Development of an Interactive Planning Model for Contraflow Lane Evaluation

REGGIE J. CAUDILL AND NANA M. KUO

Work undertaken to develop an interactive computer simulation model for assessing the impacts of contraflow lane projects along existing freeway corridors is described. The methodology presented assembles existing, extensively used travel demand and traffic flow models into an integrated planning tool. The travel and flow characteristics of a corridor are processed, and the user is presented with a summary of the predicted changes. These submodels include the Greenshields linear speed-flow model, the California diversion model, and a multinomial and incremental logit model developed by Cambridge Systematics, Inc. The interactive nature of the package allows the transportation planner to perform the evaluation with a minimum of effort. An example based on data from Washington, D.C., is used for illustration.

As the population of a city grows, the streets and highways that once served it adequately become progressively more congested, and frustrating traffic jams and the associated loss of time and money become more and more common. The many ideas that have been proposed to resolve this problem have met with varying degrees of success. Preferential with-flow and contraflow lane projects are two solutions that have proved to require fewer initial capital investments than alternatives such as expanding fixed-guideway facilities, extending bus operations, or expanding other mass transit services.

A preferential with-flow traffic lane is a lane reserved usually for the use of designated multiple-occupant vehicles (buses, carpools, and vanpools). Although this solution may reduce traffic congestion for those who share rides, it may also increase the congestion experienced by other drivers since one less lane is available to them. Consequently, a preferential lane can sometimes aggravate the existing congestion problem.

A contraflow lane, on the other hand, appears to be a more promising solution. Because traffic patterns for modern American cities commonly are unidirectional during rush hours, little more than half of the city's freeway capacity is used during these peak times. Contraflow lanes help to relieve the traffic congestion during rush hours by appropriating the lane (or lanes) closest to the median from the minor traffic stream and designating these lanes for the use of the major flow stream. Because the direction of the major flow changes with the time of day, the lanes closest to the median on both sides are both contraflow lanes and are allowed to operate in the direction of the heaviest traffic during the daily peak periods. A contraflow lane does not require a major change in the established driving habits of the average trip maker and does not inconvenience those who do not participate in ridesharing or mass transit. In fact, contraflow lanes simply provide transit riders and carpoolers with faster and more dependable means of getting to their destinations.

Several case studies of existing contraflow projects have been published (1-3). However, there has been relatively little transportation literature discussing exactly how much, if any, improvement in vehicle and passenger flow could be expected from a contraflow installation. Most contraflow projects appear to have been implemented mainly to test out the idea rather than with the expectation of a prequantified improvement. This willingness to experiment with new ideas has contributed greatly to the volume of knowledge available about contraflow lanes, but it cannot be the most effective manner in which to decide whether a contraflow lane is the appropriate solution to a city's transportation problem.

The interactive computer simulation model presented in this paper is designed to help planners decide the feasibility of implementing a designated contraflow lane into an existing corridor by predicting some of the effects that might be expected from the installation of such a lane. The approach followed integrates existing, well-developed travel demand and traffic flow models into an interactive planning tool.

CONTRAFLOW LANES

When first implemented, contraflow lanes were often restricted to buses only. Today, many contraflow projects permit both buses and multiple-occupant vehicles to use the lanes. These projects directly encourage the use of carpools, vanpools, and transit by allowing the people who use transit and ridesharing to benefit from the lower traffic congestion and higher vehicle speeds in the contraflow lanes. Contraflow projects also have received more support from nonuser groups than projects that use preferential with-flow lanes because a decrease in the congestion experienced by multiple-occupant vehicles is not generally accompanied by an increase in the congestion experienced by those who drive alone (4).

Excessive weaving of vehicles is not as big a problem with contraflow lanes as it is with preferential with-flow lanes because there is more likely to be a lower speed differential between the contraflow and unrestricted lanes than between the with-flow and corresponding unrestricted lanes (5). The smaller speed differential may be traced to the fact that, where a contraflow lane opens up a new lane for the existing traffic, a with-flow preferential lane essentially denies an old lane to the traffic. However, this is not to say that contraflow lanes are completely accident free. In fact, problems do arise when vehicles enter and exit contraflow lanes. A case in point would be the carpool-bus bypass lane on the Moanalua Freeway, where "the most predominant types [of accidents] were sideswipes involving a vehicle in the carpool lane and another attempting to enter or leave the lane, and a single vehicle losing control and colliding with a fixed object, usually the median" (6). Contraflow lanes may increase the accident rate in the corridor, but the increase is often only comparable to that which would be experienced if an extra nondesignated traffic lane had been added and usually less than if a with-flow preferential lane had been installed. In fact, after the concurrent implementation of its contraflow and ramp-metering projects, the city of Houston experienced a decrease in the overall accident rate on Interstate 45 (7).

Contraflow lanes also tend to have fewer violation problems, possibly as a result of the relatively limited number of entrance and exit ramps and the fact that congestion on all of the lanes has been reduced (4).

