demand and level of service. Further research on the subject should aim at removing the identified weaknesses in the model.

REFERENCES

1. D.E. Ward. A Theoretical Comparison of Fixed Route Bus and Flexible Route Subscription Bus Feeder Service in Low Density Areas. U.S. Department of Transportation, March 1975.
2. D. Roos and others. The Dial-a-Ride Transportation Systems. Urban Systems Lab, Massachusetts Institute of Technology, Cambridge, Rept. USL-TR-70-10, 1971. NTIS: PB 201-129.
3. G.F. Newell. Dispatching Policies for a Public Transportation Route. Transportation Science, Vol. 5, No. 1, Feb. 1971.
4. V.F. Hurdle. Minimum Cost Schedule for a Public Transportation Route. Transportation Science, Vol. 7, No. 2, March 1973.
5. V.F. Hurdle. Minimum Cost Locations for Parallel Public Transit Lines. Transportation Science, Vol. 7, No. 4, Nov. 1973.
6. B.F. Bryne and R.R. Vuchic. Public Transportation Line Positions and Headways for Minimum Cost. Presented at Fifth International Symposium on Traffic Flow Theory and Transportation, Berkeley, CA, 1973.
7. O. Adebisi. A Comparison of the Fixed-Route and Flexible-Route Strategies of Operating an Intra-urban Bus Transit System. School of Graduate Studies, Univ. of Toronto, Ontario, Canada, Ph.D. dissertation, 1978.
8. E.M. Holroyd. The Optimum Bus Service: A Theoretical Model for a Large Uniform Area. Presented at Third International Symposium on the Theory of Traffic Flow, New York, 1965.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Concurrent-Flow High-Occupancy Vehicle Treatment on Freeways–Success Story in Houston

CHARLES A. FUHS

On March 30, 1981, a 3.3-mile concurrent-flow lane began operation within the median shoulder on North Freeway (Interstate-45). The concurrent-flow lane operates inbound only from 6:00 to 8:30 a.m. and is available to authorized vehicles, which include registered and approved buses and eight-passenger vanpools. The concurrent-flow lane is an extension of contraflow preferential treatment provided further downstream; it provides a travel-time savings of about 4 min. This project is one of seven nationwide that is currently operating, is the only project to be implemented within an existing paved emergency shoulder, and is the first operation to restrict use to authorized vehicles that display an appropriate permit. A general report on the unique characteristics and results of Houston's concurrent-flow operation is presented. Comparative evaluations are presented that measure the success of this project with other concurrent-flow applications on freeways. In the first three months, an average of 257 vehicles (78 percent vanpools and 21 percent buses) traveled the lane inbound during each daily 2.5-h peak period, which facilitated the movement of 3752 commuters. The North Freeway concurrent-flow project was jointly implemented by the Texas State Department of Highways and Public Transportation and the Metropolitan Transit Authority of Harris County. Both agencies funded construction of the project with local monies and jointly managed daily operation. The success of the concurrent-flow project, as illustrated in this paper, has resulted in increased person trips on a severely congested freeway facility and has provided a travel-time incentive to vanpool and bus transit users until such time that a more permanent transitway facility can be constructed.

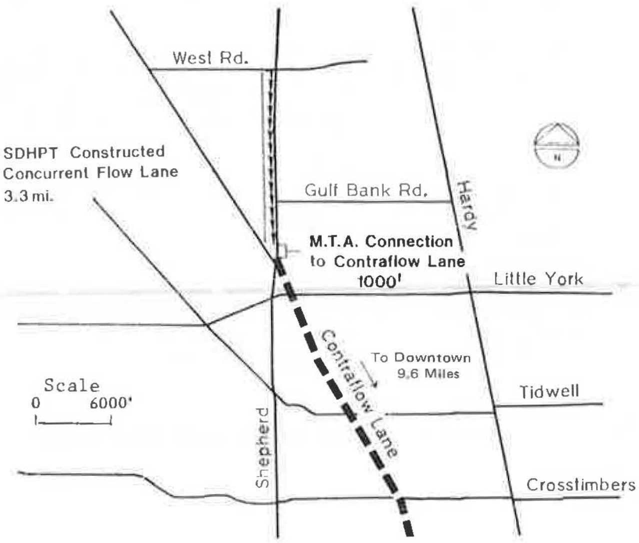
In 1979 the Metropolitan Transit Authority (MTA) of Harris County, Houston, and the Texas State Department of Highways and Public Transportation (TSDHPT) opened a 9.6-mile contraflow lane on Interstate-45N (North Freeway). The $2.1 million project, funded under a Service and Methods Demonstration program grant (Sections 5 and 6) of the Urban Mass Transportation Act of 1964 (as amended), was very successful in attracting riders into vanpools and buses. These were the only authorized vehicles that could benefit from the project, and rather rigid authorization procedures were adopted to help ensure safe operation. The contraflow lane bypassed about 6 miles of severe traffic congestion and saved users about 30-min of travel time daily. Use increased 350 percent from the 1st through 82nd week of operation to 10 900 daily trips (1). However, during the contraflow planning and implementation period from 1975 through 1979, severe traffic congestion was growing and began extending several miles upstream of the northern terminus to contraflow. An extension of the contraflow concept to alleviate this problem was complicated by several factors. Unacceptable traffic conditions upstream did not permit borrowing a lane for contraflow. Also, facility design would not accommodate a safe project termination farther north. Other alternatives were studied for bypassing congestion outside the contraflow limits.

BACKGROUND

The concurrent-flow concept was first proposed as an extension to the contraflow lane in early 1980 to alleviate congestion in the morning period. The concept could be readily implemented within an existing paved median shoulder along a 3.3-mile segment, as shown in Figure 1. The segment was unique in that the termination of the concurrent-flow lane could be transitioned directly to the contraflow lane. This segment encompassed most of the regularly recurring traffic congestion. Median drainage inlets and superelevations prohibited easy conversion of the inbound median any further. In the afternoon peak period, traffic conditions at the time did not warrant implementation of a similar treatment on the outbound shoulder.

TSDHPT subsequently designed the necessary signing and striping modifications to convert the median shoulder for bus and vanpool use. A connection ramp was designed at the downstream terminus to facilitate direct access from the concurrent-flow shoulder to the entry of contraflow. An exception was granted from Interstate standards by the Federal

Figure 1. Concurrent-flow shoulder lane.



Highway Administration in fall 1980. Project implementation was expedited by use of local monies from both agencies to fund construction. TSDHPT installed signs, restriped lanes to accommodate the lane over bridge decks, and reinforced bridge railings. MTA constructed a connection ramp and gate. Total cost to both agencies was about $130 000. Construction began in November 1980 and was completed about four months later.

Operation management of the concurrent-flow lane (CCFL) was already provided under a previous operations plan between MTA and TSDHPT for the contraflow lane. The operating plan finalized and made legal the following:

1. Operating hours and schedule,
2. Requirements for authorized vehicles,
3. Requirements for authorized drivers,
4. Rules and regulations for use of the lane,
5. Enforcement procedures,
6. Maintenance responsibilities, and
7. Emergency and breakdown procedures.

Most of the contraflow policies were transferred to encompass CCFL operation. Authorized users were designated as recipients, which included existing buses and vanpools that operate on the contraflow lane.

The plan has been made the official ruling document by an MTA-TSDHPT operations agreement, which also provided for a project management team to oversee the project and make amendments to the plan by mutual consent of the TSDHPT project engineer and MTA project manager. This arrangement has worked very well for the past two years. Amendments to the plan can be made quickly and effectively at monthly meetings without amending the governing operations agreement.

