the project was occasionally questioned, and the press responded to several minor incidents within the first few months. After ramp closures were implemented, public criticism of the impacts on the off-peak direction was markedly reduced, although underuse of the lane during portions of the peak period continued to create some criticism.

CONCLUSIONS

After 44 weeks of project operation, the general conclusion of TSDHPT, MTA, and the public is that the North Freeway contraflow demonstration has proved successful. The level of use and its continued increase have exceeded expectations. The fact that about 2300 vehicles have been removed from peak traffic and that transit is providing a desired alternative to the automobile in this corridor has made a significant impact on the expectations for MTA's regional transitway goal.

It should be noted that this paper is an interim report. UMTA's SMD program sponsored an evaluation in October 1980 that provided an opportunity for more detailed data collection and evaluation. Other reports will be forthcoming. However, the information provided is sufficient to support the decision of MTA and TSDHPT to continue contraflow operation beyond the 18-month demonstration period until such time as a separated high-occupancy facility can be incorporated into the North Freeway.

REFERENCES

1. Feasibility of Contraflow Lanes on IH 45 (North Freeway). Texas State Department of Highways and Public Transportation, District 12, Houston, Jan. 1976.
2. UMTA Section 5 Capital: Preferential Treatment--Construction of a Contraflow Lane on North Freeway. Houston Office of Public Transportation, Aug. 1977.
3. Report on Evaluation of Size and Location of "Park and Ride" Facilities Near IH 45 North and the North City Limits of Houston. Texas State Department of Highways and Public Transportation, Houston, Houston Urban Project, Oct. 12, 1976.
4. Growth Options for Houston: Technical Report. Rice Center, Rice Univ., Houston, March 1978.
5. W.R. McCasland. Summary of Ramp Closure Results. Texas Transportation Institute, Texas A&M Univ., College Station, Jan. 17, 1980.
6. State Accident Statistics: Region 4. Education Service Center, Houston, Jan. 1978-Feb. 1980.
7. Beiswenger, Hoch, and Associates. Safety Evaluation of Priority Treatment Techniques for High-Occupancy Vehicles. Federal Highway Administration, U.S. Department of Transportation, 1979.

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

Evaluation of a Contraflow Arterial Bus Lane

WILLIAM D. BERG, ROBERT L. SMITH, JR., THOMAS W. WALSH, JR., AND THOMAS N. NOTBOHM

In 1979, the city of Madison, Wisconsin, conducted a 90-day trial experiment in which a contraflow arterial bus lane was closed and all buses were rerouted into mixed-traffic lanes on a parallel arterial. The findings and conclusions of that experiment, as well as comments on generalizable conclusions that might be drawn from the Madison experience, are presented. Evaluation criteria included traffic performance, safety, transit revenue, transit ridership, and environmental impacts. The study findings supported the conclusion that the permanent closing of the bus lane would be undesirable principally because of anticipated increases in bus accidents and higher rates of fuel consumption and pollutant emissions.

In 1966, the city of Madison, Wisconsin, constructed a contraflow bus lane along a 0.9-mile section of University Avenue in conjunction with the initiation of one-way traffic flow on University Avenue and West Johnson Street, an adjacent arterial (1). As Figure 1 shows, West Johnson Street provided four lanes for eastbound traffic (parking was prohibited on both sides). University Avenue provided four lanes for westbound traffic plus one lane to be reversed for eastbound bus service. The one-way pair of arterials serves as the principal access to the Madison central business district (CBD) from extensive residential areas on the west side of the city. Both arterials also pass through the heart of the 40 000-student Madison campus of the University of Wisconsin.