However, contraflow lane projects do have their disadvantages. They are short-term solutions to a long-term problem in that they reduce the number of lanes available to the minor traffic stream, a traffic stream that will continue to increase with the population and ubiquity of the city. The design of the entrances and exits to the lane requires very careful formulation and implementation. The operation and control of the lane and driver behavior within the lane must be given continual attention because of the possibly disastrous consequences. Finally, additional considerations should be given to the design of shoulders to accommodate disabled contraflow vehicles. These drawbacks, among others, prompted the 1976 version of the Transportation and Traffic Engineering Handbook (8), which sets forth some guidelines to consider before proceeding with the installation of a contraflow lane:

1. The average speed of the freeway should decrease by at least twenty-five percent [during the trouble periods] over the normal speed or there should be a noticeable backup at signalized intersections leading to vehicles missing one or more green signal intervals; i.e., the demand should be greater than the capacity of the freeway.
2. The traffic congestion problem under investigation should be both "periodic and predictable."
3. The ratio of major to minor traffic counts should be at least two to one and preferably three to one. Otherwise, the installation of a contraflow lane could be the cause of a new traffic problem on the minor stream side of the freeway.
4. The contraflow lanes must be designed with adequate entrance and exit capacities in addition to easy transitions between the normal and the reverse flow lanes. Otherwise, the contraflow lane could be the cause of bottlenecks and other traffic problems in addition to the existing traffic congestion.

These guidelines provide general direction for the planner, but no procedure or methodology is suggested for estimating the impacts of a contraflow lane. The simulation model described in this paper provides the planner with a technical and interactive planning tool for quantitatively evaluating traffic flow improvements derived from the implementation of contraflow lanes. Its usefulness is directly related to the applicability of the travel demand and traffic flow submodels on which it is based.

CONTRAFLOW SIMULATION MODEL METHODOLOGY

The contraflow simulation model is an interactive computer package designed for a dual-screen work station consisting of an IBM/3277 display station model 2 (for alphanumeric input and output) and a TEKTRONIX 618 storage tube (for graphical input and output). The work station is linked to an IBM/3081 mainframe computer and uses the VM/370 operating system. The package can be used on any IBM-compatible full-screen terminal if the graphics are not required. The graphics are specifically designed to be displayed on a TEKTRONIX graphical attachment, but they can also be sent to a zeta 1453sx plotter if the user so desires.

The package was implemented in an interactive environment to allow the user to enter the necessary data with a great deal more ease and flexibility than is possible with a batch-operated system. For example, if a data entry error is detected in this interactive model, the user may correct the mistake without exiting from the simulation. In addition, with an interactive format the user is given the opportunity to perform multiple runs within a short period of time to determine the sensitivity of the results to specified variations in the model parameters.

The time requirement for running the simulation package is primarily related to the speed with which the data are entered. The IBM/3081 has a cycle time of approximately 26-28 nanoseconds, and the data manipulation occurs almost instantaneously after the initial data entry step. An average simulation requires, in central processing unit (cpu) time, approximately 0.6 s (without the graphics) to 1.98 s (with the graphics).

In the process of predicting the impact of a contraflow lane, the program performs a sequence of four basic tasks. Estimating the initial modal split is the first task. After the user enters the travel demand characteristics that correspond to each of the four population subgroups being considered, the program estimates the existing modal split by using a multinomial logit model developed by Cambridge Systematics, Inc. The second task in the sequence involves predicting the concentration level in the contraflow lane. This prediction is obtained by iteratively estimating the vehicle flow that will be diverted to the contraflow lane and solving the corresponding Greenshields equation for that flow.

The third task is to estimate the mean time delay, the sum of all of the time gaps that the average vehicle trying to enter the contraflow lane rejects before it is able to enter the lane. This calculation is based on the assumption that the traffic in the contraflow lane can be described by an Erlang distribution function. If the mean delay becomes too large, cars entering and exiting from the lane could be causing a new congestion problem in the main corridor. The fourth and final task is to tabulate all of the initial and final characteristics of the corridor for analysis. This final tabulation gives the user an overall view of the impacts that implementing a contraflow lane could have on the corridor being studied. A flowchart that describes the sequence of calculations performed by the program is shown in Figure 1.

Before entering the simulation, the user must compile a record of the characteristics of the corridor. These characteristics fall into four categories: (a) physical characteristics such as the number of lanes on the corridor, (b) traffic flow characteristics such as the existing and jam vehicle concentrations, (c) vehicle operating characteristics such as the number of passengers per vehicle, and (d) travel characteristics such as the trip lengths and trip times associated with the corridor. To give the user an idea of some typical parameter values, the first step in the simulation assigns the default flow and gap acceptance parameter values in addition to the travel characteristics of the area to the appropriate simulation variables. These flow and gap acceptance parameters, their abbreviations, their typical values (using the Washington, D.C., area as an example) and their units of measure are given in Table 1.

After the defaults have been assigned, the travel characteristics are written onto the MODESPLIT panel and displayed on the terminal as shown in Figure 2. A panel is a formatted alphanumeric display on a full-screen terminal that makes it possible to input and output an entire screen of data at one time instead of line by line.

