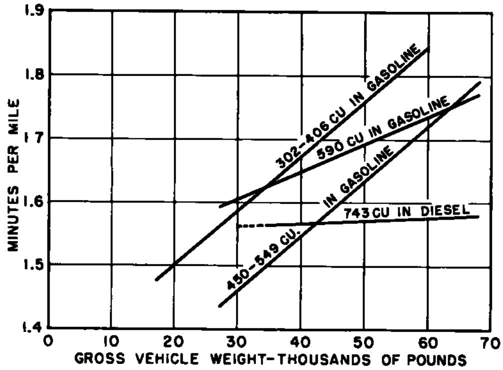


Figure 6. Comparison of average time consumption rates of rural line-haul trucks by engine size for 1.2 rise and fall.

The travel time consumption rates of commercial vehicles in urban line-haul and in city pickup and delivery service are shown in Table 9. Although time-consumption rates were not found to vary in a uniform manner with gross vehicle weight, it was noted that as the power characteristics of engines increased the time consumption decreased. Referring to the average time-consumption rates for all gasoline-powered vehicles (Tables 8 and 9) it will be seen that vehicles in rural line-haul service traveled at an average rate of 1.625 min per mi, or 36.9 mph; vehicles in urban line-haul traveled at 3.156 min per mi or 19.0 mph; and all city pickup and delivery vehicles at 5.443 min per mi or 11.0 mph. Similar figures for diesel-powered vehicles were 1.559 min per mi, or 38.5 mph for rural line-haul operation, and 2.740 min per mi, or 21.9 mph for urban line-haul operation.

Average Speeds in Free-Flowing Traffic

The second analysis made of travel time for rural line-haul operations involved the desired speeds at which vehicles traveled in free-flowing traffic when they apparently were unrestricted except by speed limits or safe driving speeds. It was possible to study the speeds by analyzing time-consumption rates on certain highway sections in Ohio and Washington where trucks traveled without experiencing more than two slow-downs per mile and no stops. The average operating speeds under these conditions were related to the four groupings of engine sizes and power characteristics and to gross vehicle weight (Table 10 and Fig. 7).

Travel time, in minutes per mile, increased sharply as the gross weight of gasoline-powered commercial trucks in the lowest range of engine size and power increased. Conversely, of course, average road speeds decreased sharply. However, as the engine horsepower and gross vehicle weight increased, the travel time increase was less pronounced. This is reflected by the steepness of the slope of the lines per 10,000-lb

TABLE 9

SUMMARY OF TRAVEL TIME CONSUMPTION RATES FOR URBAN LINE-HAUL FREIGHT VEHICLES AND CITY DELIVERY VEHICLES

Time-Consumption Rates (min/mi) for Urban Line-Haul Vehicles						Time-Consumption Rates (min/mi) for City Delivery Vehicles	
Gross Vehicle Weight (lb)	302-406 Cu In. Gasoline Engine	450-549 Cu In. Gasoline Engine	590 Cu In. Gasoline Engine	Average Gasoline Engine	743 Cu In. Diesel Engine	Gross Vehicle Weight (lb)	All Gasoline Engines
17,000	3.207	2.868	-	3.105	-	4,600	8.854
21,300	2.909	3.473	-	2.987	-	6,000	5.736
17,000	3.388	2.818	2.957	3.182	2.556	10,500	6.181
34,500	3.260	2.973	2.378	3.136	2.353	14,500	5.125
42,000	3.274	3.082	2.728	3.167	2.597	18,500	4.500
51,200	3.513	2.914	2.283	3.253	2.901	22,500	5.502
59,500	4.533	2.987	2.532	3.435	3.043	27,500	4.847
67,900	4.486	2.630	2.815	3.039	2.784	33,300	4.184
Average	3.306	2.997	2.671	3.156	2.740	Average	5.443

TABLE 10

AVERAGE SPEEDS OF GASOLINE- AND DIESEL-POWERED TRUCKS, EXPERIENCING LESS THAN TWO SLOWDOWNS PER MILE AND NO STOPS IN OHIO AND WASHINGTON RURAL LINE-HAUL OPERATION[a]