Of particular interest in securing an operations agreement was the ability of MTA to enforce restrictions that govern the use of the median shoulder. The intent of a previous ordinance enacted by the city empowering their police to enforce the contraflow project was expanded to encompass the concurrent-flow project.

CCFL was opened to authorized users on March 30, 1981, without public fanfare. Notices and driver-training information were distributed in a packet to authorized bus and vanpool drivers a week before the Monday opening. An example of this information is shown in Figure 2. Bus passengers received the notice shown in Figure 3 several days before buses began traveling in the shoulder lane. Newspaper articles represented the only media coverage on the project. Operation is shown in Figure 4.

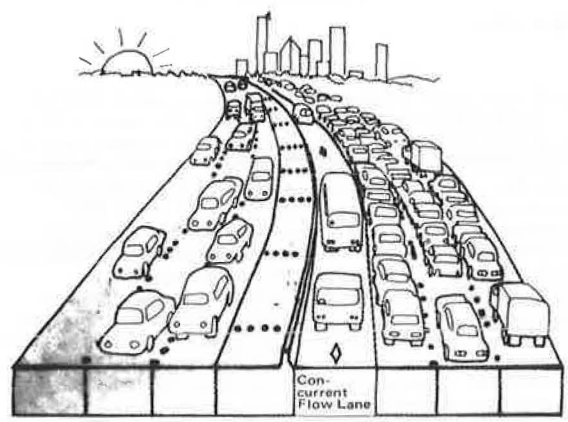
Characteristics of North Freeway

North Freeway is a standard six-lane Interstate facility within the concurrent-flow project limits. The freeway was built in 1958 and later upgraded with conversion of a 35-ft grass median into continuous asphaltic paved shoulders with standard median rail and glare screen. Average weekday traffic in this portion of the freeway averaged 145 000 vehicles in 1980 (1). Average speeds in the 6:00-8:30 a.m. peak period averaged 26 mph in level-of-service F throughout the three-mile distance (according to the Houston Chronicle, March 24, 1981). Traffic was growing at a rate of more than five percent annually. Much of this growth was being absorbed by contraflow-authorized vanpools and buses that showed a 430 percent increase in ridership to 6200 peak-period trips after 22 months of contraflow operation.

Figure 2. Cover of driver-information package.

Announcing A New Lane on the North Freeway

Expressly for Contraflow Vehicles



METRO
Metropolitan Transit Authority

Figure 3. Notice issued to bus passengers.

North Freeway Concurrent Flow Lane

Thanks to your patience and support, the North Freeway Concurrent Flow Lane has been added to improve your a.m. commute. A project of the State Department of Highways and Public Transportation, the lane extends preferential treatment an additional 3 miles along the North Freeway. Authorized vehicles will travel "with flow" in the converted median lane and may enter at any point along its length.

The Concurrent Flow Lane is an experimental project, like Contraflow, designed to provide a short-term transit improvement and data for permanent express improvements on I-45.

METRO's Contraflow crew will monitor the lane, and the Houston Police Department will enforce lane regulations.

METRO
Metropolitan Transit Authority

Figure 4. View of CCFL near West Road.

The CCFL project was proposed to encourage more use of the contraflow lane and bypass recurring traffic congestion upstream of the morning contraflow entry.

Several other freeway characteristics favored a concurrent-flow experiment on North Freeway. The 3.3-mile segment contained excellent sight distance and only three bridge structures. Full 12-ft lanes were provided adjacent a median shoulder that averaged 16 ft except at bridge structures. Parallel frontage roads along the outer separation also provided detour opportunity in event of an incident.

Project Design

CCFL extends 3.3 miles along a segment of the median shoulder that is borrowed for 2.5 h each morning. Signing designates shoulder use by authorized vehicles only with standard diamond symbols as described in the Manual on Uniform Traffic Control Devices (MUTCD) (2). Signs are posted about 1000-ft apart on the median rail. Alternate signing is placed between authorized designations that restrict emergency parking in the median during operating periods. There are no high-occupancy vehicle (HOV) diamond pavement markings or other special striping along the lane. The surface texture of the shoulder pavement was retained as white delineation gravel on a hot-mix asphaltic base. Special pavement markings would not have been visible on the white gravel. Also, the effect of driving on the shoulder surface provided better traction and discouraged use of the shoulder as a regular travel lane. The shoulder pavement was sufficient to support a low volume of daily vehicles. A typical at-grade section of the lane is illustrated before and after implementation in Figure 5.

At bridge structures, no median shoulder previously existed, although outer shoulders were provided as shown in Figure 6. Restriping and shifting main lanes to absorb the outer shoulder created sufficient width (10 ft) to accommodate the concurrent-flow median lane over bridge decks. After the first several months of trial operation, temporary paint striping was replaced with thermoplastic markings. The slight weave in main lanes, equivalent to 10 ft over a transition length of 2000 ft, is unnoticeable to general traffic.

At the northern terminus near West Road, as shown in Figure 7, is a larger-than-standard sign in the median shoulder for authorized vehicles. No special edge striping is included that might encourage entry by general traffic. In Figure 8, the plan for treatment of at-grade separations is shown for the Mt. Houston and Gulf Bank locations along the project. The southern terminus and connection to the contraflow lane is highlighted in Figure 9. The CCFL separates from the median as an exclusive connector ramp, tying into an existing contraflow ramp used only in the evening operating period. This ramp feeds inbound vehicles over a short concurrent-flow segment on a bridge structure to the previous contraflow entry. The concurrent-flow segment of this third bridge is separated by yellow pylons from adjacent traffic. This connection is about 10 ft wide. Several gates are employed at the transition to the exclusive ramp and entry to the contraflow lane to prohibit use outside the operating period.

Operating Plan

Procedures and supervision of the CCFL are vested in the Operations Department of MTA. A crew of eight employees used to deploy the contraflow lane monitor the CCFL during operating periods and perform minor setup functions, including pylon installation and gate opening near the contraflow entry. An MTA wrecker previously located along the contraflow lane was moved upstream to the beginning of the CCFL to monitor entering vehicles and respond to incidents in both projects more effectively.

The contraflow crew spend part of their 1.5-h deployment period from 4:30 to 6:00 a.m. removing any debris and towing any stalled vehicles from the median shoulder section. TSDHPT also maintains a regular schedule for sweeping the median.

The minimal operation cost associated with daily deployment of CCFL is absorbed as part of the deployment costs of the contraflow lane. The monthly cost to MTA for contraflow averages $50 000, with approximately two-thirds of this total involving labor. Operation costs are locally funded.

Two groups of eligible CCFL vehicles--vanpools and buses--are included as potential users. In order to be authorized for the contraflow lane, rather rigid requirements must be met. Eligible vehicles include the following:

1. All MTA transit vehicles,
2. Suburban commuter buses operated under contract to MTA,
3. Other full-sized transit vehicles being operated on regularly scheduled services and approved by MTA pursuant to the requirements as listed, and
4. Vans designed to carry eight or more passengers (including driver) and approved by MTA pursuant to the following requirements.

For vehicles defined under 3 and 4 above, authorization also requires that at least eight passengers be registered, that both vehicle and driver must have met minimum insurance requirements, the driver has a good driving record and successfully completed an MTA-sponsored contraflow-training course, and the vehicle has a valid inspection sticker and contraflow-authorization decals affixed appropriately.

Probably the most important aspect of this management procedure is the issuance of authorized MTA decals that appear on the front and back windshields of each vehicle. An example decal is shown in Figure 10. These decals are highly visible to enforcement officers (the printing is black and red on a white background). This unique approach to the authorization or restriction of vehicles to a transit preferential treatment greatly simplified enforcement and provided close controls over Houston's first steps toward a regionwide transitway system.

Figure 5. CCFL at-grade implementation.