The University Avenue contraflow lane functioned without difficulty until March 1, 1967, when a student walked into the side of an eastbound bus and was seriously injured. Considerable discussion ensued, and there were claims that the bus lane was ill-advised and that eastbound bus operations should be moved to Johnson Street. This proposal was presented to the Madison Common Council on May 23, 1967, where it was rejected by unanimous vote. Following further study and discussion over the next several years, on May 5, 1970, the Common Council again rejected a proposal to move eastbound buses to Johnson Street. In the years following 1970, the contraflow lane was used by increasing volumes of bicyclists but nevertheless operated successfully and without major incident. In recent years, University Avenue and West Johnson Street have each carried more than 20 000 vehicles/day. In a given hour, as many as 40 buses share the contraflow lane with as many as 300 bicycles. In 1976, the right curb lane on University Avenue was designated as a reserve lane for buses, bicycles, and right-turning vehicles.

Then, in 1978, a controversy arose. After extensive evaluation of alternative design projects for the overall improvement of the University Avenue-Johnson Street corridor, the Madison Common Council rejected the entire set of candidate alternatives and expressed a renewed interest in relocating eastbound bus operations to Johnson Street. The principal issues underlying the relocation sentiment were closely related to the design features of the proposed University Avenue improvements, the heavy use of the bus lane by bicyclists, and the large concentrations of pedestrian movements crossing University Avenue during university class-change times. Groups of students and downtown residents were vocal in their opposition to the bus lane because of

Figure 1. Contraflow bus lane and inbound bus routes.

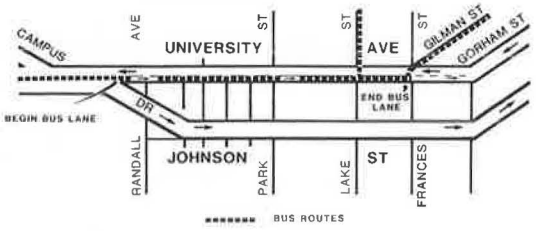
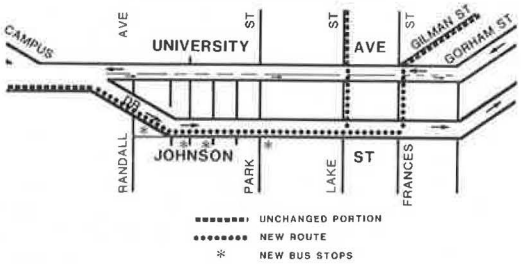


Figure 2. Inbound bus routes during 90-day trial.



1. Perceived safety problems associated with bicycle use of the contraflow bus lane and the large volume of pedestrian movements,
2. The desire to avoid widening University Avenue (this was a requirement of the recommended design alternative, which was to have provided exclusive lanes for both bicycles and buses), and
3. A general sentiment against any proposal that would directly or indirectly benefit motorists.

As a result of the controversy and intense political pressures, the Madison Department of Transportation (DOT) was directed to develop a plan for testing the feasibility of relocating eastbound bus routes from the University Avenue contraflow lane to the mixed-traffic lanes on West Johnson Street. A plan for a 90-day trial and impact evaluation was subsequently adopted and implemented against the recommendation of the city director of transportation. The purpose of this paper is to present the findings and conclusions of that experiment (2).

EXPERIMENTAL PLAN

The 90-day trial relocation of eastbound buses from the University Avenue contraflow lane to the mixed-traffic lanes on Johnson Street was initiated on April 15, 1979 (see Figure 2). Implementation of the plan required the removal of five bus stops on the south side of University Avenue and the installation of four bus stops on West Johnson Street. On the east side of Frances Street and on the west side of Lake Street between University Avenue and Johnson Street, it was necessary to remove 13 on-street parking spaces to provide adequate vehicle clearances (Figure 2). During the trial, the contraflow lane was closed to all traffic except eastbound bicycles. Extensive publicity through print and electronic news media, as well as special survey and monitoring activities, preceded the trial. Data collection and analysis were the result of a cooperative effort by staff of the Madison DOT, the Wisconsin DOT, and the University of Wisconsin Department of Civil and Environmental Engineering.