Gross Vehicle Weight (lb)	Time-Consumption Rates[b]							
	302-406 Cu In. Gasoline Engine		450-549 Cu In. Gasoline Engine		590 Cu In. Gasoline Engine		743 Cu In. Diesel Engine	
	Min/mi	Mph	Min/mi	Mph	Min/mi	Mph	Min/mi	Mph
17,000	1.34	44.8	-	-	-	-	-	-
21,300	1.38	43.5	-	-	-	-	-	-
27,000	1.43	42.0	1.35	44.4	1.36	44.1	-	-
34,500	1.50	40.0	1.40	42.9	1.38	43.5	1.483	40.5
42,000	1.57	38.2	1.44	41.7	1.40	42.9	1.486	40.4
51,200	1.65	36.4	1.50	40.0	1.43	42.0	1.490	40.3
59,500	-	-	1.56	38.5	1.45	41.4	1.493	40.2
67,900	-	-	1.61	37.3	1.47	40.8	1.497	40.1

[a]Average rate of rise and fall, 1.3 ft per 100 ft.
[b]Rates were computed by the following formulas: 302-406 cu in., mpm, 1.18035+0.00916W; mph, 49.1986-0.25747W. 450-549 cu in., mpm, 1.17435+0.00643W; mph, 49.2757-0.17956W. 590 cu in., mpm, 1.2909+0.00264W; mph, 46.0567-0.07742W. 743 cu in., mpm, 1.4696+0.00040W; mph, 41.1719-0.01905W. (W=GVW in thousands of pounds.)

increase in GVW. For the lowest gasoline-powered engine size, the rate increased 0.09 min per mi for each increase of 10,000 lb in GVW. For the medium gasoline-powered engine size, the corresponding increase was 0.06 min per mi, and for the 590-cu in. engine gasoline-powered vehicles and the diesel-powered vehicles the increases were 0.03 and 0.01 min per mi, respectively.

The relative performance of the four groupings of vehicles (Fig. 7) point up the consideration that while better fuel economy is attained with smaller engines for the gross vehicle weights investigated, the penalty of using smaller engines is an increase in travel time consumption at higher vehicle weights.

Time-Consumption Rates Compared

Another important use of the current study data was in comparison with the average time-consumption rates reported in the 1948 Pennsylvania study (2). Travel-time-consumption rates for the two studies are shown in Figure 8, using the average rates for all vehicles.

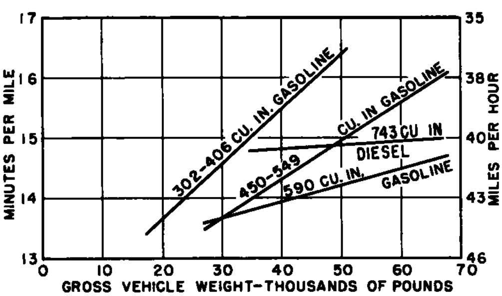


Figure 7. Average time consumption rates for trucks operating in free-flowing traffic on rural line-haul service with an average rate of rise and fall of 1.3 feet per 100 feet.

The time-consumption rates obtained in the 1958 study, considering the average travel time for all conditions of traffic, are labeled "average traffic" (Fig. 8) and were found to be 26 percent higher than corresponding data reported in the Pennsylvania study. A comparison of greater significance, however, can be made between the 1958 study ("free-flowing traffic") and those of 1948 Pennsylvania study, because both were made under similar conditions. The time-consumption rates of gasoline-powered trucks traveling in free-flowing traffic were 10 percent higher than corresponding data reported in the Pennsylvania study.

EFFECT OF TRAFFIC ON PERFORMANCE

One of the main objectives of the study was to investigate the effect of varying traffic volumes on the performance of commercial vehicles. Other studies (1 through 4) have made a good start in determining the fuel consumption and travel time for uniform speeds, stops and starts, and slowdowns; and in finding out how certain factors, such as gradient, rise and fall, horizontal curvature, gross vehicle weight, and engine characteristics, affect fuel and time consumption. However, little has been available in the literature as to the effect of varying traffic volumes.

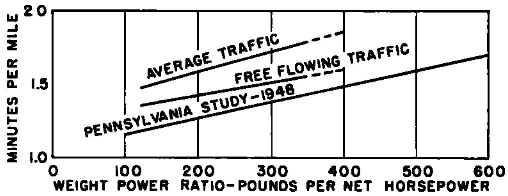


Figure 8. Comparison of 1957-58 travel time rates for rural line-haul gasoline-powered trucks for 1.2 rate of rise and fall with 1948 Pennsylvania study data based on 1.3 rate of rise and fall.

It was hoped that this study would provide a means for estimating the added operating cost brought about by frictions in the traffic stream. The basic approach was one of considering the number of speed changes per mile for varying volume conditions, the percentage of the total number of speed changes that were stops and starts, and the average speed change in terms of miles per hour of a stop or slowdown. It was reasoned that if such information could be provided, the added cost for having to operate other than at a uniform speed could readily be assessed.