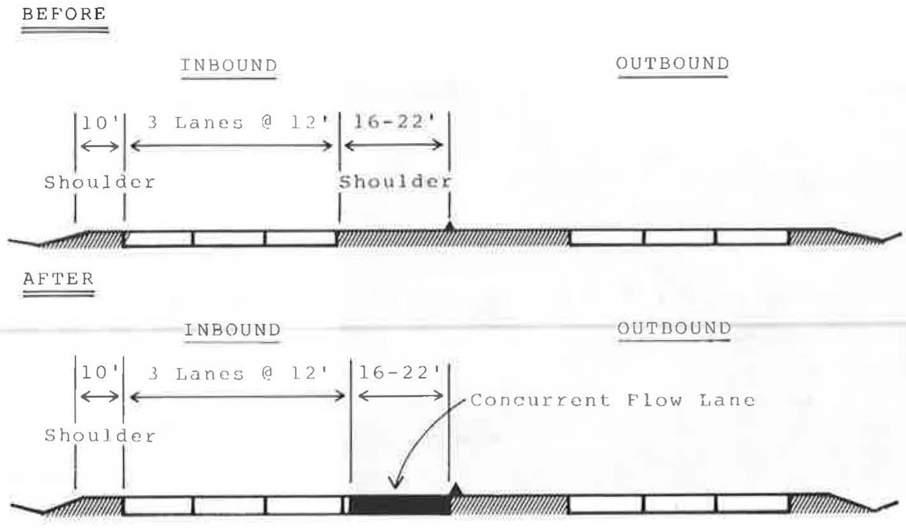
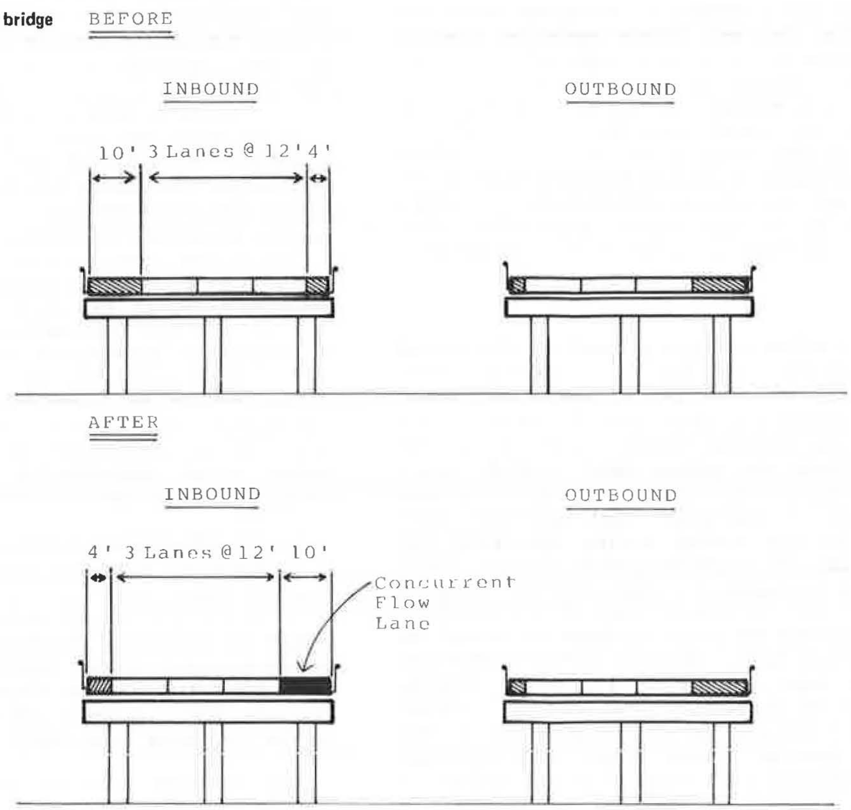


Figure 6. CCFL implementation on bridge decks.



Moreover, this approach was easily adapted to the CCFL after already being established for contraflow operation.

Unauthorized vehicles are easily identifiable if they do not display a proper decal. Police can deter or remove vehicles along the CCFL by setting up a monitoring point anywhere along the shoulder lane. A 16-ft-wide space (wider near bridge structures) is sufficient for patrols to park adjacent to the median rail without disrupting CCFL operation. The number of attempted violations have averaged from three to seven occurrences/day.

During the first month of operation, two patrols of the Houston Police Department were furnished to deter violators. They maintained fixed positions along the lane at locations of high visibility atop approaches to bridges. After a month the police were removed. In the following months, officers assigned to the contraflow-lane project provided infrequent patrols on the concurrent-flow segment. Violation rates have remained low with this support.

Operating rules for drivers of the CCFL are more rigorous than policies and procedures adopted on similar nationwide projects. A summary of these rules, extracted from the MTA driver training manual, is included below (3):

1. Operational rules: (a) Entry at any point along length of shoulder, no exit except in emergency; (b) headlights on; (c) no passing; and (d) 3-s minimum spacing between vehicle ahead and through connection ramps to contraflow entry; at

Figure 7. Concurrent-flow plan--West Houston.