The MODESPLIT panel is displayed four times, once for each population subgroup being considered in this simulation. These subgroups are those who have access to (a) transit only, (b) transit and shared

Figure 1. Methodology sequence.

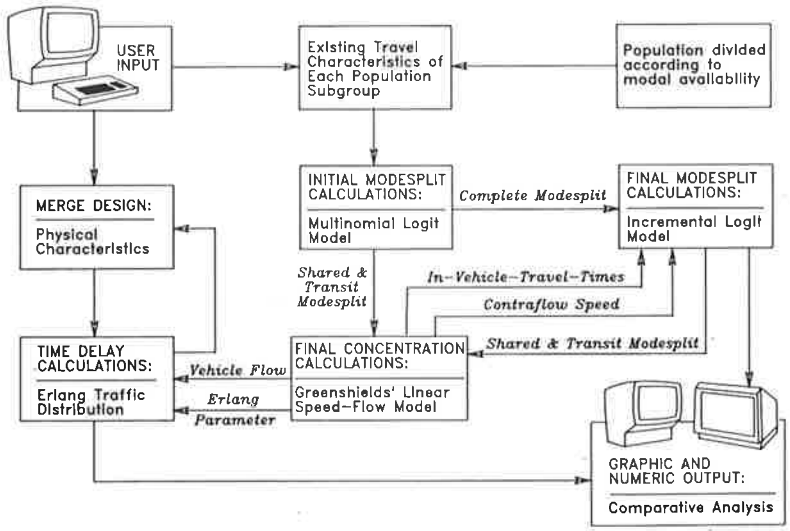

Figure 2. Travel characteristics.

DRIVE ALONE:	
OPTC (¢):	130.00
IVTT (minutes):	44.00
OVTT (minutes):	16.70
BW (1 TO 0):	.78
Disp. Income ($):	10400.00
Cars/Licensed Driver:	.90
SHARED RIDE:	
total OPTC (¢):	152.50
IVTT (minutes):	53.00
OVTT (minutes):	19.30
GW (1 or 0):	1.00
# Workers/household:	1.97
Employees/Comm. Acre:	107.00
Disp. Income ($):	10300.00
Cars/Licensed Driver:	.68
TRANSIT:	
OPTC (¢):	99.00
IVTT (minutes):	55.80
OVTT (minutes):	36.32

POPULATION SUBGROUP:
TRANSIT, SHARED RIDE, AND DRIVE ALONE

Fraction of Total Pop:	.62
Avg Household Income($):	13238.29
Avg Trip Length (miles):	8.19

INITIAL FLOW PARAMETERS:

Number of lanes/side:	3.00
Free Flow Speed(mph):	55.00
Concentration/lane:	110.00
Jam Concentration:	140.00
Avg Shared Ride Load Size:	2.50
Avg Transit Load Size:	50.00
Frac of Trip in Line Haul:	.70
Diversion Rate to Cflow:	.90

Table 1. Parameters used in contraflow simulation.

Parameter	Typical Value	Abbreviation
No. of lanes	>3	-
Free-flow speed (mph)	55	V_f
Concentration (vehicles/mile)	110	K
Jam concentration (vehicles/mile)	140	K_j
Vehicle flow (vehicles/h)	1296	Q
Avg shared load (passengers)	2.50	L_s
Avg transit load (passengers)	50	L_t
Fraction of trip spent in line-haul	0.70	-
Diversion rate to contraflow lane	0.90	Div
Angle of merge (°)	2	-
Type of merge	Parallel	-
Length of acceleration lane (ft)	400	-

ride, (c) shared ride and drive alone, and (d) all three modes of travel. If the user does not choose to consider any of the four subgroups displayed, a value of zero may be indicated for the "fraction of total pop" variable. This option allows the planner to run the simulation by using aggregate data and specifying that the entire population has access to all three modes of travel. The user may also enter all the data for the existing travel characteristics for each subgroup requested by the panel or accept any of the default values shown on the panel. Once these values have been input, the initial modal splits are calculated by using the multinomial logit modal-split model proposed by Cambridge Systematics, Inc.:

$$P(i{:}A) = e^{U_i} / \sum_{m \in A} e^{U_m} \quad (1)$$

where

m,i = travel mode alternatives,
A = set of possible choices,
P(i:A) = probability of choosing alternative i out of the set of available alternatives A, and
U_i = utility of alternative i.

The Cambridge Systematics model was used because it can handle more than two modes of transportation and because it includes a variable for in-vehicle travel time that would be affected directly by the installation of a designated contraflow lane (9).

The relative attractiveness of each mode in terms of its travel time, level of service, and cost-effectiveness is quantified by its utility function (9). The following utility equations for drive alone (Ud), shared ride (Us), and transit (Ut) were calibrated for the Washington, D.C., area by Cam-

Table 2. Travel characteristics parameters.

