Impact of Using Freeway Shoulders as Travel Lanes on Fuel Consumption

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A general procedure, based on data derived from the American Association of State Highway and Transportation Officials "Redbook", to compute the savings in fuel consumption that result from the use of low-cost conversions of urban freeway shoulders to travel lanes is presented. The data required for the analysis are traffic volumes, speeds, and vehicle classifications before and after the improvements. Three example projects are presented to illustrate the range of benefits in terms of total travel time and fuel consumption. The projects were implemented in Houston with three different objectives: relieve a main-lane freeway bottleneck, bypass a main-lane queue, and provide priority operation for high-occupancy vehicles (HOVs). The results of the study indicate that major improvements in traffic operations can be achieved from the additional capacity provided by the shoulder lanes. The magnitude of the improvements depends on the type of use of the lane, the geometric design, and the traffic conditions in the freeway section to be modified. In the three examples, the annual savings in fuel ranged from 187 875 gal for relieving a bottleneck to 7890 gal for bypassing main-lane queues to 3423 gal for HOV priority operations. The savings are the result of improvements in the average speeds of vehicles that use the modified sections. If the improvements can be related to a modal shift for the HOV priority operations, the savings are much greater.

Over the years, design standards have established a typical cross section for urban freeways with six or more lanes to be 12-ft lanes with 8- to 10-ft shoulders on both sides of the roadways. However, rising traffic demands and declining financial resources have forced transportation agencies to consider modification of these design standards to increase capacity. One approach that is inexpensive and fast to implement is the conversion of the roadway shoulders to travel lanes. The advantages of increasing capacity of a section "overnight" are obvious: increased service volumes, lower travel times, and reduced traffic delays. There are also disadvantages, both to the users and the transportation agency: the quality of ride may be less than desirable, the reduction of space available for emergency parking increases the potential for accidents that involve disabled vehicles, and the pavement structure of the shoulder may not be designed to handle the increased loads, thereby resulting in increases in maintenance costs and a need for early replacement of the shoulder. There was concern that the total accident rate would increase, but that has not happened (1).

There are ways to reduce or eliminate these disadvantages:

1. The shoulder can be strengthened and the riding surface can be improved prior to the conversion,
2. A temporary shoulder or special vehicle turnout bays can be constructed for disabled vehicles, and
3. The traffic loads applied to the shoulder can be reduced by restricting the use by heavier vehicles and/or restricting the use to peak periods only, when the additional capacity is needed.

These measures can also extend the life of the shoulder for many years.

There are several reasons for considering the use of the shoulder for travel (1):

1. Overloading the outside lane: The shoulder can be converted to an auxiliary lane.
2. Bypassing main-lanes queues: Queues formed at freeway-to-freeway interchanges can block traffic movements that are not required to pass through the bottleneck.
3. Relieving freeway bottlenecks: Freeway sections that have traffic demands that exceed the roadway capacity can benefit from the added capacity.
4. Reducing merge conflicts: Freeway interchange merge areas that are overloaded or are high accident locations can be improved by using the shoulder on one roadway to move the merge area away from the interchange or to eliminate it entirely.
5. Providing for priority operation of high-occupancy vehicles (HOVs): A shoulder can be converted to an HOV-only lane to provide a higher level of service during peak periods.
6. Improving capacities in work zones: Shoulders can be used to restore some of the capacity lost by lane closures for maintenance and construction activities.

BENEFITS OF USING SHOULDERS FOR TRAVEL

The primary benefit in the conversion of the shoulder to a travel lane is the increase in capacity at very low costs. The amount of benefits will vary greatly, depending on the reason for the conversion, the geometric design of the section, and the traffic conditions. The following examples are presented to illustrate the range of benefits that can be obtained.