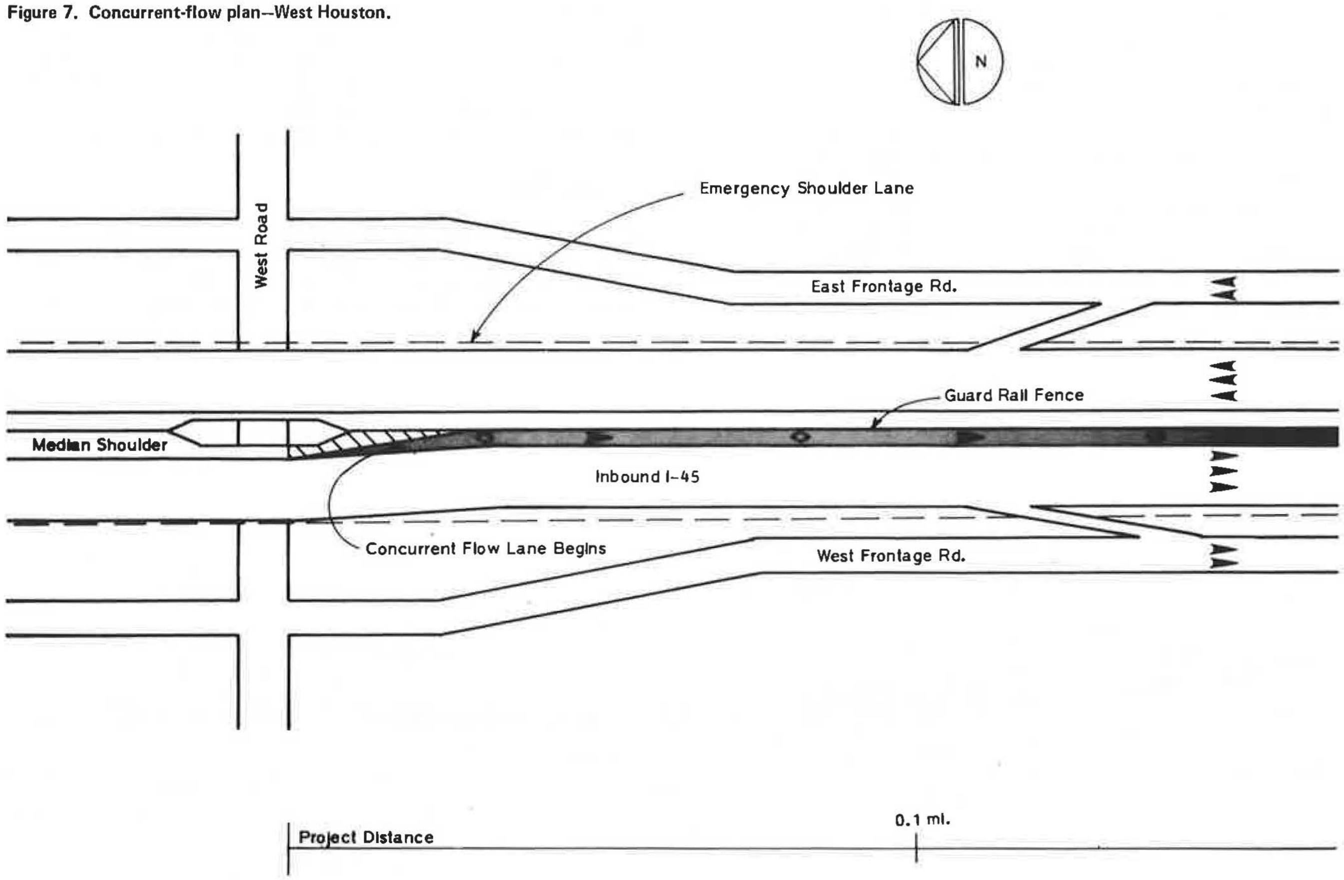
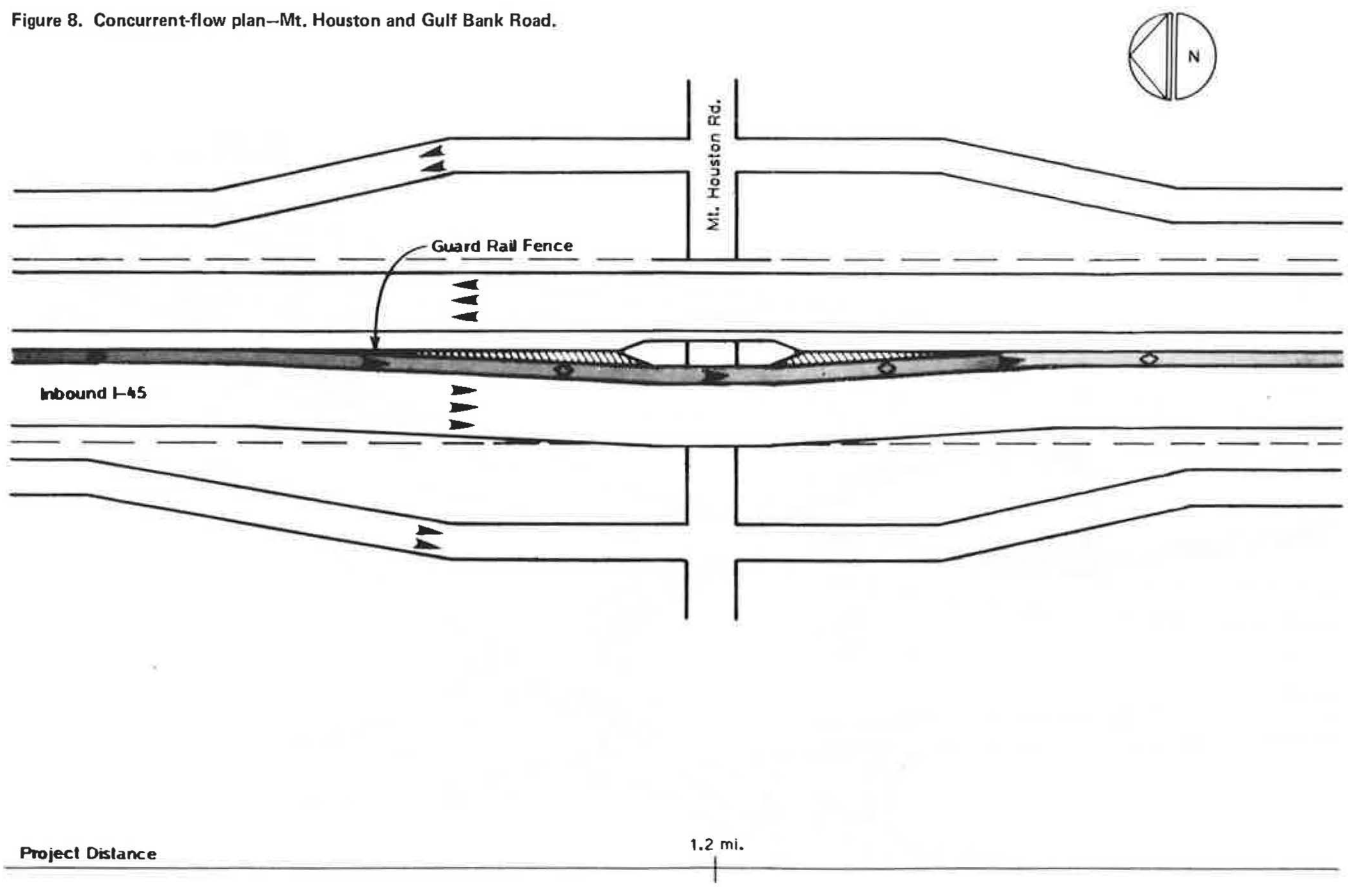


Figure 8. Concurrent-flow plan--Mt. Houston and Gulf Bank Road.



contraflow entry reduce speed to 30 mph when passing police surveillance point.

2. Entering lane: (a) Turn on headlamps; (b) enter from leftmost travel lane next to median shoulder, checking for oncoming vehicles in shoulder; (c) use turn indicator; and (d) yield to oncoming vehicles to your left in shoulder as you merge.

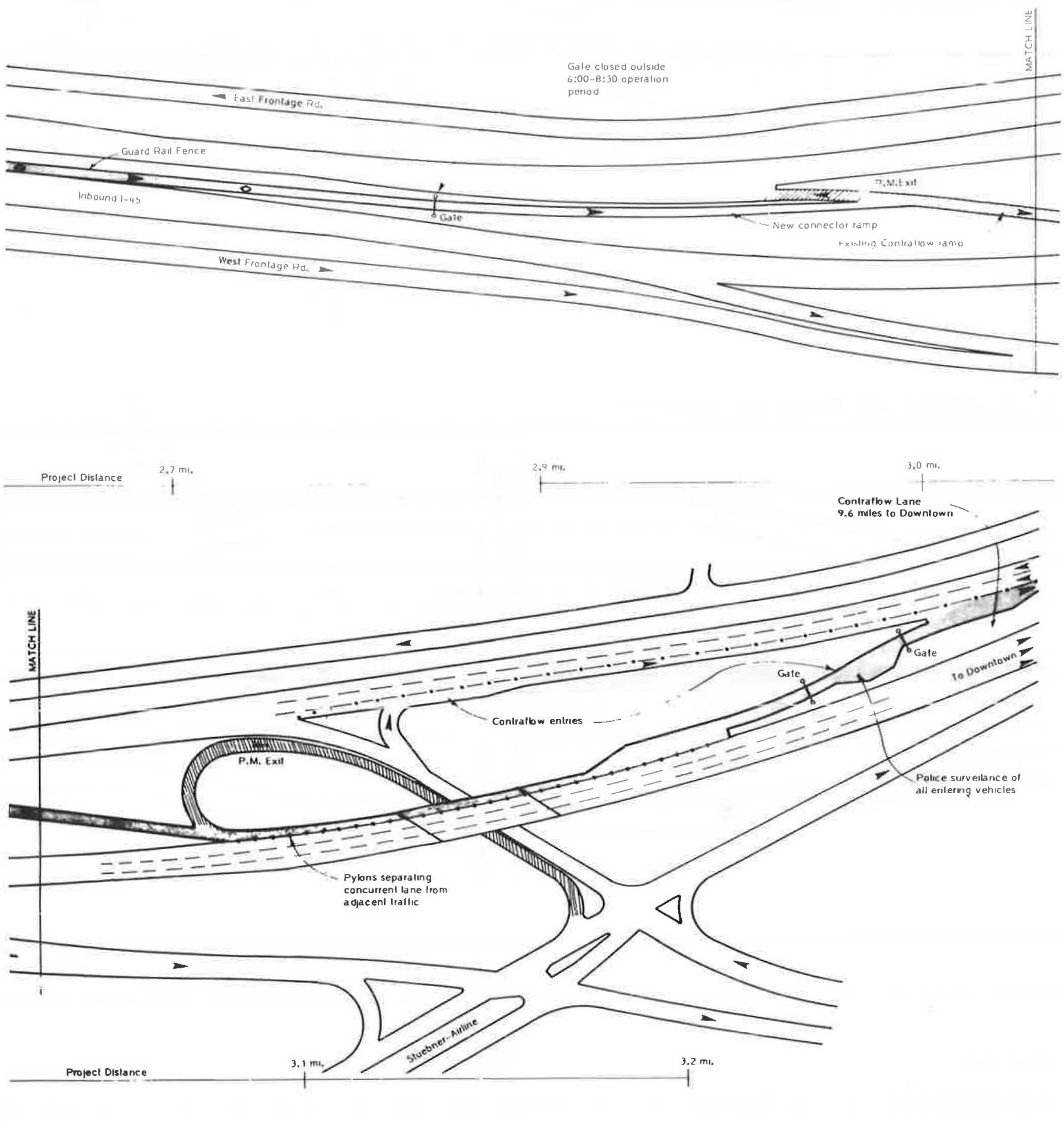
3. Entering contraflow lane: Enter the median shoulder lane or enter via the North Shepherd and Stuebner-Airline ramp. (There is no longer an entry to contraflow from I-45 at the North Shepherd overpass.)