Parameter	Mode	Typical Value	Abbreviation
Round-trip out-of-pocket travel cost (¢)	D	130.00	OPTC
	S	152.00	
	T	99.00	
Round-trip in-vehicle travel time (min)	D	44.00	IVTT
	S	53.00	
	T	55.80	
Round-trip out-of-vehicle travel time (min)	D	16.70	OVTT
	S	19.30	
	T	36.32	
One-way trip distance (miles)		8.19	DIST
Automobile availability (cars/driver)	D	0.90	AALD
	S	0.68	
Breadwinner		0.78	BW
Destination in CBD		1.00	DCITY
Annual income ($)		13 238.29	INC
Annual disposable income ($)	D	10 400.00	DINC
	S	10 300.00	
Incentive programs		1.00	IP
Number of workers per household		1.97	NWORK
Employment density (employees/commercial acre)		107.00	DTECA

Note: D = drive alone, S = shared ride, T = transit.

bridge Systematics by using a least-mean-squares method:

$$Ud = -3.24 - (28.8 * OPTC/INC) - (0.0154 * IVTT) - (0.160 * OVTT/DIST) + (3.99 * AALD) + (0.890 * BW) - (0.854 * DCITY) + (0.000\,071 * DINC) \quad (2)$$

$$Us = -2.24 - (28.8 * OPTC/INC) - (0.0154 * IVTT) - (0.160 * OVTT/DIST) + (1.62 * AALD) + (0.287 * IP) - (0.404 * DCITY) + (0.000\,071 * DINC) + (0.0983 * NWORK) + (0.000\,65 * DTECA) \quad (3)$$

$$Ut = -(28.8 * OPTC/INC) - (0.0154 * IVTT) - (0.160 * OVTT/DIST) \quad (4)$$

Cambridge Systematics has done a number of tests on the transferability of these utility functions to cities other than Washington, D.C. (10). The travel characteristics used in these equations, their abbreviations, typical values, and units of measure are given in Table 2.

In these equations, OPTC/INC is defined as the round-trip out-of-pocket travel cost measured in cents divided by the total income measured in dollars. For the driver, the out-of-pocket travel cost (OPTC) includes the cost of gasoline, oil, lubrication, and maintenance in addition to travel tolls and parking charges. For the ridesharer, it is all of the above costs dispersed among the members of the carpool or the ridesharing group, and for the transit rider it would simply be the bus fare (11).

The effect of "different income groups valuing savings in cost differently" is reflected in the OPTC/INC term, which appears in the utility functions for all three modes (10). The inverse effect of income level on the bus modal share is reflected in the lack of a positive disposable income coefficient or variable (DINC) in the transit utility function. In the shared-ride and drive-alone utility functions, though, DINC is measured in dollars, and "for Washington, disposable income was defined as household income minus $800 times the number of persons in the household" (11).

IVTT is the round-trip in-vehicle travel time measured in minutes. The IVTT is defined as the time spent in actual transportation from the origin to the final destination and back again. For car drivers, this may be found by dividing the round-trip distance by the average trip speed (11). This includes the time spent picking up and dropping off riders and the time spent waiting when the bus stops for passengers to board and alight (11).

The excess time--the time spent walking to and from a parking lot or bus stop or waiting for and tranferring between buses--is accounted for in the level-of-service measure (OVTT/DIST), the round-trip out-of-vehicle travel time in minutes divided by the average one-way trip length in miles. The OVTT/DIST term reflects "the effect that a traveller making a short trip values savings in wait or walk time more than he or she would when making a long trip" (10).

The variable AALD is the variable for automobile availability, which appears only in the utility equations for shared riders and for people who drive alone. It is measured in terms of the number of automobiles available in a household divided by the number of licensed drivers in the household (11).

The variable BW indicates whether the tripmaker is the "breadwinner," the main source of income for the family. The variable DCITY is another indicator variable for the destination of the tripmaker [one if bound for the central business district (CBD) and zero otherwise]. For this simulation, DCITY was implicitly taken to be one because, in most cities that experience heavy periodic and unidirectional traffic congestion during the morning peak hour, a majority of the traffic is destined for the CBD. It should be noted that DCITY contributes negatively to the utility functions of the shared-ride and drive-alone modes. This is to account for the "congestion and the inconvenience associated with driving into the CBD in large cities" (11).

The variable IP is designed to "reflect the effect of large organizations offering carpool incentives" (11). In the Washington, D.C., area, the large organization was taken to be the government, and thus IP was interpreted to be one if the majority of the population subgroup were government employees and zero otherwise. However, generally the user should enter a one (1) for IP only if there are a large number of sizeable employee incentive programs in the CBD and a zero (0) otherwise. The variable NWORK is the average number of workers in the average household, and DTECA is the employment density in the work zone, "the number of employees divided by [the] commercial area in acres" (11). Travel costs must be entered in cents, incomes in dollars, and times in minutes.

When all of the average travel characteristics of each population subgroup have been entered, the program calculates the utility of each mode for each of the four population subgroups. These utilities are then used to find the corresponding modal splits, which are then normalized over the entire population. Next, the program iteratively estimates the vehicle concentrations for the contraflow as well as for the unrestricted traffic lanes. To date, little research has been done in estimating the concentration on the unrestricted lanes after the implementation of the contraflow lane. However, a reasonable assumption is that the concentration will not be reduced significantly by the removal of the multiple-occupant vehicles. In fact, the Houston I-45 contraflow project has reported "negligible impacts on peak-direction traffic volumes and travel speeds" (3). During a rush hour, the buses and carpools diverted to the contraflow lanes are replaced by other single-occupant vehicles. Consequently, the concentration in the unrestricted lanes is assumed to remain constant.