Speed Changes per Mile

What are probably the most significant results of this study, speed changes per mile, were computed for trucks with different gross weights operating over three types of rural highways with varying average daily traffic and are shown in Table 11. An attempt was made to develop similar data for urban operation, but the lack of traffic data for the irregular routes traveled made this impossible.

TABLE 11

SPEED CHANGES PER MILE MADE BY TRUCKS OPERATING OVER THREE TYPES OF RURAL HIGHWAYS WITH VARYING AVERAGE DAILY TRAFFIC

Average Daily Traffic	Highway Section Mileage	Number of Trips	Total Miles Traveled	Speed Changes per Mile for Vehicles with Average GVW (1,000 lb) 17.0	23.1	27.4	36.3	43.7	52.2	Average
(a) 4-Lane Divided, Controlled Access										
46,700	6.56	54	354.24	1.56	2.05	-	2.38	2.71	2.36	2.19
23,300	3.62	54	195.48	0.62	0.83	-	1.17	1.90	1.99	1.24
12,700	8.19	54	442.46	0.38	0.62	-	0.53	0.66	0.74	0.60
(b) 4-Lane Undivided, Uncontrolled Access										
15,700	31.71	54	1,712.34	1.73	1.79	-	2.12	2.35	2.34	2.03
10,300	48.78	54	2,634.12	1.59	1.55	-	2.07	2.03	2.12	1.82
5,200	5.67	52	153.79	-	1.19	-	1.58	1.47	1.73	1.53
(c) 2-Lane										
8,800	27.30	56	1,528.80	-	-	2.75	2.74	2.61	2.69	2.71
6,000	57.58	56	3,224.48	-	-	2.24	2.14	2.15	2.31	2.18
2,000	20.52	56	1,149.12	-	-	1.59	1.48	1.35	1.70	1.50

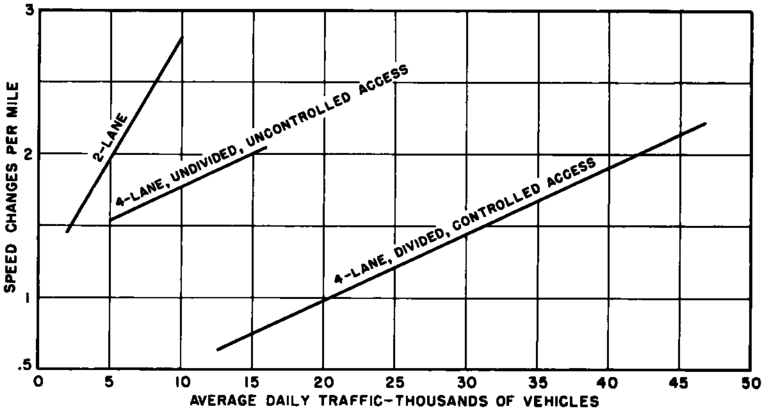


Figure 9. Average speed changes per mile for rural line-haul trucks, by average daily traffic and type of highway.

The average values of speed changes per mile (Table 11) are shown as straightline relationship (Fig. 9) established for the three types of highways. The benefits accruing from the elimination of impediments to free-flowing traffic are clearly illustrated by comparing the speed changes per mile on the 4-lane divided, controlled-access facility with those on the 4-lane undivided, uncontrolled-access facility. For an average daily traffic of 15,000 vehicles, there were an average of 2.0 speed changes per mile on the 4-lane uncontrolled-access highway as compared with a rate of about 0.8 on the 4-lane controlled access highway. Speed changes per mile on 2-lane highways increase from 2.0 to 2.8 where the average daily traffic increased from 5,000 to 10,000. In contrast, speed changes per mile on the 4-lane uncontrolled-access highway increased from 1.5 to 1.8 over the same average daily traffic range.

Data for 4-lane divided highways with no access control were not obtained in sufficie quantity for analysis. It is reasonable to expect that the relationship for this type of highway would fall between that for the two 4-lane highways shown in Figure 9, and would probably lie closer to the 4-lane undivided, uncontrolled-access highway.