4. Negotiating a disabled vehicle: (a) Slow at least 200 ft behind disabled vehicle, (b) signal right-turn indicator to merge back into leftmost travel lane, (c) maneuver around disabled vehicle, and (d) reenter shoulder lane by using left-turn indicator and carefully merge from leftmost lane.

Project Use

During the first three months of project operation, use of the concurrent-flow shoulder lane grew from 250 to 280 vehicles/operating period (4). Vehicles were composed of 22 percent buses and 78 percent

Figure 9. Concurrent-flow plan at termination.



vanpools. A more detailed record of vehicle use along the CCFL is presented in Figure 11 (4) and the table below (4):

1981	Beginning, West Road	Midpoint, Mt. Houston	Termination, Contraflow Entry
February (before CCFL)	151	173	190
April	207	236	249
May	242	254	259
June	254	265	281

Figure 11 illustrates the growth in use at three locations along the lane. Total vehicles increased an average of 14 percent along the lane. This increase was commensurate to increases on the contraflow lane during the previous three months. Since entry to the shoulder is unrestricted, vehicles (particularly vanpools) load onto the lane throughout its length from various freeway feeder ramps. Few buses enter the freeway throughout this segment. There is no user demand for exiting the lane. Before the CCFL project, 21 percent of the users were entering the freeway within the project limits. After three months only 10 percent were entering the freeway downstream of the beginning of the CCFL. Apparently a number of vanpools have shifted travel patterns from parallel arterials to benefit from this project.

The extent of diversion among vanpools is presented in more detail in Figure 12 (4). There are two entry points to the contraflow lane. The first is directly from I-45 inbound via the CCFL; the other is via Stuebner-Airline, a major surface arterial. In a December 1980 origin-destination survey, 78 percent of all vanpools entered the contraflow lane via the I-45 crossover. After CCFL implementation in May, 95 percent were entering from the CCFL. Similar increases in the percentage of total contraflow vanpools loading onto I-45 farther upstream are indicated. No information has been collected after CCFL implementation to determine specific changes on parallel arterials.

This distribution of vehicle volumes in the CCFL is not uniform throughout the operating period. As illustrated in Figure 13 (4), as much as two-thirds of the total volume travels in the lane in the peak hour (6:30-7:30 a.m.). This distribution is similar to earlier distributions made during the first two years on the contraflow project farther downstream. The profile of users by time has not apparently changed due to increased growth or characteristics of enforcement.

RESULTS

Travel Speeds and Time Savings

Travel speeds presented were made between the beginning of the CCFL (West Road) and just upstream of lane termination (Gulf Bank Road), an effective length of 3 miles. Speeds in the main lanes adjacent to the CCFL were determined by floating-car studies. Studies were made during the first month of operation and are presented in Table 1 (4). Vehicles in the CCFL averaged 48 mph while vehicles in main lanes averaged 26 mph. Travel times for this distance are as follows: CCFL, 3.75 min and main lanes, 6.92 min. Thus, a net savings of 3.17 min/user was initially realized, which resulted in a daily savings of about 190 person-h. Travel-time studies are continuing at this time. It is expected that daily savings will continue to increase as a factor of growth in use.

Breakdown Incidents on CCFL

Deployment of the contraflow-project wrecker to respond to incidents on both projects has worked well. The wrecker sweeps the CCFL in advance of each operating period, removing any disabled vehicles. The wrecker is within several minutes response time of a breakdown incident on the CCFL by being stationed at the beginning of the lane. About 10 breakdown incidents have been logged during the first three months, but no incidents have involved authorized vehicles. Because of the width of the

Figure 10. Authorized vehicle decals.

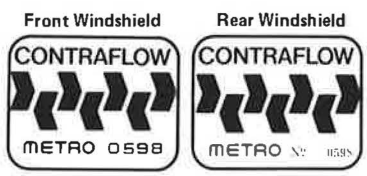


Figure 11. Vehicle use of CCFL.

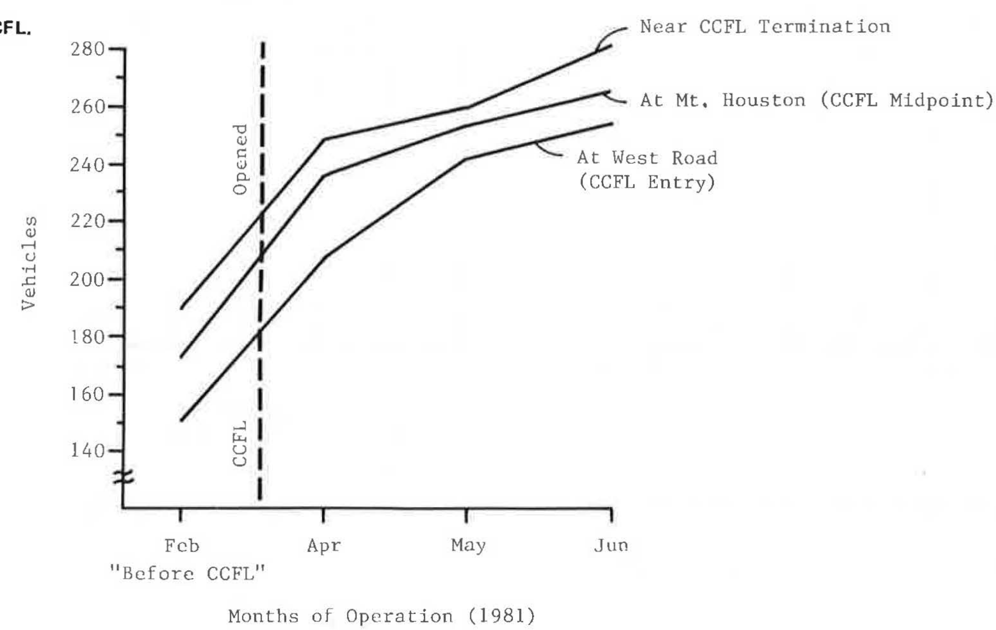


Figure 12. Changes in vanpool routes after implementation.