Example A: Relieving a Freeway Bottleneck

The Southwest Freeway (US-59) in Houston was restriped to add an additional lane for a distance of 1 mile (2) (see Figure 1). The section was four lanes for one-third of a mile and three lanes for two-thirds of a mile. The added lane changed the cross section to five lanes for one-third of a mile, four lanes for one-third of a mile, and three lanes for one-third of a mile. In this example, the additional lane had a very high use because of the high volumes destined for the two exit ramps. The results were an increase of 22 percent in the service volumes to 1700 vehicles/h, a reduction in total travel time during the 2-h peak period of 1000 vehicle-h, and an increase in the average speeds from 20 to 40 mph over a distance of 3 miles (2 miles upstream of the modified section).

Many projects have reported similar results [Table 1 (3)], such as

1. Denver, on I-25, with travel time savings of 500 vehicle-h, and the speeds increased from 26 to 46 mph, and
2. Los Angeles, on the Santa Monica Freeway (I-10), with travel time savings of 850 vehicle-h, and the speeds increased from 22 to 40 mph (3).

Example B: Bypassing Main-Lane Queues

The West Loop Freeway (I-610) in Houston was restriped to provide a bypass lane 0.5 mile in advance of the interchange of I-10 (see Figure 2). The traffic in the evening peak period destined for westbound (outbound) I-10 formed queues of a maximum

Figure 1. Use of shoulder lane on Southwest Freeway (US-59) in Houston.

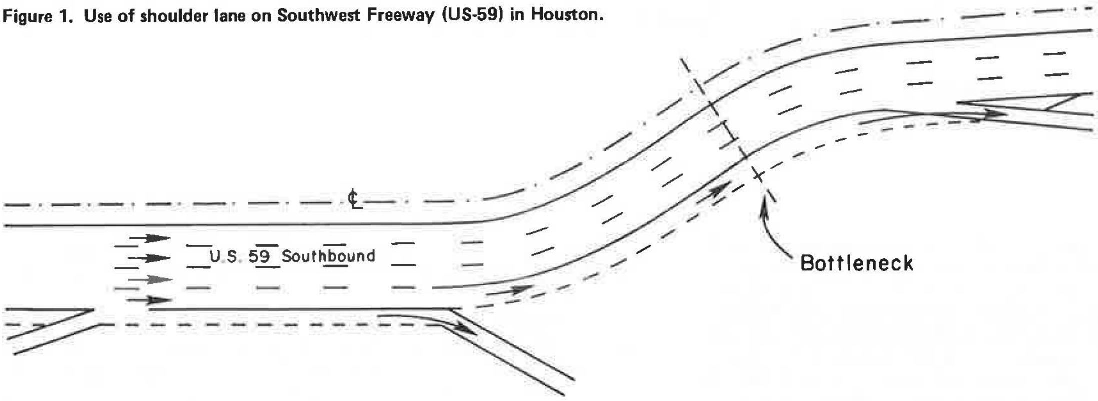
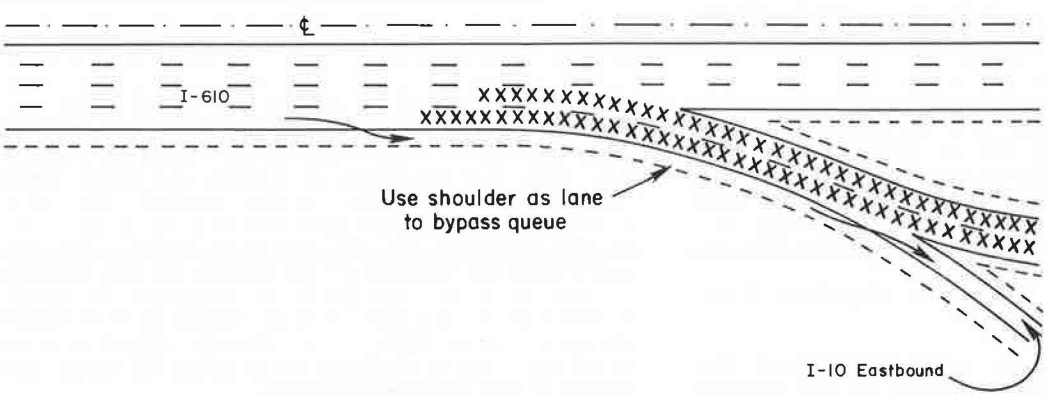


Table 1. Summary of operational experience.