The contraflow concentration, on the other hand, is determined by estimating the original shared-ride and transit vehicle flow and assigning a fraction (the diversion rate) of this flow to the contraflow lane. The corresponding concentration is found by solving for the larger real root of the quadratic equation derived from the Greenshields linear speed-flow model. The Greenshields model is as follows:

$$Q = K * Vf(1 - K/K_j) \tag{5}$$

where Q is the fraction of original multiple-occupant vehicle flow (vehicles/h) and the other terms are as previously defined. The quadratic equation derived from the Greenshields model is as follows:

$$0 = K^2 - (Kj)K + (Q * Kj/Vf) \tag{6}$$

Not all of the original bus and shared-ride flow is assumed to be diverted into the contraflow lane for the following reasons:

1. The entire length of the trips will not be spent in the contraflow lane.
2. Some trips may not be long enough to warrant the use of the contraflow lane.
3. The vehicles using the contraflow lanes must weave across the freeway when entering and exiting.

Consequently, some adjustment factor is necessary and is estimated by using the California diversion formula and setting the distance saved from using a contraflow lane equal to zero (12). The California diversion formula is as follows:

$$P = 50 + 50(d + 0.5t)/\sqrt{[(d - 0.5t)^2 + 4.5]} \tag{7}$$

where

P = percentage of trips via contraflow,
d = distance saved (miles), and
t = time saved (min).

From the estimate of the contraflow concentration, a new speed and the corresponding in-vehicle travel time (IVTT) are found by using the following relations, which are also derived from the Greenshields linear speed-flow model (Equation 5):

$$V = Vf(1 - K/Kj) \tag{8}$$

and

$$IVTTnew = IVTTold[(1 - p) + (p * Vold/Vnew)] \tag{9}$$

where p is the fraction of the total trip length spent on the line-haul portion of the freeway.

To reduce the data requirements, an incremental logit model is used to calculate the new modal split based on the new IVTT. With this new modal split, the iterative process continues until the most recent estimate of the concentration differs from the previous estimate by not more than 1 percent, which usually takes three or four iterations. At this point, the new modal split is displayed and the Erlang parameter that describes the variability of the speed distribution in the contraflow lane is calculated. In lieu of a more reliable method, the assumption has been made that the traffic volume is distributed linearly with the Erlang parameters. To find the appropriate Erlang parameter, the program first divides the flow capacity (2000 vehicles/h) into six equally spaced ranges and matches each range with an Erlang parameter. The parameter ranges from one if the traffic in the contraflow lane is truly random and the volume is equal to zero to six if the traffic volume is approaching the capacity of the contraflow lane (13). Finally, the contraflow volume is compared with these ranges and the corresponding Erlang parameter is assigned.

Next, the simulation proceeds to display the initial and final speeds as well as the contraflow concentration and the Erlang parameter. The user then enters the following design parameters for the merge between the unrestricted and the contraflow lanes: (a) the jam concentration, (b) the angle at which vehicles will be allowed to merge into the contraflow lane, (c) the type of merge (one for taper and zero for parallel), and (d) the length of the acceleration lane in units of 100 ft. These parameters are used to calculate the critical time gap, the mean delay, and the variance of the delay by using formulas based on the assumption that the gaps in the contraflow lane have an Erlang distribution (13). The Erlang distribution function, Erlang mean delay function, and Erlang variance function, respectively, are given below:

$$f(t) = [(aQ)^a/(a - 1)!]\, t^{(a-1)}\, e^{-(aQt)} \tag{10}$$

$$\mu(t)_a = \left\{ e^{(aQT/3600)} - \sum_{i=0}^{a} [(aQT/3600)^i/i!] \right\} /Q \sum_{i=0}^{a-1} [(aQT/3600)^i/i!] \tag{11}$$

$$\sigma^2(t)_a = \left[\left((a+1)\left\{ e^{(aQT/3600)} - \sum_{i=0}^{a+1} [(aQT/3600)^i/i!] \right\}\right) \div \left\{ aQ^2 \sum_{i=0}^{a-1} [(aQT/3600)^i/i!] \right\}\right] + \mu^2(t)_2 \tag{12}$$

where

a = Erlang parameter,
T = critical time gap (h), and
t = time gap (s).

In these calculations, delay refers to the sum of all time gaps that a vehicle attempting to merge into the contraflow lane will reject before it finds one large enough for it to accept. The mean delay and the variance of the delay are statistics that give the user some indication of the state of the queuing process that is being experienced by the vehicles attempting to get into the contraflow lane. If the mean delay and the variance become too large, one may surmise that the merging procedure is not proceeding smoothly and that the queue of vehicles trying to get into the contraflow lane could be causing more traffic congestion than the contraflow lane is relieving. These characteristics of the merging process, shown in Figure 3, are displayed on the terminal.

