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Impact of Two-Way Left-Turn Lanes on Fuel Consumption

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Two-way left-turn lanes (TWLTLs) serve to eliminate conflict between midblock left turns and through traffic moving in the same direction. The purpose of this study was to evaluate the potential fuel savings generated by TWLTLs through reduced stops and delays. In the first part of the paper, the results of two earlier studies are examined and related to fuel efficiency and fuel savings. In the second part, the results of a simulation study are presented. The simulation study estimated annual fuel savings generated by the introduction of TWLTLs on sections of two-way two-lane and two-way four-lane arterials under various combinations of driveway density, average daily traffic, and left-turn frequency. The magnitude of the benefits to be derived from TWLTLs obviously depends on the magnitude of the existing midblock left-turn conflicts. On two-lane roadways, potential fuel savings can be substantial even at relatively low volumes. Fuel savings on four-lane roadways compared favorably with fuel savings estimated to result from another energy conservation method, the right-turn-on-red policy.

Urban streets must serve two distinct and conflicting functions, namely, the movement of traffic and the provision of access to abutting properties. The operating characteristics of a given street are largely determined by the compromises involved in serving these two functions. Those streets that are designated to favor one of these functions present relatively little problem to the transportation engineer. For example, freeways serve well the movement function, and local streets provide easy access to all properties. Most arterials, however, serve both movement and access. Even arterials, which were originally intended to serve the movement function, eventually attracted commercial, industrial, or high-density residential developments, i.e., the high accessibility resulted in an increased intensity of land use. The nature and the intensity of these developments often created left-turn demands to driveway entrances between intersections that led to conflicts between left turners and through traffic.

In many cases, the conventional median with left-turn pockets is a good solution. There are instances, however, when the need for access to abutting properties from both directions is there, but the pattern of location of the driveways makes left-turn pockets impractical. The prohibition of left turns would eliminate the conflict between through traffic and turning traffic, but it seriously limits the accessibility of the properties and would therefore be often unacceptable. Median two-way left-turn lanes (TWLTLs) may offer a solution.

A TWLTL is a single lane identified by pavement markings and signs and reserved for the exclusive use of left-turning traffic from either direction. Left turns can be made from any point along the median lane.

The major function of this lane is to provide a deceleration and waiting lane for left turns to minor traffic generators (major traffic generators are better served by one-way left-turn pockets), including abutting properties and minor streets. Secondary functions include the separation of opposing traffic flows, an acceleration lane for vehicles turning left into the arterials from minor streets and driveways, an emergency lane in case of temporary lane closures due to maintenance or accidents, and a lane for use by emergency vehicles, especially during peak hours.

A TWLTL can simultaneously improve access to land use and increase the speed of through traffic by eliminating the conflict between left-turning vehicles and through traffic moving in the same direction. Left-turning vehicles can wait in safety for appropriate gaps in the opposing through traffic.

Initial concerns with the potential hazard of head-on collisions between left-turning vehicles that enter from the opposite direction have been proved unfounded (1,2). Several studies have shown TWLTLs to be beneficial by reducing both left-turn-related accidents and delays. Guidelines have been published regarding the application and design of TWLTLs (3,4). One of the more specific guidelines states (5):

> The two-way left-turn lane is operationally warranted on arterial highways that have average daily traffic (ADT) volumes higher than 10 000 and traffic speeds faster than 48 km/h (30 mph). The number of driveways should exceed 60 in 1.6

km (1 mile), and there should be fewer than 10 high-volume driveways. Left-turn driveway maneuvers in 1.6 km should total at least 20 percent of the through traffic volume during peak periods. High rates of accidents that involve left-turn maneuvers can also warrant this technique.

PURPOSE OF STUDY

The purpose of this study is to investigate the potential of TWLTLs to save fuel in urban areas by reducing stops and travel delays. In the first part, results of past delay studies reported in the literature are related to some widely accepted methods of estimating fuel savings.

In the second part, a simulation study is conducted to evaluate the relative magnitude of potential fuel savings under various conditions. Results are compared with fuel savings from another energy-conservation measure.

REVIEW OF LITERATURE

A recent Federal Highway Administration (FHWA) publication (6) suggests that average transient speed as measured by travel time is a good composite parameter for reflecting stops and slowdowns and is closely related to fuel consumption. By using data from a previous study conducted by General Motors (7), the following relation is suggested for urban conditions where speeds are usually at or below 35 mph:

$$\text{Fuel consumption (gallons per vehicle-mile)} = 0.0362 + (0.746/\bar{V}) \quad (1)$$

where $\bar{V}$ is in miles per hour. The equation will be used to relate the results of past delay studies to fuel consumption.