City	Freeway	Capacity Increases (vehicles/h) Before	After	Delay Reduction (vehicle-h/day)	Speed Increase (mph) Before	After
Denver	I-25	6376	7146	500	26	46
Houston	Southwest (US-59)	5800	7100	1000	-	-
Los Angeles	Santa Monica (I-10)	7680	9600	850	22	40
	San Bernardina	6900	7600	850	-	-
	Pomona	-	-[a]	100	30	40
	Ventura	7700	8500	750	30	56
	Golden State	-	-[b]	820	37	55
	Santa Ana	7700	8500	625	20	50
Nashville	I-65, I-265	4150	5200	-	-	-[d]
Portland	I-5, I-405	3400	4120	-	-	-[d]
	Banfield	-	-[c]	-	33	38
San Francisco	CA-280	5460	7090	250	-	-

[a]Increased capacity by providing a truck climbing lane.
[b]Increased volumes.
[c]Vehicles increased by 2 percent and persons increased by 10 percent.
[d]Free flow.

Figure 2. Use of shoulder lane on West Loop Freeway in Houston.



length of 1 mile. The traffic destined for eastbound I-10 was delayed unnecessarily. Providing the bypass lane during the peak period saved 16 vehicle-h for 830 vehicles that used the 0.5-mile bypass. This represents an increase in speeds from 20 to 45 mph.

Example C: HOV Priority Lane

The 3 miles of the inside shoulder of the North Freeway (I-45) in Houston was converted to an HOV priority lane for vehicles that were authorized to use a contraflow lane (4) (see Figure 3). There are 62 buses and 218 vanpool vehicles that use the shoulder lane during the morning peak period. Travel time savings to HOVs were 3.17 min/vehicle, which resulted in a daily savings of 14.8 vehicle-h. In terms of persons carried, the savings were much more significant, resulting in 190 person-h/day. The average speeds for HOVs increased from 26 to 48 mph, while the speeds in the main lanes were unchanged.

Many other projects can be cited for all of the various reasons for converting shoulders to travel, and each would have a unique set of benefits in terms of travel time saved and improvements in average speeds.

IMPACT ON FUEL CONSUMPTION

Estimates of savings of fuel as a result of the

Figure 3. Use of median shoulder as HOV lane on North Freeway (I-45) in Houston.

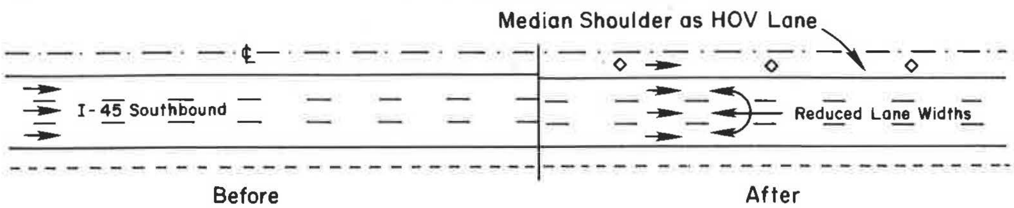


Table 2. Fuel-consumption rates for vehicle type 1 on freeways by LOS and average speed.

Avg Speed (mph)	Fuel Consumption (gal/vehicle mile) by Level of Service					
	A	B	C	D	E	F
5						0.3970
10						0.1649
15						0.1028
20						0.0772
25						0.0641
30					0.0433	0.0574
35				0.0420	0.0428	0.0431
40			0.0426	0.0429	0.0444	
45		0.0427	0.0443	0.0450	0.0465	
50	0.0438	0.0454	0.0471	0.0486		
55	0.0468	0.0489	0.0512			
60	0.0494	0.0519				
65	0.0567					

Note: Table is based on the proportion of fuel cost to total cost at various speeds as reported in the 1977 AASHTO Redbook (5) and applied to total costs as reported in Buffington and McFarland (7). The table is adjusted for 1980 costs of fuel. The fuel costs of the latter report were originally based on the fuel-consumption rates reported by Claffey (8) and Winfrey (9).