The scope of the experiment was limited to a study of the short-range operational, safety, economic, and environmental impacts of the proposed change in transit routing. The following evaluation criteria were agreed on and included:

1. Traffic performance measures--Travel time and delay through the corridor by mode would be compared by using both field data and simulation data generated by the TRANSYT/6C computer model (3,4).
2. Safety measures--A comparison of traffic accidents by type of accident occurring within the University Avenue and Johnson Street corridors would be made for comparable time periods before and during the trial.
3. Revenue measures--Special farebox meter readings would be taken on appropriate bus lanes entering and leaving the University Avenue-Johnson Street corridor and at the end of every run for comparable time periods before and during the trial.
4. Ridership--The special farebox meter readings would provide an indication of any systemwide changes in ridership. A survey of passengers boarding and leaving buses within the corridor would also be undertaken before and during the trial to determine the attitudes of and any effects on transit system users within the affected corridor. A mail-back questionnaire would be used in the survey.
5. Environmental measures--Air-quality and fuel-consumption impacts would be evaluated by using the TRANSYT/6C computer model.

The decision to use the TRANSYT/6C model as a supplement to the field data-collection studies was made on the basis of expediency and the need to generate certain performance and environmental measures that would otherwise have been impossible to obtain. For the simulation analyses, two alternative bus-operation plans (see Figures 3 and 4) were evaluated under both morning and evening peak-hour conditions (5). The first alternative represented the base, or before, condition in which eastbound buses operate in the University Avenue contraflow lane. It was assumed that the existing contraflow lane was widened and resurfaced as proposed in the recommended University Avenue reconstruction plan. The second alternative represented the experimental operating strategy in which eastbound buses were temporarily relocated to the mixed-traffic lanes on Johnson Street. The network over which traffic flow was simulated consisted of the University Avenue-Johnson Street corridor from Breese Terrace to State Street. This included all connecting streets as well as the intersection at Park and Dayton Streets.

Figure 3. Contraflow bus-operation plan.

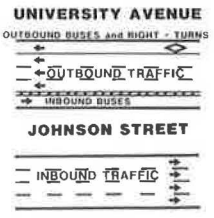


Figure 4. Mixed-flow bus-operation plan.

Table 1. Bus travel-time data.

Peak Period	Path	Average Time (min) Before Rerouting[a]	During Rerouting[b]	Difference	Change (%)
Morning	Campus Drive to Gilman and State	5.8	5.1	−0.7	−12.1
	Park Street to Gilman and State	3.3	3.6	+0.3	+9.1
Evening	Campus Drive to Gilman and State	7.9	7.1	−0.8	−10.1
	Park Street to Gilman and State	4.5	5.2	+0.7	+15.5

[a]April 11, 1979. [b]April 25, 1979.

Table 2. Impact of relocation of eastbound bus operations on average travel time along selected paths.

Path	Morning Peak Period Before Condition (min)	Morning Peak Period Change (%)	Evening Peak Period Before Condition (min)	Evening Peak Period Change (%)
Automobile				
Campus Drive and University Avenue to Johnson and Broom Streets	2.77	+2.2	3.05	+2.0
Bus				
Campus Drive and University Avenue to Frances Street and University Avenue	4.49	+5.6	4.78	+13.0
Campus Drive and University Avenue to Lake Street and University Avenue	4.00	+12.8	4.12	+33.3

Table 3. Impact of relocation of eastbound bus operations on network travel time.

Vehicle Category	Morning Peak Period Travel Time in Before Condition (vehicle-h/h)	Morning Peak Period Change (%)	Evening Peak Period Travel Time in Before Condition (vehicle-h/h)	Evening Peak Period Change (%)
Automobile	238.88	+0.9	351.35	–
Bus	6.17	+6.4	7.35	+12.8
Total	245.05	+1.0	358.70	+0.3

Table 4. Accident data: four-year average and April 15-June 15, 1979, trial period.