Ohio Study

The Ohio study clearly demonstrated that the impact of TWLTLs, in terms of delay reduction, depend very much on the pre-TWLTL condition (1). The three before-and-after case studies showed results ranging from negative to statistically significant positive impact on speeds. Average running speeds were computed by eliminating from the travel time all delays that were not related to midblock left turns. Test vehicles were used to collect travel-time data. Each data point represents approximately 40 runs.

Site 1 involved the restriping of a 36-ft-wide four-lane roadway as a three-lane roadway. The ADT was 16 320 vehicles. As could be expected at this volume level, the elimination of one through lane in each direction offset the beneficial effects of the TWLTL and average speeds as well as fuel consumption (expressed in miles per gallon) dropped: i.e.,

Direction	Period	Avg Speed (mph)	Fuel Efficiency (miles/gal)
Eastbound	Before	34.5	17.3
	After	30.9	16.6
Westbound	Before	33.2	17.0
	After	28.5	16.0

In conclusion, at site 1, the conversion of two through lanes into a TWLTL improved the access function of the roadway at the expense of the through movement function.

At site 2, a 59-ft-wide four-lane arterial was restriped as a five-lane roadway. The ADT was 17 610 vehicles. The intensity of the strip development varied along the 1-mile-long site, but was not high. Consequently, the improvement was not statistically significant:

Direction	Period	Avg Speed (mph)	Fuel Efficiency (miles/gal)
Eastbound	Before	32.3	16.9
	After	33.4	17.1
Westbound	Before	33.6	17.1
	After	34.4	17.3

Although there was a reduction in the number of conflicts between left-turning and through vehicles, the total numbers were not high, and therefore the impact on speeds was not significant.

Site 3 involved the widening of a 31-ft two-lane roadway to 36 ft and restriping it as a three-lane roadway. The ADT was 14 070 on the north half of this study section and 12 940 on the south half. Development intensity was especially low on the south half. The results for the two sections are given below:

Direction	Period	Avg Speed (mph)	Fuel Efficiency (miles/gal)
North half			
Northbound	Before	35.2	17.4
	After	38.6	18.0
Southbound	Before	38.5	18.0
	After	39.8	18.2
South half			
Northbound	Before	29.3	16.2
	After	32.6	16.9
Southbound	Before	30.1	16.4
	After	32.9	17.0

The left-turn conflicts, expressed as the number of brakings, were relatively high at this site (1327 compared with 614 and 575 at sites 2 and 3, respectively), and consequently the reduction in conflict had the most significant impact on average speeds and fuel consumption at this site.

In conclusion, the potential of TWLTLs as a way to reduce fuel consumption obviously depends very much on the nature and extent of the problem TWLTLs are introduced to solve.

Midwest Research Institute Study

The subject of the Midwest Research Institute study was the control of direct access to arterial highways and included TWLTLs as one of the median treatments (5). Level of development and highway ADT were defined as follows:

Item	Definition
Level of development (driveways/mile)	
Low	<30
Medium	30-60
High	>60
Highway ADT	
Low	<5000
Medium	5000-15 000
High	>15 000

The effectiveness of the TWLTL in reducing delay was estimated by assuming a value for the increase in average running speed. The following assumptions were made to estimate reductions in delay for typical four-lane highways:

1. Arterials with low traffic volumes or low levels of development would not experience any increase in running speed.

Table 1. Reduction in stops, two-lane roadway, 1000-ft section.

Driveway Density[a] (no./mile)	Traffic Volume[b] (vehicles/h)	Reduction in Stops (no./h) by Left-Turn Volume[c]		
		35 vehicles/ h/1000 ft	70 vehicles/ h/1000 ft	105 vehicles/ h/1000 ft
30	350	23	36	45
	700	98	157	290
	1000	186	612	982
60	350	0	14	29
	700	69	189	206
	1000	140	804	1216
90	350	18	27	48
	700	74	206	244
	1000	326	814	1630

[a]Total number of driveways on both sides of street.
[b]Volume in each direction, including left turns.
[c]Volume in each direction.

Table 2. Reduction in delay, two-lane roadway, 1000-ft section.