Once the delay has been calculated, the new passenger flow can also be found by multiplying the vehicle flows by the different modal splits and the corresponding load factors and vehicle size adjustment factors. These calculations are performed by assuming that only a fraction of the total multiple-vehicle flow will occur in the contraflow lane. This will be the same fraction, the diversion rate, that was calculated previously. Therefore, new modal splits for the unrestricted lanes must be determined. The new modal share for the (i)th mode in the unrestricted lanes is estimated by using the following equation:

$$M(i) = MSPLIT(i)/\left\{ MSPLIT(D) + (1 - Div)\,[MSPLIT(S) + MSPLIT(T)] \right\} \tag{13}$$

where M(i) is the modal split to the (i)th mode and (i) equals (D)rive alone, (S)hared ride, (T)ransit. Similarly, a new modal split for the contraflow lane needs to be estimated, and this is accomplished by using the following equation:

$$M(i) = MSPLIT(i)/[MSPLIT(S) + MSPLIT(T)] \tag{14}$$

where M(i) is the modal share to shared ride or transit and (i) equals (S)hared ride, (T)ransit.

Figure 3. Contraflow merge characteristics.

```
INTIAL CONCENTRATION:      110 VEH/MIL
OLD SPEED:  12 mph   NEW SPEEDS:  22 mph   12 mph

E[Contraflow lane concentration]                  90
E[Unrestricted lane concentrations]              110
Angle of Merge ( in degrees )                      2
Type of Merge (0=parallel, 1=taper)                0
Length of Accel Lane (100's of feet)               4
Erlang Parameter                                   5
(1 to 6 = random to stalled traffic)

     CRITICAL TIME GAP (seconds):                  4
     MEAN DELAY (seconds):                        28
     VARIANCE OF DELAY (seconds):                169

Type Y to respecify merge parameters, and N otherwise.
```

Finally, the new passenger flows are given by the following equations:

$$CPV = \{CFLOW[(LFS * SSPLITc) + (LFT * TSPLITc/1.6)]\} \div (SSPLITc + TSPLITc) \qquad (15)$$

$$UPV = RFLOW[(LFD * DSPLITr) + (LFS * SSPLITr) + (LFT * TSPLITr/1.6)] / DSPLITr + SSPLITr + TSPLITr \qquad (16)$$

where

- CPV = contraflow passenger volume (passengers/h),
- UPV = unrestricted passenger volume (passengers/h),
- CFLOW = contraflow vehicle flow,
- RFLOW = unrestricted vehicle flow,
- LFD = drive-alone load size = 1,
- LFS = shared-ride load size,
- LFT = transit load size,
- DSPLITr = modal share to drive alone,
- SSPLITr = modal share to shared ride in unrestricted lanes,
- TSPLITr = modal share to transit in unrestricted lanes,
- SSPLITc = modal share to shared ride in contraflow lane, and
- TSPLITc = modal share to transit in contraflow lane.

The 1.6 factor in the transit calculations is to adjust for the size of a bus (i.e., one bus is approximately 1.6 vehicle equivalents) (14).

Once all of the calculations have been performed, the pertinent flow characteristics of the freeway before and after the installation of the contraflow lane are displayed in tabular and graphical forms. The panel with alphanumeric data is shown in Figure 4, and the graphic display is shown in Figure 5. The comparison of the initial and final corridor characteristics offers the user a variety of criteria by which to judge the feasibility of implementing a contraflow lane. By running several simulations with different initial concentrations, the user could also judge what the minimum initial concentration would have to be to justify the use of a contraflow lane.

SIMULATION EXAMPLE

A sample simulation was performed with the typical parameter values indicated earlier in this paper. The simulation used the average travel demand characteristics of work trips in the Washington, D.C., area and reasonable estimates of the existing and jam concentration and various other physical design and flow parameters for a hypothetical corridor. The panels and graphs with the parameter values used in the simulation are shown in Figures 2-5.

This particular simulation predicts that the average speed over the hypothetical corridor will increase from about 12 to 15 mph if a contraflow lane were installed in the example corridor. This increase in the average speed in the corridor would also be accompanied by a decrease in average concentration from 110 to 104 vehicles/mile; an increase in the total vehicle flow from 3889 to 5655 vehicles/h; an increase in the total passenger flow from 25 669 to 26 802 passengers/h; a redistribution of modal split toward shared ride and transit; and a decrease in the in-vehicle travel time from 48 to 40 min. These statistics appear to confirm the hypothesis that contraflow lanes can contribute to a significant improvement in the level of service in the corridor. In particular, a contraflow lane can greatly increase the total passenger flow that the corridor can handle.

To determine the correlation between the change in passenger flow and the initial concentration level, a series of simulations was run. The initial concentration was varied in increments of 5 vehicles/mile while the physical parameters, flow parameters, and travel characteristics were kept constant. The results of these simulations are shown in Figure 6. As the graph in Figure 6 shows, the introduction of a contraflow lane can lead to a dramatic increase in passenger flows when the initial concentration is close to the jam concentration.