Category	Four-Year Average University Avenue	Four-Year Average Johnson Street	1979 University Avenue	1979 Johnson Street
Accidents				
Total	30.75	27.25	18	23
Injury	7.75	6.0	2	6
Vehicle miles (000 000s)	2.052	2.117	1.726	1.849
Accident rate (%)	15.0	12.9	10.4	12.4

FINDINGS

The results of the various field studies and the simulation analyses are summarized below. Examination of traffic counts conducted before and during the experiment revealed no significant changes in automobile, pedestrian, and bicycle flow patterns. The only changes involved the buses that were rerouted to West Johnson Street (Figure 2).

Traffic Performance Measures

Field observations of bus travel times during the peak hours (6:00-9:00 a.m. and 3:00-6:00 p.m.) indicated that eastbound buses that traveled the entire corridor length had slightly shorter travel times on West Johnson Street than on University Avenue in both morning and evening peak hours (see Table 1). Buses that entered the corridor at Park Street had slightly longer travel times on Johnson Street than on University Avenue. This suggested that bus travel times are faster on Johnson Street in spite of the delays caused by the required weaving and turning maneuvers between Park and State Streets. However, the comparison was misleading in the sense that the before data were not representative of the expected performance of the contraflow lane under the proposed corridor reconstruction plan. The before data measured in the field included the effects of an extremely poor pavement surface in the contraflow lane, two more traffic signals on University Avenue than on Johnson Street, the presence of bicycles in the contraflow lane (which is too narrow for buses and bicycles to pass each other), and one more bus stop on University Avenue than on Johnson Street.

The simulation analyses that were conducted by using the TRANSYT/6C model permitted a number of these factors to be controlled. Assuming comparable pavement surface quality, no bicycles in the contraflow lane, and one less bus stop on Johnson Street than on University Avenue, it was found that both automobile and bus travel times through the corridor could be expected to increase should the contraflow bus lane be abandoned (see Table 2). The expected impact of closure of the contraflow lane on overall network travel time for both automobiles and buses is given in Table 3. It was again apparent that the contraflow lane would reduce travel times, especially for buses.

Safety Measures

Table 4 provides a summary of traffic accidents and vehicle miles of travel that occurred during the 90-day trial and comparable time periods in the four previous years. All reported traffic accidents that occurred along University Avenue and West Johnson Street between Bassett Street and Babcock Drive were mapped and analyzed as part of the study. Although the data suggest that safety would be enhanced by rerouting buses back into mixed traffic on West Johnson Street, a chi-square test of the difference in the number of before and after accidents revealed that the differences indicated in Table 4 were not statistically significant. The 90-day trial was simply too short a time period on which to test safety impacts in a before-and-after type of comparison.

Table 5. Rates of bus-involved accidents.

Street	Number of Bus Miles	Bus Accidents		
		Type	Number	Number per 100 000 Bus Miles
Johnson Street eastbound	50 525[a]	Bus/bicycle	1	13.8
		Bus/automobile	6	
		Total	7	
University Avenue Eastbound	196 960	Bus only	2	5.1
		Bus/pedestrian	5	
		Bus/automobile	3	
		Total	10	
Westbound	259 372	Bus/bicycle	1	5.4
		Bus/automobile	13	
		Total	14	

[a]Primarily university campus buses.

As an alternative approach to the safety issue, rates of bus-involved accidents for the four-year period ending in 1978 were examined (see Table 5). During this time period, there were buses operating in the mixed-traffic lanes on Johnson Street, in the contraflow (eastbound) bus lane on University Avenue, and in the reserved (westbound) bus lane on University Avenue. The data clearly suggest that bus operations in both the eastbound contraflow lane and the westbound reserved bus lane were substantially safer than bus operations in the mixed-traffic lanes on Johnson Street. Moreover, by using a rate quality control test, these differences were found to be statistically significant. The reason for the better safety record can be directly attributed to a reduction in traffic conflicts and stream friction made possible by the separation of buses and automobiles.

Revenue and Ridership Measures

The effect of the trial on transit revenue and ridership was seen as one of the most important evaluation criteria. However, because of yearly variations in ridership, a fare increase that went into effect on January 1, 1979, and other factors that influence ridership, it was not possible to determine whether or to what extent the 90-day trial had any direct effect on ridership or revenue.