Driveway Density[a] (no./mile)	Traffic Volume[b] (vehicles/h)	Reduction in Delay (min/h) by Left-Turn Volume[c]		
		35 vehicles/ h/1000 ft	70 vehicles/ h/1000 ft	105 vehicles/ h/1000 ft
30	350	4.1	8.8	11.4
	700	13.7	16.8	43.8
	1000	19.4	44.2	79.8
60	350	0	3.8	9.0
	700	5.3	24.1	30.3
	1000	16.1	75.6	123.6
90	350	1.8	6.5	14.4
	700	6.9	30.2	37.6
	1000	47.3	83.6	271.1

[a]Total number of driveways on both sides of street.
[b]Volume in each direction, including left turns.
[c]Volume in each direction.

2. Average running speeds on arterials without median treatments are assumed to be as given below:

Highway ADT	Level of Development	Avg Running Speed (mph)
Medium	Medium	35
	High	30
High	Medium	30
	High	25

3. For a medium level of development, there is an increase of 5 mph in average running speed during the 2 h of each day that show the highest traffic volume. These hours are assumed to include 20 percent of all through vehicles.

4. For a high level of development, there is an increase of 5 mph in average running speed during the 4 h of each day when traffic volume is highest. These hours are assumed to include 35 percent of all through vehicles.

The estimated reduction in delay that results from the introduction of a 1-mile TWLTL is given below, including the corresponding reduction of fuel consumption. The fuel consumption was calculated by Equation 1, based on the above assumptions made by the Midwest Research Institute:

Level of Development	ADT	Annual Reduction per Mile in Delay (h)	Annual Reduction per Mile in Fuel Consumption (gal)
Low	Low	0	0
	Medium	0	0
	High	0	0
Medium	Low	0	0
	Medium	2 628	1 960
	High	6 935	5 175
High	Low	0	0
	Medium	6 059	4 520
	High	17 046	12 715

Table 3. Reduction in stops, four-lane arterial, 2000-ft section.

Driveway Density[a] (no./mile)	Traffic Volume[b] (vehicles/h)	Reduction in Stops (no./h) by Left-Turn Volume[c]		
		35 vehicles/ h/1000 ft	70 vehicles/ h/1000 ft	105 vehicles/ h/1000 ft
30	350	8	6	24
	700	13	59	87
	1050	100	78	599
60	350	5	9	24
	700	17	45	105
	1050	98	237	-[d]
90	350	5	7	26
	700	12	38	114
	1050	88	271	589

[a]Total number of driveways on both sides of street.
[b]Volume in each direction, including left turns (divided equally in each lane).
[c]Volume in each direction.
[d]Jammed flow in no-TWLTL case. Simulation incomplete.

Table 4. Reduction in delay, four-lane arterial, 2000-ft section.

Driveway Density[a] (no./mile)	Traffic Volume[b] (vehicles/h)	Reduction in Delay (min/h) by Left-Turn Volume[c]		
		35 vehicles/ h/1000 ft	70 vehicles/ h/1000 ft	105 vehicles/ h/1000 ft
30	350	1.5	1.1	2.7
	700	0.8	6.8	8.7
	1050	8.4	58.6	112.6
60	350	0.2	1.9	5.9
	700	0.8	4.6	23.9
	1050	6.8	36.3	-[d]
90	350	0.4	0.9	4.1
	700	0.4	3.0	22.2
	1050	5.8	44.6	142.3

[a]Total number of driveways on both sides of street.
[b]Volume in each direction, including left turns (divided equally in each lane).
[c]Volume in each direction.
[d]Jammed flow in no-TWLTL case. Simulation incomplete.

SIMULATION STUDY

Computer simulation models of sections of two-way two-lane (1000-ft) and two-way four-lane (2000-ft) arterials with and without TWLTLs were developed at the University of Nebraska by using the General Purpose Simulation System (GPSS) language. The simulation models are described in more detail elsewhere (8).

The output of the simulation study included reduction in stops and reduction in delay during 1-h simulated periods and under various combinations of driveway densities, traffic volumes, and left-turn volumes. Tables 1-4 summarize the results of the simulation study.

The next step involved the conversion of the stops and delay reduction into hourly fuel savings by using the same relation that is used by the Signal Operations Analysis Package (9):

$$\text{Excess fuel (gal)} = 0.01 \times \text{stops} + 0.6 \text{ delay (h)} \quad (2)$$

Tables 5 and 6 summarize the hourly fuel savings on two- and four-lane roadways that result from the introduction of TWLTLs under various traffic and development density conditions.