SUGGESTIONS FOR FURTHER RESEARCH

This paper investigates the effect of contraflow projects only in the major flow direction. Further work will be done to evaluate the effect of contraflow projects in the minor flow direction. This work could help the planner to estimate the expected useful life of the contraflow project before the lanes in the minor flow direction become too congested to allow the contraflow lane to continue operation.

Additional work should also be done to investigate the choice of transportation models used in this simulation and to calibrate these models by using real-life case studies. This research will serve to validate the predictions obtained from this simulation.

CONCLUSIONS

Contraflow lanes appear to be a promising solution

Figure 4. Numerical summary of results.

CHARACTERISTICS:	INITIAL	FINAL
SPEED (miles/hour) (C)ontraflow:		22
(U)nrestricted:	12	12
AVERAGE SPEED PER LANE:	12	15
CONCENTRATION (veh/mile/lane) C:		90
U:	110	110
AVERAGE CONCENTRATION PER LANE:	110	104
VEHICLE FLOWS (veh/hr/lane) C:		1766
U:	1296	1296
(total vehicles/hour):	3889	5655
PASSENGER FLOWS (pax/hr/lane) C:		22182
U:	8556	1540
(total passengers/hour):	25669	26802
NORMALIZED MODESPLITS (Drive Alone):	52	46
(Shared Ride):	30	34
(Transit):	17	19
NORMALIZED IVTT (minutes):	48	40

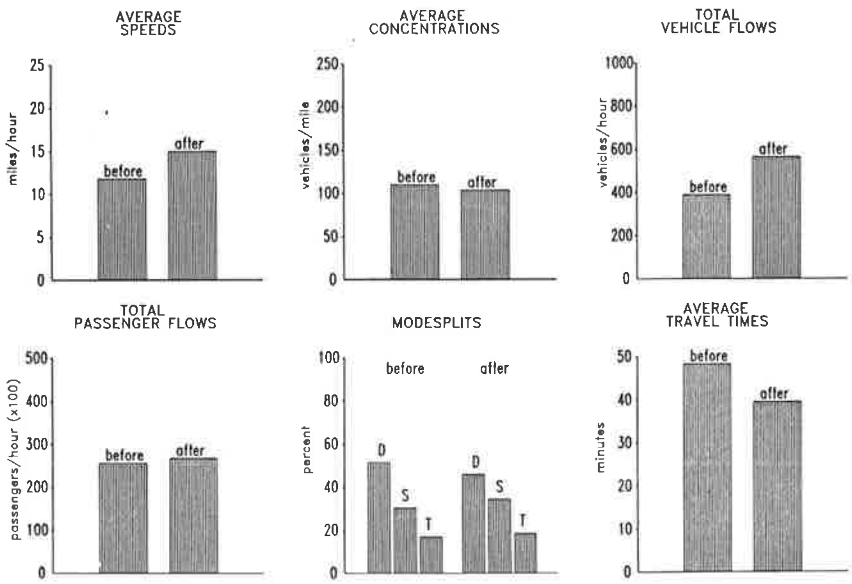

Figure 5. Graphical summary of results.

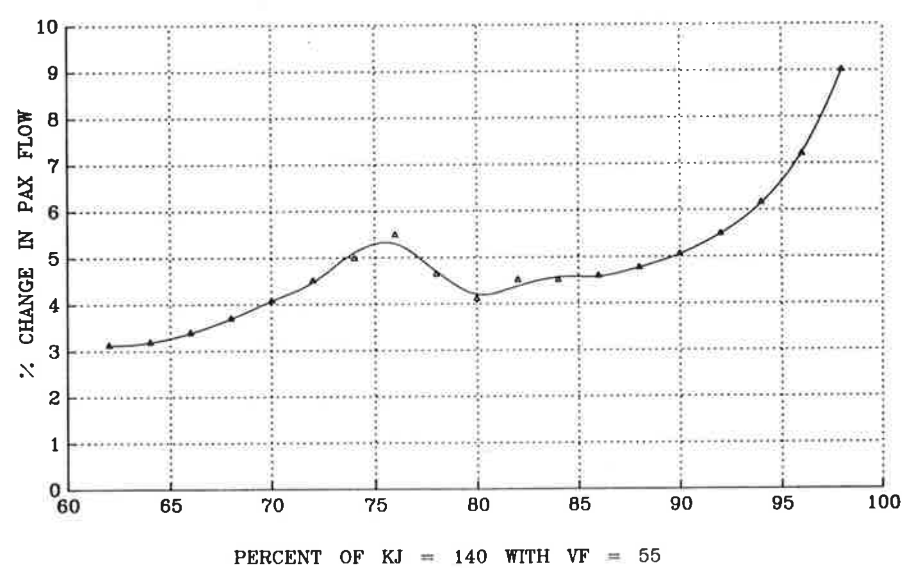

Figure 6. Changes in passenger flow versus initial concentration levels.

to traffic congestion in urban areas. If traffic congestion has been a sustained and periodic problem in a corridor, then the introduction of a contraflow lane could significantly improve the passenger flow in the corridor. The simulation program presented in this paper provides an effective method for the transportation engineer to test the feasibility of such a lane. The interactive nature of the program allows the planner to perform the evaluation with a minimum of effort. In particular, the graphical as well as numerical summary of results easily allows the planner to compare initial and final traffic conditions.