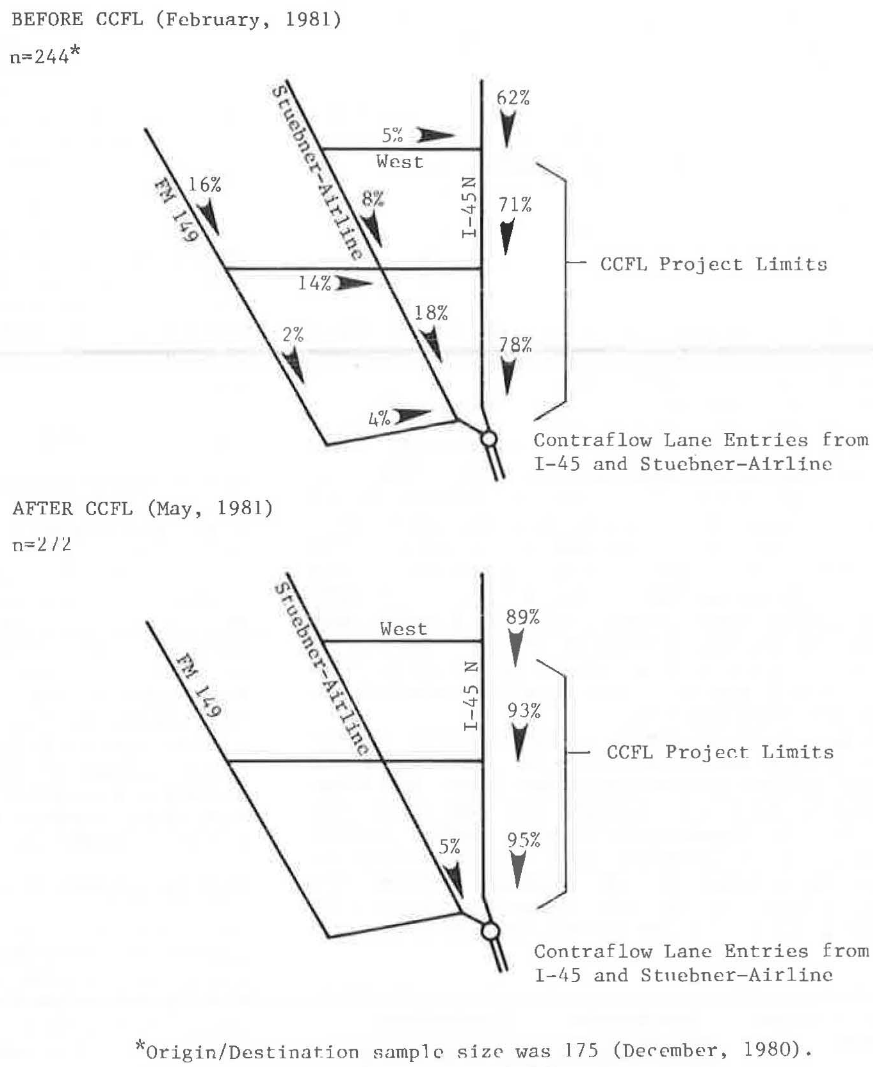


Figure 13. Vehicles traveling in CCFL.

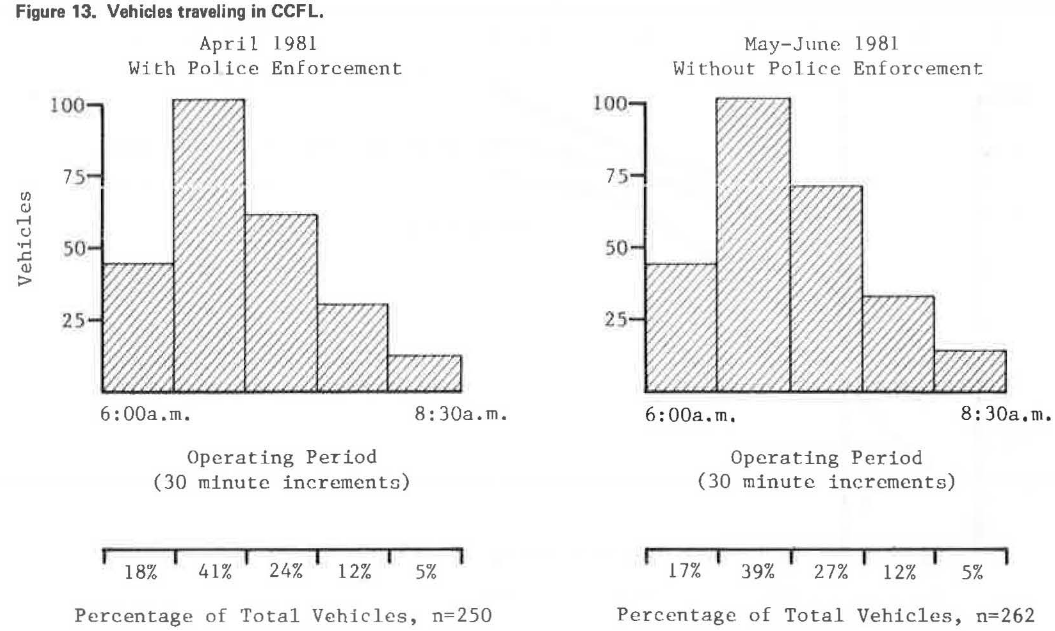


Table 1. Average speeds in CCFL and main lanes.

	6:00-6:30 a.m.		6:30-7:00 a.m.		7:00-7:30 a.m.		7:30-8:00 a.m.		8:00-8:30 a.m.		Average	
Date	CCFL	ML	CCFL	ML	CCFL	ML	CCFL	ML	CCFL	ML	CCFL	ML
4-7-81	35	21	47	27	39	18	44	19	45	27	42	22
4-10-81	50	29	48	28	49	20	41	24	44	35	49	27
4-13-81	48	33	46	20	45	17	47	21	50	26	47	23
4-16-81	51	35	51	35	47	19	48	27	56	45	51	32
4-20-81	48	27	50	20	45	20	49	21	53	32	49	24
4-22-81	50	27	44	29	49	20	52	17	56	31	50	25

Notes: ML = main lanes.
For CCFL, $\bar{X}$ = 48 and S = 3; for ML, $\bar{X}$ = 26 and S = 4.

Table 2. Number of violators by location.

Date	West Road	Mt. Houston	Gulf Bank Road
With Enforcement[a]			
4-7-81	2	3	3
4-10-81	0	1	2
4-13-81	1	2	1
4-16-81	0	4	2
4-20-81	0	0	0
4-22-81	0	3	2
4-24-81	9	7	5
Without Enforcement[b]			
5-5-81	5	10	3
5-6-81	7	7	5
5-14-81	12	13	5
5-21-81	2	6	3
6-19-81	8	8	7
6-22-81	5	2	4

[a] $\bar{X}$ = 2, 3, and 2 and S = 3.0, 2.3, and 1.6 for West Road, Mt. Houston, and Gulf Bank Road, respectively.
[b] $\bar{X}$ = 7, 8, and 4 and S = 3.4, 2.9, and 1.8 for West Road, Mt. Houston, and Gulf Bank Road, respectively.

median, authorized vehicles have either negotiated incidents within the shoulder or merged into adjacent lanes and reentered the CCFL. Slow travel speeds in adjacent lanes usually permit this infrequent maneuver without difficulty.