Table 4. Fuel-consumption rates for vehicle type 3 on freeways by LOS and average speed.

Avg Speed (mph)	Fuel Consumption (gal/vehicle mile) by Level of Service					
	A	B	C	D	E	F
5						3.1346
10						1.0550
15						0.5660
20						0.3784
25						0.2963
30					0.1567	0.2445
35				0.1503	0.1552	0.1613
40			0.1529	0.1566	0.1646	
45		0.1613	0.1676	0.1722	0.1745	
50	0.1778	0.1860	0.1951	0.2026		
55	0.1928	0.2041	0.2167			
60	0.2017	0.2128				
65	0.2208					

Note: Table is based on fuel-consumption rates and fuel costs as a proportion of total costs as reported in the 1977 AASHTO Redbook (5) and on total costs reported by Buffington and McFarland (7). The table is adjusted for 1980 costs of fuel.

Table 3. Fuel-consumption rates for vehicle types 2 and 4 on freeways by LOS and average speed.

Avg Speed (mph)	Fuel Consumption (gal/vehicle mile) by Level of Service					
	A	B	C	D	E	F
5						0.6765
10						0.3491
15						0.2249
20						0.1772
25						0.1635
30					0.1139	0.1577
35				0.1250	0.1281	0.1319
40			0.1329	0.1346	0.1395	
45		0.1412	0.1457	0.1486	0.1528	
50	0.1486	0.1542	0.1603	0.1654		
55	0.1613	0.1687	0.1769			
60	0.1782	0.1862				
65	0.1981					

Note: Table is based on fuel-consumption rates and fuel costs as a proportion of total costs as reported in the 1977 AASHTO Redbook (5) and on total costs reported by Buffington and McFarland (7). The table is adjusted for 1980 costs of fuel.

improved traffic operations can be determined from the vehicle miles of travel at the average speed for the before and after conditions. Fuel-consumption rates for freeways have been developed from data reported in the 1977 American Association of State Highway and Transportation Officials (AASHTO) "Redbook" (5) and updated to 1980 costs by Buffington and McFarland (6) (see table below and Tables 2-4):

Vehicle Type No.	Vehicle Type Description
1	Automobiles, pickups, and panel trucks (2-axle, 4-tire)
2	Single-unit trucks (other than 2-axle, 4-tire)
3	Truck tractor-semitrailer or trailer combinations
4	Buses

The rates in Tables 2-4 provide conservative measures, since the average fuel-consumption rates have continued to decline with newer vehicle models.

The fuel-consumption tables provide a range of values at speeds greater than 30 mph based on the quality of flow as measured by the level of service (LOS). Any type of freeway improvement can be analyzed if before-and-after data on traffic volumes, speeds, and composition of traffic are known. For the study of the conversion of shoulders to travel lanes, LOS D is used to describe the after conditions because of the reduction of lateral clearances, quality of roadway surface, and lane widths. For the example projects, the impact on fuel consumption is calculated in the following manner.

Example A: Relieving a Freeway Bottleneck

The statistics for this example are as follows:

13 800 vehicles during a 2-h peak period,
20-mph before speed (LOS F),
40-mph after speed (LOS D),
3-mile length of freeway affected by modification,
97 percent type 1 vehicles (passenger cars, light trucks),
2 percent type 2 and 4 vehicles (medium trucks and buses), and
1 percent type 3 vehicles (heavy trucks)

The change in the vehicle fuel-consumption rate is as follows (from Tables 2-4):

$$(0.97)(0.0772 - 0.0429) + (0.02)(0.1772 - 0.1346) + (0.01)(0.3784 - 0.1566) = 0.0363 \text{ gal/vehicle mile.}$$

The average daily savings can be calculated for the total vehicle miles traveled during the peak period:

Table 5. Summary of example projects.