The accuracy of this approach depends on the accuracy of each of the associated travel demand and traffic flow submodels on which it is based. These submodels, although far from perfect, have been tested and used extensively over the past 20 years. The methodology described in this paper should have comparable usefulness as a planning tool for assessing the impacts of contraflow lanes.

REFERENCES

1. D. Kaku, W. Yamamoto, F. Wagner, and M. Rothenberg. Evaluation of the Kalanianaole Highway Carpool/Bus Lane. Offices of Research and Development, FHWA, Rept. FHWA-RD-77-100, Aug. 1977.
2. H.S. Rose and D.H. Hinds. South Dixie Highway Contraflow Bus and Carpool Lane Demonstration Project. TRB, Transportation Research Record 606, 1976, pp. 18-22.
3. R.N. Taube and C.A. Fuhs. Houston's I-45 Contraflow Transit Project. TRB, Transportation Research Record 798, 1981, pp. 39-45.
4. J.W. Billheimer. The Santa Monica Freeway Diamond Lanes: Evaluation Overview. TRB, Transportation Research Record 663, 1978, pp. 8-16.
5. J.W. Billheimer. The Santa Monica Freeway Diamond Lanes: Freeway Accident Analysis. TRB, Transportation Research Record 663, 1978, pp. 1-7.
6. D. Kaku, W. Yamamoto, F. Wagner, and M. Rothenberg. Evaluation of the Moanalua Freeway Carpool/Bus Bypass Lane. Offices of Research and Development, FHWA, Rept. FHWA-RD-77-99, Aug. 1977.
7. Cambridge Systematics, Inc. Houston North Freeway Contraflow Lane Evaluation Technical Memorandum: Summary of Pre-Contraflow Conditions. Transportation Systems Center, U.S. Department of Transportation, Cambridge, MA, Aug. 1980.
8. Institute of Traffic Engineers. Transportation and Traffic Engineering Handbook. Prentice-Hall, Inc., Englewood Cliffs, NJ, 1976.
9. Cambridge Systematics, Inc. Guidelines for Travel Demand Analyses of Program Measures to Promote Carpools, Vanpools, and Public Transportation. Office of Energy Conservation and Environment, Federal Energy Administration, Nov. 1976.
10. Cambridge Systematics, Inc. Tests of Transferability and Validation of Disaggregate Behavioral Demand Models for Evaluating the Energy Conservation Potential of Alternative Transportation Policies in Nine U.S. Cities. Office of Energy Conservation and Environment, Federal Energy Administration, April 1977.
11. T. Atherton. Approaches for Transferring Disaggregate Travel Demand Models. Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, Master's thesis, Feb. 1975.
12. R.J. Paquette, N. Ashford, and P.H. Wright. Transportation Engineering Planning and Design. Ronald Press Co., New York, 1972.
13. D.R. Drew. Traffic Flow Theory and Control. McGraw-Hill, New York, 1968.
14. L.J. Pignataro. Traffic Engineering: Theory and Practice. Prentice-Hall, Inc., Englewood Cliffs, NJ, 1973.

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Abridgment

Garden State Parkway HOV Lane

JOHN C. POWERS

Operation of a lane reserved for high-occupancy vehicles (HOVs) in each direction along 12 miles of the Garden State Parkway was studied. The HOV lane was established in November 1980 by addition of a lane in each direction to the existing six-lane divided and controlled-access roadway. Peak-period traffic flows before the addition of the HOV lane were characterized by levels of service D, E, and F along 5 or more miles of the road section that was widened. Information on numerous weekday peak-period traffic characteristics collected during the first year of HOV lane operation is reported. The definition of a carpool changed from three or more to two or more occupants in June 1981. A number of comparisons are presented for the two 6-month periods as well as for data collected before the HOV lane operation. Traffic before and after addition of the HOV lane was monitored for impacts of the HOV lane on HOV use, HOV and non-HOV travel time, automobile occupancy, person throughput, accident experience, HOV lane violations, and vehicle speeds. Results in terms of travel time, persons using HOVs, and accident data are reported.

In November 1980, the newly added median lanes of each direction of travel on a 12-mile section of the Garden State Parkway were opened as concurrent-flow, continuous-access, high-occupancy-vehicle (HOV) lanes. The minimum occupancy level was set at three or more persons.

In June 1981 the carpool definition was reduced to two or more persons, and in June 1982 the restrictions were lifted entirely. This paper reviews and summarizes travel time, HOV use, and accident data collected during the first 12 months of HOV lane operation.

TRAVEL TIME SAVINGS

Comparisons of speeds in the reserved and unreserved lanes during the three-or-more operation revealed that HOVs saved more than 0.7 min/mile when congestion occurred during the northbound morning peak period (see Figure 1). At typical congestion levels during this peak period, the savings averaged as much as 3.2 min for the full length of the HOV