Violations

During the first month (March 30 to April 27), two patrols of the Houston Police were stationed on the CCFL. Violations during this period are presented in Table 2 (4).

Survey data were collected over seven days during this period, yielding a range of up to nine violations being sited at any given location during an operating period. Violators were sited more often near the beginning of the lane at West Road where police seldom were stationed, but observances were irregular. If an average of 2.3 sitings/day is used throughout the project, the percentage of violators to authorized users represented less than 1 percent of daily vehicles during police enforcement.

During the following months, police enforcement was removed. Average sitings of violators increased slightly, varying from an average of 1.8 to 3.4 observances/location daily and reflecting less than 2 percent of all traffic in the median.

Accidents

The CCFL recorded two minor accidents through June. Both involved minor property damage and involved unauthorized vehicles accidentally or intentionally entering the median shoulder and colliding with an authorized vehicle traveling in the lane. To date the two incidents reflect the only reported accidents during an initial period when 55 000 vehicle miles were logged on the shoulder lane.

There has been no observed change in accidents on adjacent lanes. Information compiled from accident records over the length of the project [taken from State Accident Statistics--Region 4, Educational Service Center (February-May 1981)] is given in the table below for accidents coded for the 8000-10 300 blocks of North Freeway, 6:00-8:30 a.m. (note: inbound accidents are traffic adjacent to the CCFL operation):

	Inbound		Outbound	
Condition	Date	Time (a.m.)	Date	Time (a.m.)
Before (February-March)	3-6-81	6	3-4-81	7
	3-11-81	6		
After (April-May)	4-9-81	8	5-6-81	6
	5-20-81	6		
	5-20-81	8		

Only three accidents were reported during the first two months compared with two accidents in a similar 60-day period prior to the opening of the project. This reflects an accident rate of 1.1 accidents/million vehicle miles (MVM) before to 1.7 accidents/MVM after. Rates in the outbound side remained unchanged at about 0.9 accident/MVM in free-flow conditions. Note that this evaluation is rather limited, encompassing only a 60-day period before and after the project. An extended period of operation is needed to more fully assess accident impacts to users and nonusers.

Costs and Benefits

An initial cost/benefit analysis is presented to provide some indication of the relative significance this project has made after a rather short period of operation. Costs of the project include initial construction ($130 000) and daily operation. Manpower requirements needed for the adjoining contraflow-lane project are used to monitor and provide wrecker response on the CCFL. There may be some additional manpower needed, but this cost is absorbed within regular crew shifts required by the contraflow operation. Special police enforcement is no longer used; thus, no enforcement cost is considered necessary at the present time.

The benefits to users involve an initial travel-time savings of 190 person-h. There may also be some savings to main-lane drivers when an average of 250 authorized vehicles are removed, but these impacts are probably negligible when compared with significant latent demand that exists in the corridor for freeway capacity.

A reduction in travel time does reflect a reduction in fuel consumption. This project expedited

movement of about 3900 persons in 250 vehicles. If it is assumed that without the CCFL these commuters would be riding in private automobiles with an average vehicle occupancy ratio of 1.4 persons/vehicle, the resulting fuel savings would be about 112 000 gal of gasoline/year, assuming a fuel-consumption rate of 17 miles/gal.

COMPARISON WITH OTHER FREEWAY CONCURRENT-FLOW PROJECTS

Concurrent-flow reserved lanes have been demonstrated on freeways elsewhere, and similar projects are currently operating in Portland, Miami, Honolulu, and the San Francisco area (5-7). There have also been unsuccessful demonstrations in Boston and Los Angeles (8). These projects have been the subject of intense review and evaluation. Applications to date have been criticized because they have experienced increased accident rates and are difficult to enforce. Recommendations made from this experience include the following:

1. A CCFL should only be implemented in conjunction with the addition of a freeway lane; a general-traffic lane should not be designated for HOV use;
2. The CCFL should span a location of normal peak-period freeway congestion; otherwise, HOVs will not receive an adequate travel advantage and will have difficulty merging into and out of the lane;
3. Project implementation should be preceded by a vigorous public-information campaign;
4. Project implementation should contain a thorough, well-planned enforcement program; monitoring by motorcycle officers is encouraged for mobility and selective enforcement techniques are recommended as a minimum approach to violation control, with continuous special enforcement encouraged to achieve a desired level of motorist compliance;
5. The project should contain median shoulders or refuge areas for public safety and enforcement monitoring; and
6. Signing and markings should conform to MUTCD standards to reduce driver confusion.

Most design-related recommendations were incorporated into the I-45N project. These included the following:

1. The CCFL was borrowed from a previously designated emergency shoulder; thus, no general-traffic lane was affected;
2. The length and period of designation were specifically selected to bypass a recurring segment of traffic congestion;
3. Median signing conformed to MUTCD standards; lane markings were not included because of the rough white gravel texture of the shoulder and contrast difficulties; and
4. Refuge areas for vehicle breakdowns and enforcement monitoring were available in wider portions of the project near bridge approaches.

Operational recommendations based on experience from other projects were carefully considered by the CCFL management team. Variances from recommendations were made where appropriate to meet specific needs of this project and develop conformity between concurrent-flow and contraflow project operating rules and regulations. Several examples of these variations with accompanying justifications follow:

1. Project implementation and opening were not widely advertised and covered. Because a specific user group on the contraflow lane had already been identified and authorized, there was no incentive to initially seek more users. Second, the project was implemented as an experiment. As such, the management team could more easily modify or terminate this experiment without affecting a previous success record in HOV applications if the project were introduced without a vigorous information campaign. Finally, the earlier implementation of the contraflow lane on the same freeway already familiarized motorists with the objectives of HOV preferential treatment and the term authorized users.
2. Enforcement was considered a necessary part of CCFL operation but no rigorous program could be implemented. Cooperation from the Houston Police Department was requested and received for the first 30 days of project operation. Following this period a series of steps were taken to ensure compliance. Existing police patrols under contract to MTA were asked to expand their coverage area to include the CCFL on a selective basis. Authorized users were asked to report observed violators to MTA. Reports were followed up by correspondence to vehicle owners. These steps have been effective in keeping observed sitings below 2 percent of lane use.
3. Rules and regulations for operating in the CCFL include use of headlights, procedures for maneuvering around a stalled vehicle, and no exiting except on the termination into the contraflow lane. These procedures are more rigorous than other CCFL projects, as are the authorization procedures. The management team felt that retention of the more stringent policies adopted for the contraflow lane would better ensure safe operation on the CCFL.

A comparison of operating characteristics of the Houston, Miami, San Francisco, and Portland projects is included in Table 3 (5-7,9). The Houston project nets the best comparative travel-time savings shown at 1.1 min/mile. Initial use is second only to US-101 in San Francisco. Occupancies before project implementation were impacted by contraflow-lane operations that were initiated 19 months earlier.

CONCLUSIONS

The concurrent-flow shoulder lane operation on I-45N in Houston has made a perceptible improvement in user travel time without impacting adjacent traffic characteristics. A sizable number of authorized users have rerouted their trips to benefit from this improvement. The $130 000 cost for construction, funded entirely from local sources, has reflected very high cost benefits. Enforcement procedures have been minimized and accident rates have not detrimentally affected the CCFL or adjacent lanes after three months of operation.

These findings are in variance from the consensus of experience collected nationwide on the applicability of a CCFL on freeways. The success experienced in Houston may be a result of the following unique characteristics:

1. Facility design--The CCFL did not remove a regular traffic lane from the general public. The shoulder lane was wide enough in places to facilitate police monitoring and apprehension of violators. The surface texture of rough delineation gravel was retained, thereby alleviating potential preceptions of shoulder use for a regular travel lane. The CCFL also turned into contraflow preferential treatment downstream at a location under constant police surveillance.
2. Management control--MTA maintained stringent authorization procedures for CCFL eligibility. A highly visible windshield sticker was required as

Table 3. Operating characteristics of concurrent-flow HOV projects.