Reliance therefore had to be placed on the transit-user survey conducted before and during the trial. The survey involved the distribution of 4777 mail-back questionnaires to bus passengers (2756 before and 2021 during the trial) in the University Avenue-Johnson Street corridor. The before survey was conducted on Thursday, April 12, 1978, and had a 49 percent response rate. The during survey was conducted on Thursday, April 26, 1979, and had a 54 percent response rate. In each case, surveys were distributed during the hours of 7:00-9:00 a.m., 10:00 a.m.-noon, 3:00-5:00 p.m., and 7:00-9:00 p.m. The during survey was conducted only two weeks after the before survey so that rider characteristics, which change with the approach of examination time and the end of the university school year, would remain constant. There was also the possibility of a work stoppage in connection with the expiration of the bus-driver contract on May 1, 1979.

The results of the transit-user survey are summarized below:

1. Frequency of use--Approximately 88 percent of the respondents both before and during the trial stated that they used the bus at least three times per week, which indicates the very large percentage of regular bus riders with destinations in the subject corridor.

2. Street crossings--Before the trial, 19.3 percent of the respondents had to cross both University Avenue and Johnson Street to get to or from their destinations. During the trial, 65.4 percent had to cross both streets. The two surveys correlated well to indicate that 70 percent of riders have destinations north of University Avenue, 17 percent have destinations south of Johnson Street, and 13 percent have destinations between Johnson Street and University Avenue.

3. Walking distance--There was an increase in overall walking distance for bus users as a result of the trial, as indicated in the following table:

No. of Blocks Walked	Respondents (%)	
	Before Trial	During Trial
0-2	67.9	51.3
3	16.9	26.1
≥4	15.2	22.6

4. Convenience--Before the trial, 94.4 percent of the respondents rated the service on University Avenue as either good or very good. Only 3.7 percent of the respondents felt the service was poor or very poor. This very favorable perception of service was severely affected by the trial. Only 53.1 percent rated Johnson Street good or very good, and 43 percent rated Johnson Street service as poor or very poor. This represented a significant difference in the respondents' perception of convenience.

5. Route preference--Before the trial, 78.3 percent of the respondents indicated a preference for the University Avenue contraflow lane whereas 14.1 percent indicated a preference for Johnson Street. During the trial, 66.4 percent of the respondents continued to indicate a preference for the University Avenue route while 25.8 percent indicated a preference for the Johnson Street route. Preference for the University Avenue route continued very strong among the more frequent bus users; 82 percent of the respondents who rode three or more times per week preferred the contraflow lane.

Environmental Measures

The TRANSYT/6C computer model that was used to generate traffic performance data for the corridor network also produced estimates of fuel consumption and exhaust emissions by mode. These data are summarized in Table 6 and are based on the same assumptions previously discussed regarding the characteristics of the before-and-after network. (The ranges of variance noted in the footnotes to Table 6 are the results of varying selected computer input parameters. All other values were found to be stable estimates.)

Table 6. Impact of relocation of eastbound bus operations on network fuel consumption and pollutant emissions.

Measure of Effectiveness	Morning Peak Period		Evening Peak Period	
	Before Condition	Change (%)	Before Condition	Change (%)
Fuel consumption (gal/h)				
Automobile	453.53	-	630.06	+0.6
Bus	18.82	-7.3	21.13	+4.3[a]
Total	472.35	-0.3	651.19	+0.6
Emissions (kg/h)				
Hydrocarbons				
Automobile	24.24	+0.5	37.17	+0.7
Bus	0.66	+8.2[b]	0.81	+17.3
Total	24.90	+0.6	37.98	+1.0
Carbon monoxide				
Automobile	258.27	+0.4	408.68	+0.8
Bus	6.67	+13.8[c]	8.66	+21.1
Total	264.94	+0.7	417.34	+1.2
Nitrogen oxides				
Automobile	12.47	-0.2	18.62	+0.2
Bus	0.28	-7.5[d]	0.27	+5.5[e]
Total	12.76	-0.5	18.89	+0.2

[a]Actual increase may vary from 1.2 to 7.5 percent.
[b]Actual increase may vary from 6.1 to 10.3 percent.
[c]Actual increase may vary from 11.7 to 16.0 percent.
[d]Actual decrease may vary from 3.6 to 12.9 percent.
[e]Actual increase may vary from 3.6 to 7.4 percent.