Project Designation	No. of Vehicles Affected	Change in Speed (mph) Before	After	Length of Project (miles)	Change in Travel Time (vehicle-h)	Change in Fuel Consumption (gal/year)
A	13 800	20	40	3.0	-1000	-187 875
B	830	20	45	0.5	-16	-7 890
C	280	26	48	3.0	-14.8	-3 423
C′	2 765	48	26	3.0	+304	+115 135

Table 6. Speed-fuel relation for passenger cars.

Travel Time (min/mile)	Avg Speed (mph)	Fuel Consumption (gal/mile)	Fuel Economy (miles/gal)
60.0	1	0.7822	1.278
20.0	3	0.2849	3.510
12.0	5	0.1854	5.394
8.6	7	0.1428	7.004
6.7	9	0.1191	8.397
5.5	11	0.1040	9.614
4.6	13	0.0936	10.686
4.0	15	0.0859	11.637
3.5	17	0.0801	12.487
3.2	19	0.0755	13.251
2.9	21	0.0717	13.942
2.6	23	0.0686	14.570
2.4	25	0.0660	15.142
2.2	27	0.0638	15.667
2.1	29	0.0619	16.149
1.9	31	0.0603	16.594
1.8	33	0.0588	17.005
1.7	35	0.0575	17.387

0.0363 gal/vehicle mile x 13 800 vehicles x 3 miles = 1503 gal of fuel saved each weekday.

These benefits are only achieved when the roadway operates without incident. The number of incident-free days is assumed to be 125/year, which results in an annual savings of 187 875 gal of fuel.

Example B: Bypassing Main-Lane Queues

The statistics for this example are as follows:

830 vehicles use the 0.5-mile bypass lane,
20-mph before speed (LOS F) on incident-free days,
10-mph before speed (LOS F) on incident days,
45-mph after speed (LOS D), and
Only type 1 vehicles can use the bypass lane.

The average change in the vehicle fuel-consumption rate for nonincident days is as follows:

(0.0772 - 0.0450) = 0.0322 gal/vehicle mile.

For incidents days it is

(0.1649 - 0.0450) = 0.1199 gal/vehicle mile.

The annual savings in fuel consumption are

(0.0322 gal/vehicle mile + 0.1199 gal/vehicle mile) 830 vehicles) (0.5 mile) (125 days) = 7890 gal.

Example C: HOV Priority Lane

The statistics for this example are as follows:

62 buses (type 4) and 218 vanpools (type 1) use the 3-mile priority lane each weekday,
26-mph before speed (LOS F), and
48-mph after speed (LOS D).

The before speed is assumed to be the same for incident days. The average change in the vehicle fuel-consumption rate is

(62/280) (0.1775 - 0.1587) + (218/280) (0.0628 - 0.0472) = 0.0163 gal/vehicle mile.

The annual savings in fuel consumption are

0.0163 gal/vehicle mile x 280 vehicles x 3 miles x 250 days = 3423 gal.

Example C': Elimination of HOV Priority Lane and Return to Passenger Vehicles

If the 3595 persons who use the buses and vanpools in the HOV lane were to switch back to passenger vehicles and use the main lanes at an average speed of 26 mph, the fuel consumption would be

3595 persons ÷ 1.3 persons/vehicle x 0.0628 gal/vehicle x 3 miles x 250 days/year = 130 232 gal, compared with 15 097 gal used in the priority lane.

Table 5 summarizes the results of the example projects.

MAINTENANCE AND RECONSTRUCTION OF SHOULDER USE

Routine maintenance of a shoulder lane can be conducted during off-peak periods when volumes can be accommodated on the main lanes of the freeway without additional delay and operating costs to the motorists. However, if the shoulder must be rebuilt, the capacity of the freeway will be less than the original capacity. The additional energy expended during construction by traffic that is displaced by the reduced capacity can then be estimated.