	Miami, I-95			San Francisco, US-101			Portland, Banfield Freeway		Houston, North Freeway	
Variable	Before	Bus and 3-Person Carpool	Bus and 2-Person Carpool	Before	Bus Only	Bus and 3-Person Carpool	Before	Bus and 3-Person Carpool	Before	Bus and Vanpool
Critical peak period	4:00-6:00 p.m.	4:00-6:00 p.m.	4:00-6:00 p.m.	4:00-7:00 p.m.	4:00-7:00 p.m.	4:00-7:00 p.m.	7:00-8:00 a.m.	7:00-8:00 a.m.	6:00-8:30 a.m.	6:00-8:30 a.m.
Length of HOV lane (miles)	-	6.7	6.7	-	3.7	3.7	-	3.3	-	3.3
Total peak directional lanes	3-4	4-5	4-5	3	4	4	2-3	3-4	3	4
No. of HOV lanes	-	1	1	-	1	1	-	1	-	1
Volume										
All lanes	11 355	12 825	15 290	13 600	13 137	13 098	3557	4025	12 382	12 600
HOV lanes	-	618	2057	-	191	647	-	203	-	262
HOV lanes (bus only)	-	23	23	-	148	150	-	23	-	58
HOV lanes per total volume (%)	-	4.8	13.5	-	1.5	4.9	-	5.0	-	2.1
Vehicle occupancy (persons per vehicle)										
All lanes	1.28	1.37	1.42	1.30	1.30	1.36	1.22	1.26	1.62[a]	1.70
HOV lanes	-	2.23	1.79	-	2.21	2.96	-	2.81	-	16.0
Person throughput										
All lanes	14 875	18 221	22 338	24 439	24 567	25 365	4329	5611	12 723	13 461
HOV lanes	-	1981	4347	-	5719	7172	-	1067	-	4194
HOV lanes per total throughput (%)	-	10.9	19.5	-	23.3	28.3	-	19.0	-	31.2
Speed (mph)										
General lanes	29.6	35.6	41.6	34.1	43.3	47.6	38.2	37.9	26	26
HOV lanes	-	50.0	50.4	-	53.4	53.4	-	51.5	-	48
Travel time (min)										
General lanes	13.5	11.3	9.6	6.5	5.1	4.7	5.2	5.2	7.0	6.9
HOV lanes	-	8.0	8.0	-	4.2	4.2	-	3.8	-	3.7
Accident rate per MVM	5.1	4.7	2.4	4.2	9.6	12.8	0.9	0.8	1.1	1.7

[a]Includes contraflow buses and vanpools previously traveling in all lanes.

part of the authorization procedure. Signing restricted CCFL use to authorized vehicles, and sticker visibility, in addition to vehicle appearance, helped police enforcement and public recognition of violators.

3. Public attitudes--Although the CCFL was the first concurrent-flow freeway application in Houston, it was not the first preferential treatment project. North Freeway commuters were exposed to the contraflow concept over a 9.6-mile segment of the freeway in August 1979. The definition for authorized vehicles was not new to commuters. Many people, including the news media, called the CCFL an extension of the contraflow project. This sequence of staging the concurrent-flow experiment after contraflow may have improved the chances for public acceptance of the concept.

After three months of project operation, the general conclusion of the TSDHPT-MTA project management team, the users, and the public is that the North Freeway CCFL has proved successful. The level of use and its continued increase have met expectations. The fact that an additional 190 person-h are saved daily and 260 buses and vanpools have been afforded exclusive access around a congestion bottleneck has enhanced transit and vanpooling as a desired alternative to the automobile in the corridor. Both the CCFL and contraflow projects to date have accomplished a daily savings of 3300 person-h and removal of 4500 automobiles from peak-direction traffic, significantly impacting expectations for regional transitways on many of Houston's corridors in the future.

I hope that the information presented substantiates the initial conclusions drawn regarding the concurrent-flow application in Houston. The project will continue to be monitored and modified by the management team, as appropriate, until such time that a more permanent transitway facility can be incorporated into the North Freeway.

REFERENCES

1. I-45 Contraflow Interim Report. Metropolitan Transit Authority, Houston, May 1980.
2. Manual on Uniform Traffic Control Devices. FHWA, 1978.
3. Addendum to Driver Training Manual. Metropolitan Transit Authority, Houston, March 1981.
4. Summary of Operations of the Concurrent Flow Lane. Texas Transportation Institute, Texas A&M Univ., College Station, Draft Rept., July 1981.
5. C.A. Fuhs and others. Operational Experience with Concurrent Flow Reserved Lanes. Texas Transportation Institute, Texas A&M Univ., College Station, Rept. 205-4, July 1977.
6. Beiswenger, Hoch, and Associates. Enforcement Requirements for High-Occupancy Vehicles. FHWA, Dec. 1978.
7. Beiswenger, Hoch, and Associates. Safety Evaluation of Priority Techniques for High-Occupancy Vehicles. FHWA, Feb. 1979.
8. H.J. Simkowitz. A Comparative Analysis of Results from Three Recent Non-Separated Concurrent Flow High-Occupancy Freeway Lane Projects: Boston, Santa Monica, and Miami. Cambridge Systematics, Inc., Transportation Systems Center, Cambridge, MA, Draft Rept., Jan. 1978.
9. Beiswenger, Hoch, and Associates; Texas Transportation Institute. Occupancy, Volume, and Park-and-Ride Surveys. Metropolitan Transit Authority, Houston, Jan. 1981.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Review of Bus Costing Procedures

WALTER CHERWONY, SUBHASH R. MUNDLE, BENJAMIN D. PORTER, AND GREGORY R. GLEICHMAN

With changing policies regarding transit funding at all levels of government, transit planners will be required to monitor more carefully existing bus systems as well as examine intensively proposed service changes. A key aspect of this responsibility will be an assessment of transit finances. During the past two decades, the focus of research has been placed on the estimation of demand and revenue. In the next few years, increasing efforts will be directed to the estimation of bus operating costs and the underlying relation that impacts expenditures. A discussion of various procedures and techniques that have been developed and applied in the past to estimate operating costs is presented. The methods have been grouped to form broad generic types, which in turn have been subdivided further by unique approaches. To illustrate the present state of the art, each approach has been illustrated by a single model. This cost-estimation review clearly indicates the evolutionary nature of cost-estimation procedures. The latest research efforts are typically more accurate and sensitive to drivers' wages and work rules that reflect the labor-intensive nature of bus transportation. It is anticipated that an understanding of the prevailing cost-estimation procedures will aid transit planners in their activities and enable them to contribute to the literature on costing procedures.

Almost every transit system today has established a mechanism to monitor existing bus service performance and conduct service planning in a systematic fashion. The techniques and approaches vary widely; some systems perform cursory reviews of their needs and others use sophisticated techniques to perform detailed operations and planning activities. A key element of this analysis involves estimating the costs to provide present service as well as computing the cost impacts of proposed service changes. This need has become acute due to the limited financial resources of all public services, including public transportation. More than ever, transit managers are focusing their attention on improving the productivity, effectiveness, and efficiency of their transit systems. A key component of this new cost consciousness is a strong interest in developing a technique that accurately estimates the cost of present routes and the cost of proposed service changes.

Recognizing this need, the Urban Mass Transportation Administration (UMTA) has commissioned Booz, Allen and Hamilton to develop a uniform technique or set of techniques that will accurately reflect the cost of providing bus service. An initial step in this study is a review of cost-estimation techniques