The next step involved the estimation of annual fuel savings. This required that an assumption be made regarding the impact of TWLTLs during the day. If the simulated hourly volumes represent peak flows on a given arterial, then the assumptions made by Midwest Research Institute offer a simple method to estimate ADTs and annual fuel savings. These previously listed assumptions say that

1. For a medium level of development, the TWLTL is assumed to affect traffic during the 2 h of each day that show the highest traffic volume. These hours are assumed to include 20 percent of all through vehicles. Driveway densities of 30 and 60/mile are in this category, and annual savings were calculated accordingly (i.e., annual savings = hourly savings x 2 x 365).
2. For a high level of development, the impact is assumed to be significant during the 4 h of each day when the traffic volume is highest. These hours are assumed to include 35 percent of all through vehicles. Annual savings were calculated accordingly at driveway densities of 90/mile.

Tables 7 and 8 summarize the estimated annual fuel savings. It needs to be emphasized that these savings are related to very short sections only, and since typical volumes on TWLTLs are considerably higher (all three test sites in the Ohio study were close to 1 mile long), fuel savings would also be higher.

CONCLUSION

The benefits to be derived from the introduction of TWLTLs depend very much on the type and intensity of existing conflicts created by midblock left turns. The Ohio field studies illustrated this point fairly clearly. The simulation study provided further quantitative evidence.

The estimated reductions in stops, delays, and fuel savings are very high on two-lane roadways (Tables 1, 2, 5, and 7). It needs to be pointed out, though, that the highest simulated volumes (20 000-23 000 ADT) are not likely to occur in reality. However, potential fuel savings are also substantial in the 7000-16 000 ADT range, even at the lowest level of development.

Estimated fuel savings on four-lane roadways (Table 8) are much lower in comparison. This is to be expected, since the simulated four-lane roadway carried practically the same ADT volumes as the two-lane roadway. The driveway densities and turning volumes, as well as through traffic volumes, are well within the range of realistic expectations. Annual fuel savings range from 38 to 5338 gal. In order to place these savings in the proper perspective, it was necessary to compare these quantities with fuel savings from some other energy-conservation method.

Table 5. Reduction in fuel consumption, two-lane roadway, 1000-ft section.

Driveway Density[a] (no./mile)	Traffic Volume[b] (vehicles/h)	Reduction in Fuel Consumption (gal/h) by Left-Turn Volume[c]		
		35 vehicles/ h/1000 ft	70 vehicles/ h/1000 ft	105 vehicles/ h/1000 ft
30	350	0.271	0.448	0.564
	700	1.117	1.738	3.338
	1000	2.054	6.562	10.618
60	350	0.000	0.178	0.380
	700	0.743	2.131	2.363
	1000	1.564	8.796	13.396
90	350	0.198	0.335	0.624
	700	0.809	2.362	2.816
	1000	3.733	8.976	19.011

[a]Total number of driveways on both sides of street.
[b]Volume in each direction, including left turns.
[c]Volume in each direction.

Table 6. Reduction in fuel consumption, four-lane arterial, 2000-ft section.

Driveway Density[a] (no./mile)	Traffic Volume[b] (vehicles/h)	Reduction in Fuel Consumption (gal/h) by Left-Turn Volume[c]		
		35 vehicles/ h/1000 ft	70 vehicles/ h/1000 ft	105 vehicles/ h/1000 ft
30	350	0.095	0.071	0.267
	700	0.138	0.652	0.957
	1050	1.084	1.366	7.216
60	350	0.052	0.109	0.299
	700	0.178	0.496	1.289
	1050	1.048	2.733	-[d]
90	350	0.054	0.079	0.301
	700	0.124	0.410	1.362
	1050	0.938	3.156	7.313

[a]Total number of driveways on both sides of street.
[b]Volume in each direction, including left turns (divided equally in each lane).
[c]Volume in each direction.
[d]Jammed flow in the no-TWLTL case. Simulation incomplete.

Table 7. Annual reduction in fuel consumption, two-lane roadway, 1000-ft section.