Analysis of Speed Changes

Of considerable importance were the percentages of total speed changes representing stops and slowdowns. Speed changes caused by stops and slowdowns are given in Table

TABLE 12

NUMBER AND PERCENTAGE OF SPEED CHANGES OCCASIONED BY SLOWDOWNS AND STOPS OF TRUCKS IN WASHINGTON AND OHIO RURAL AND URBAN LINE-HAUL TRAVEL

	Washington			Ohio			Total		
Speed Changes	Slow-downs	Stops	Speed Changes	Slow-downs	Stops	Speed Changes	Slow-downs	Stops	Speed Changes
Rural line-haul:									
Number	5,358	795	6,153	8,036	935	8,971	13,393	1,731	15,124
Percent	87.1	12.9	100.0	89.6	10.4	100.0	88.6	11.4	100.0
Urban line-haul:									
Number	1,220	613	1,833	1,581	1,688	3,269	2,801	2,301	5,102
Percent	66.6	33.4	100.0	48.4	51.6	100.0	54.9	45.1	100.0

12 from results of the studies made in Ohio and Washington, the only states where stops were recorded. On the average, complete stops occasioned about 11 percent of the speed changes in rural line-haul operations and about 45 percent in urban line-haul operations.

Compiled from the limited data available, an analysis of speed changes in miles per hour was made and it was found that an average stop in rural areas was made from a speed of 26 mph. On city streets the average stop was made from a speed of 18.9 mph. The average change in speed for slowdowns in both rural and urban areas was 11.4 mph.

To illustrate the significance of a speed change in terms of motor-fuel consumption and to confirm that fuel consumption increases with an increasing number of speed changes per mile, gasoline-consumption rates were computed for road sections having different rates of speed change per mile, for different gross-vehicle weights. The average rates are given in Table 13 for the three types of operation.

The straightline relationships established for the data in Table 13 are shown in Figure 10. An increase of one speed change per mile for a vehicle weighing 30,000 lb traveling on a rural highway resulted in an average fuel-consumption increase of 0.010 gal per mi. The corresponding increase for vehicles in urban line-haul operation was

TABLE 13

GASOLINE-CONSUMPTION RATES FOR TRUCKS IN LINE-HAUL AND CITY PICKUP AND DELIVERY OPERATION FOR VARIOUS RATES OF SPEED CHANGE PER MILE

Average Gross Vehicle Weight (lb)	Gasoline-Consumption Rates in Gallons per Mile for Indicated Number of Speed Changes per Mile						
	1	3	4	5	7	9	12
Line-haul, rural:							
17,000	0.134	0.142	-	0.160	0.181	-	
34,500	0.180	0.198	-	0.226	0.250	-	-
42,000	0.200	0.222	-	0.255	0.279	-	-
53,000	0.228	0.257	-	0.300	0.322	-	-
57,000	0.239	0.270	-	0.311	-	-	-
68,000	0.268	0.305	-	-	-	-	-
Average	0.197	0.220	-	0.251	0.279	-	-
Line-haul, urban:							
17,000	0.143	0.149	-	0.153	-	-	-
26,000	0.159	0.180	-	0.198	-	0.324	-
28,000	-	-	-	-	0.246	-	-
52,000	0.206	0.268	-	0.328	0.409	0.426	-
58,000	0.217	-	-	-	-	-	-
59,000	-	0.292	-	-	0.457	-	-
61,000	-	-	-	0.373	-	-	-
62,000	-	-	-	-	-	0.465	-
Average	0.185	0.224	-	0.269	0.333	0.382	-
City pickup and delivery:							
6,000	-	-	0.111	-	-	-	0.145
10,500	-	-	0.131	-	-	-	0.167
18,500	-	-	0.165	-	-	-	0.206
27,500	-	-	0.204	-	-	-	0.250
33,300	-	-	0.229	-	-	-	0.279
Average	-	-	0.143	-	-	-	0.168

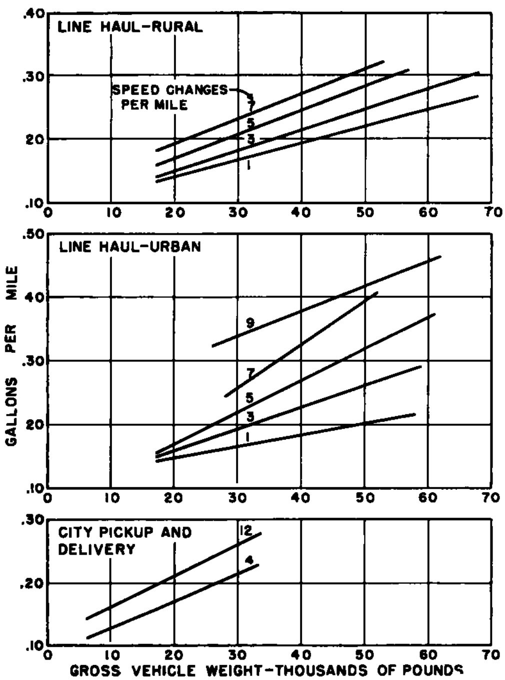


Figure 10. Gasoline consumption rates, by rate of speed change per mile and by gross vehicle weight, for line-haul and city delivery vehicles.