Consider example A. To reconstruct the shoulder lane, the capacity of the three original lanes would be reduced to 5100 vehicles/h during the construction period. This would result in the diversion of 3600 vehicles to an alternate route. For this analysis, assume that

1. The freeway would revert to the original operating conditions of 20 mph.
2. The 3600 vehicles would use arterial streets with an average speed of 10 mph over a 4-mile trip. The fuel-consumption rate for this traffic is taken from a recent study of arterial street operation [Table 6 (10)].
3. All trucks and buses will stay on the freeway.

The daily fuel consumption prior to the modification of the shoulder lane is calculated as follows:

(0.0772 gal/vehicle mile x 13 386 vehicles + 0.1772 gal/vehicle mile x 276 vehicles + 0.3784 gal/vehicle mile x 138 vehicles) (3 miles) = 3403 gal/day.

The daily fuel consumption during the reconstruction of the lane is calculated as follows:

(0.1108 gal/vehicle mile)(3600 vehicles)(4 miles)
+ (0.0772 gal/vehicle mile x 10 386 vehicles
+ 0.1772 gal/vehicle mile x 276 vehicles + 0.3784 gal/vehicle mile x 138 vehicles)(3 miles) = 4304 gal/day.

Therefore, the reconstruction of the shoulder would cost 901 gal/day.

In examples B and C, the traffic that uses the shoulder is returned to the main lanes of travel during reconstruction. The only deterioration in operation would be a reduction in capacity. For these examples, the bottleneck is further downstream, and thus the freeway operating characteristics in the area would be unaffected.

SUMMARY

The conversion of a freeway shoulder to a travel lane is an immediate and low-cost solution for increasing capacity. The results are higher travel speed, lower total travel times, and reduced fuel consumption.

Problems of shoulder pavement deterioration can be lessened by limiting the use of the lane to passenger vehicles during the peak periods only. The impact of the added capacity on fuel consumption will vary, depending on geometric design, traffic conditions, and use of the shoulder lane.

The reconstruction of a shoulder lane after several years of travel may be necessary. However, the daily fuel consumption during the period of reconstruction should not exceed the amount saved during the use of the shoulder for travel.

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Vehicular Fuel-Consumption Maps and Passenger Vehicle Fleet Projections

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The procedures and preliminary results of a study aimed at assessing the fuel-consumption characteristics of passenger vehicles that are representative of the current and near-future fleet in order to update the fuel-consumption models of computerized traffic simulation and optimization programs are presented. The paper identifies 21 engine-drivetrain combinations that are representative of 74 percent of the 1979-1985 passenger vehicle fleet and describes an instrumentation system that permits the collection of the microscopic on-the-road and laboratory test data necessary to fully assess the real-world fuel-consumption characteristics of vehicles.

The problem that this paper discusses is very simple to state: How can we reduce fuel consumption from vehicles operating on a street network? Unfortunately, the answers are quite complex.

Resolving this problem requires a dual approach. First, we need more energy-efficient vehicles; second, we need a means of accurately estimating and predicting fuel consumption from vehicles that operate on a network in order to accurately assess the energy impacts of different traffic-control strategies and roadway designs.

Breakthroughs in technology achieved by automotive engineers have provided the means of manufacturing more energy-efficient vehicles. Today automobiles that average 25-35 miles/gal (10.6-14.8 km/L) are common (1). The problems that still remain for the transportation engineer are how to assess and predict vehicular fuel consumption in any given operating environment and how to enhance roadway designs and traffic-control strategies in order to provide an environment where vehicles can operate more efficiently.

The Federal Highway Administration (FHWA) and others have developed computer programs that evaluate geometric designs and traffic-control strategies (primarily for urban areas) from environmental and energy conservation standpoints. Use of these models by many users has demonstrated their potential as effective tools in the development of traffic engineering measures that reduce motorist operating costs; fuel consumption; costs associated with planning, designing, and implementing new traffic-