Driveway Density[a] (no./mile)	ADT	Reduction in Fuel Consumption (gal) by Left-Turn Volume[b]		
		35 vehicles/ h/1000 ft	70 vehicles/ h/1000 ft	105 vehicles/ h/1000 ft
30	7 000	200	325	410
	14 000	815	1 270	2 440
	20 000	1500	4 800	7 750
60	7 000	0	130	280
	14 000	540	1 555	1 725
	20 000	1140	6 420	9 780
90	8 000	290	490	910
	16 000	1180	3 450	4 110
	23 000	5450	13 100	27 800

[a]Total number of driveways on both sides of street.
[b]Volume in each direction.

Table 8. Annual reduction in fuel consumption, four-lane arterial, 2000-ft section.

Driveway Density[a] (no./mile)	ADT	Reduction in Fuel Consumption (gal) by Left-Turn Volume[b]		
		35 vehicles/ h/1000 ft	70 vehicles/ h/1000 ft	105 vehicles/ h/1000 ft
30	7 000	69	52	195
	14 000	101	476	699
	21 000	791	997	5268
60	7 000	38	80	218
	14 000	130	362	940
	21 000	765	1195	-[c]
90	8 000	39	58	220
	16 000	90	299	994
	24 000	685	2304	5338

[a]Total number of driveways on both sides of street.
[b]Volume in each direction.
[c]Jammed flow in the no-TWLTL case. Simulation incomplete.

Table 9. Reduction in fuel consumption, four-lane arterial.

Driveway Density[a] (no./mile)	ADT	Reduction in Fuel Consumption (gal/vehicle) by Left-Turn Volume[b]		
		35 vehicles/ h/1000 ft	70 vehicles/ h/1000 ft	105 vehicles/ h/1000 ft
30	7 000	0.000 14	0.000 10	0.000 38[c]
	14 000	0.000 10	0.000 47	0.000 68
	21 000	0.000 52	0.000 65	0.003 44
60	7 000	0.000 07	0.000 16	0.000 43[c]
	14 000	0.000 13	0.000 35	0.000 92
	21 000	0.000 50	0.000 78	-[d]
90	8 000	0.000 04	0.000 06	0.000 22[c]
	16 000	0.000 04	0.000 15	0.000 49
	24 000	0.000 45	0.001 50	0.003 48

[a]Total number of driveways on both sides of street.
[b]Volume in each direction.
[c]Quantities under these lines exceed 0.000 29 gal/vehicle, the estimated savings from RTORAS.
[d]Jammed flow in the no-TWLTL case. Simulation incomplete.

The Institute of Transportation Engineers (ITE) published a report in 1980 by Wagner (10) on fuel-conservation impacts of various transportation improvement measures. The most widely implemented measure included in the report is the introduction of right-turn-on-red-after-stop (RTORAS). Fuel savings from RTORAS were calculated for a hypothetical area of 1 million population. It was estimated that an annual traffic volume of 5530 million vehicles will save 1.62 million gal. This corresponds to saving 0.000 29 gal/vehicle. Because RTORAS is considered to be a significant energy-conservation policy, the selection of the above 0.000 29 gal/vehicle fuel savings could be considered a valid yardstick with which to evaluate fuel savings from TWLTLs.

The annual fuel savings shown in Table 8 were therefore recalculated in gallons per vehicle, as shown in Table 9. The steplike heavy line within the table separates the quantities that exceed the savings from RTORAS from those that do not. The following observations can be made from the data presented in Table 9:

1. At a given driveway density, potential fuel savings increase as total volumes (ADT) increase. This increase is more rapid at higher left-turn volumes.
2. Fuel savings change as driveway density changes at a given ADT level and given left-turn volume. This is not unexpected, since changing driveway density changes the average left-turn volumes per driveway. However, no clear pattern can be identified. More research is needed in this area.

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Effect of Bus Turnouts on Traffic Congestion and Fuel Consumption

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The NETSIM simulation model was employed to determine the energy impacts of using bus turnouts. Two sets of computer runs were made. The first one consisted of 80 runs of a single intersection with different values of independent variables. The second consisted of six runs of three different networks. The result was that bus turnouts were found to have some potential for improving the fuel efficiency of the general traffic stream but only at high values of volume-to-capacity ratios, high bus volumes, and long bus-loading times.

There have been a number of papers written in the past few years concerning the effect of various traffic engineering alternatives on automotive fuel consumption. One set of measures studied include such traffic-flow improvements as right-turn-on-red (1), improved signalization (1,2), one-way versus two-way street patterns (2), cycle length (3), and exclusive turn bays (4).

Another set of traffic engineering alternatives that have potential for fuel savings involves changes in bus operations. These alternatives include such measures as near side versus far side