0.021 gal per mi, and for city delivery vehicles the average increase was 0.0056 gal per mi. The greater rate of speed change for urban line-haul operation as compared to rural line-haul operation is probably due to the higher incidence of stops and slowdowns. City pickup and delivery vehicles consume less gasoline per speed change than the urban line-haul vehicles because stops and slowdowns are of lesser magnitude, as evidenced by an average speed of 11 mph.

Also of importance is the indication that fuel consumption attributable to a speed change increases with gross vehicle weight. For example, the fuel consumed for an increase of one speed change per mile for rural line-haul operations was 0.0092 gal for vehicles with 20,000-lb GVW and 0.0142 gal for 50,000-lb GVW.

Data for travel time-consumption rates due to one speed change per mile were also developed (Table 14). The average time-consumption rate did not appear to increase with gross weight but the average value for all gross vehicle weights increased as the speed changes per mile increased.

The average time consumed in one speed change for rural line-haul operation was found to be 0.26 min, or 15.6 sec; for urban line-haul operation 0.27 min, or 16.2 sec; and for city pickup and delivery operation 0.38 min, or nearly 23 sec. In spite of the fact that the speeds from which stops and slowdowns were made were higher in rural than in urban line-haul operation, the time consumption per speed change is about equal, probably because the percentage of total speed changes that are stops is much higher in the urban line-haul.

The increased fuel- and time-consumption rates for one speed change have been developed principally for illustrative purposes, although they can be used in estimating benefits. When data are available from controlled tests (3, 4) on a variety of vehicles, the data herein presented may be refined.

COST OF A SPEED CHANGE

The approximate cost of a stop is included in this article more as a matter of interest than with the idea of establishing valid cost values. Many sections of rural highway studied were traveled by line-haul vehicles without experiencing any stops and with less than two slowdowns per mile. Likewise certain urban sections of highway studied were traveled by line-haul vehicles with a high incidence of stops but with less than two slowdowns per mile.

To estimate the cost of a stop the entire fuel consumption rate for the rural travel with no stops was subtracted from the fuel-consumption rate for urban travel where a high incidence of stops occurred. The difference is attributed solely to the effect of stops because slowdowns were the same in both instances. It should be remembered though, that the average stop was made from 26 mph in rural areas and 19 mph in urban areas. Dividing the total consumption per mile due to traffic stops by the number of stops per mile gave the consumption rates per stop (Table 15). Gasoline consumed per stop showed a definite increase as the GVW increased. For example, if a cost per gallon of fuel of 30 cents is used, the cost of a stop would range from one-half cent for

TABLE 14

AVERAGE TRAVEL TIME-CONSUMPTION FOR TRUCKS IN LINE-HAUL AND CITY PICKUP AND DELIVERY OPERATIONS FOR VARIOUS RATES OF SPEED CHANGES PER MILE

Type of Travel	Average Time Consumption in Minutes per Mile For the Indicated Number of Speed Changes per Mile							Avg Time Lost per Speed Change (min)
	1	3	4	5	7	9	12	
Rural	1.48	1.89	-	2.33	3.05	-	-	0.26
Urban	2.35	2.69	-	3.20	3.81	4.53	-	0.27
City pickup and delivery	-	-	4.39	-	-	-	7.43	0.38

TABLE 15

GASOLINE CONSUMPTION RATES FOR TRUCKS IN LINE-HAUL OPERATION DUE TO TRAFFIC STOPS, BY GROSS VEHICLE WEIGHT

Gross Vehicle Weight (lb)	Gallons per Stop	
	Actual Rate	Computed Rate[a]
17,000	0.014	0.017
21,300	0.030	0.024
27,000	0.034	0.034
34,500	0.044	0.046
42,000	0.054	0.058
51,200	0.076	0.073

[a]Computed from straightline formula 0.001625W-0.0103. (W=GVW in thousands of pounds.)

a GVW of 17,000 lb to more than 2 cents for a GVW of 51,000 lb.

Knowing the number of speed changes saved, the proportion of stops and slowdowns, and the magnitude of each, it is possible to compute the added cost of fuel and travel time of a speed change if the extra fuel and time consumed during the speed change is known. Thus, using speed changes per mile as a measure of congestion, the benefits may be computed that accrue from highway improvements that reduce congestion. It is realized that at present the tool is rough, but it can be refined. This is planned, using digital recorders instead of human observers.

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