With the exception of fuel consumption and emissions of nitrogen oxides during the morning peak period, the before condition yields the best overall performance. The degradation in bus performance under the relocation strategy is the most apparent impact, especially during the evening peak period. Although the percentage reduction in automobile efficiency is relatively small, when examined in absolute terms these changes can exceed those associated with buses. For example, in the case of fuel consumption during the evening peak period, the percentage increase in bus fuel consumption under the relocation plan is about seven times as great as the percentage increase in automobile fuel consumption. However, in terms of gallons consumed per hour, the impact on automobile traffic is about four times greater than that on buses.

CONCLUSIONS

The purpose of this study was to determine the feasibility of relocating eastbound buses from the contraflow lane on University Avenue to mixed-traffic conditions on West Johnson Street. Based on the findings discussed above, it was recommended to the Madison Common Council that relocating buses to West Johnson Street would not be desirable because

1. The historical (pretrial) bus accident rate is substantially higher on Johnson Street than on University Avenue,
2. There is no evidence that overall traffic safety could be significantly improved by relocation,
3. Seventy percent of the bus users in the corridor would be forced to cross an additional major street and walk further to reach their destinations,
4. There could be a long-range negative impact on transit ridership because of longer walking time and distance for a majority of bus users in the corridor,
5. Overall fuel consumption and vehicle emissions would be higher, and
6. Relocation would result in no significant measurable improvement to the transit system.

It was further stated that the study results reaffirmed the original contention and basis for constructing the contraflow lane in 1966--namely, that the contraflow lane does in fact provide more convenient transit service, more efficient overall transit and traffic operations, and a higher level of safety than mixed traffic flow on West Johnson Street.

The current status of the bus-lane controversy remains unresolved. Eastbound buses still operate in the mixed-traffic lanes on West Johnson Street even though the 90-day trial ended more than a year ago. The city will not be making any changes until a completely new set of corridor improvement alternatives is evaluated.

Deriving generalizable conclusions from the Madison experience is difficult. Although the city is known for its innovative efforts in transportation, it must also contend with a politically active, and often unpredictable, constituency quite unlike those of most other cities. If there is a lesson to be learned, it is that relatively short contraflow lanes are not likely to produce performance improvements of a magnitude that will necessarily outweigh the possible disbenefits perceived by influential special-interest groups. Nevertheless, the results of the 90-day trial and the various analyses did tend to confirm the relative advantages of contraflow bus lanes in congested areas.

REFERENCES

1. H.S. Levinson, W.F. Hoel, D.B. Sanders, and F.H. Wynn. Bus Use of Highways: State of the Art. NCHRP, Rept. 143, 1973.
2. University Avenue-West Johnson Street 90-Day Trial Bus Route Evaluation Study. Madison Department of Transportation, Madison, WI, Final Rept., Nov. 1979.
3. D.I. Robertson. TRANSYT: A Traffic Network Study Tool. Road Research Laboratory, Crowthorne, Berkshire, England, Rept. LR 253, 1969.
4. TRANSYT/6C Model Workshop. Institute of Transportation Studies, Univ. of California, Berkeley, Student Workbook, 1977.
5. W.D. Berg and T.N. Notbohm. Traffic Performance and Transit Ridership Impacts of Closing the University Avenue Contra-Flow Bus Lane. Department of Civil and Environmental Engineering, Univ. of Wisconsin, Madison, Feb. 1980.

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