Evaluation of Reduction in Minimum Occupancy for Car Pools That Use a Priority Freeway Lane

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One of the primary control parameters associated with the use of preferential treatments for high-occupancy vehicles, specifically car pools, is the minimum occupancy of automobiles qualified to use the treatment. This parameter varies among the many projects around the nation but is usually between two and four persons per vehicle. The significance of the value used is in terms of the person-moving performance compared with the degree of priority given the high-occupancy vehicles. A priority lane was provided on I-95 in Miami for buses and car pools of three or more persons but, when the person-moving performance failed to meet the desired goal, the minimum car-pool occupancy was reduced to two persons. This unique action had predictable but significant results. The priority advantage previously afforded the high-occupancy vehicles was reduced to a large degree, but the total system effectiveness of the freeway, as well as its safety, were significantly improved. As a result, enforcement and operating problems were reduced and public acceptance was increased.

In recent years, there has been a proliferation of priority-treatment projects for high-occupancy vehicles (HOVs) in urban areas. These programs are a result of the need for low-capital-cost transportation improvements to enhance the person-moving capacity of existing highway facilities and to conserve energy (and improve the environment) by promoting the use of transit and other HOVs, notably car pools.

The techniques used to provide preferential treatment vary from situation to situation and have been reported extensively in the literature (1, 2, 3, 4). One of the more common ones is to reserve a lane on an urban freeway for use by buses and car pools during the peak hours.

A demonstration projection of this type was implemented in Dade County, Florida, in December 1975 on the I-95-NW 7th Avenue corridor; the associated express bus service was named the Orange Streaker. The complete project consisted of a 4-year program to implement and evaluate HOV priority-treatment techniques on both an arterial street [NW 7th Avenue (US-441)] and an urban freeway (I-95). The results of the project are detailed elsewhere (5, 6, 7).

The portion of the project in which the express buses and car pools used I-95 (phase 2 of the project) had a unique operational feature that warrants special attention. On January 10, 1977, the minimum occupancy of car pools authorized to use the priority lanes was reduced from three to two persons. This paper discusses the system in general, describes some theoretical considerations of the car-pool definition, and reports on the actual results of the change.

PROJECT DESCRIPTION

I-95 is the primary highway facility in the northern corridor of Dade County, connecting major residential areas in northern Dade and southern Broward counties with major employment areas in the greater Miami area. The freeway corridor is about 16 km (10 miles) long, extending between the Golden Glades interchange and the Miami central business district. The project area and its principal geographic and transportation facilities are shown in Figure 1 of another paper by Courage and others in this Record. I-95 is an 8- to 10-lane divided, fully access-controlled Interstate highway. The HOV priority lanes were constructed in the median between the Golden Glades and 36th Street interchanges, a length of about 11.7 km (7.3 miles). Thus, the capacity of the general lanes was not reduced by providing the priority lanes. Typical views of the freeway are shown in Figure 1. All lanes are the standard 3.7 m (12 ft) wide, and the right shoulders are 2.4 m (8 ft) wide. The freeway is divided by a concrete barrier wall that is separated from the traveled way by only 0.6 m (2 ft) in each direction.

The project also included a temporary 967-space park-and-ride lot located at the Golden Glades interchange. In March 1977, a new, permanent, 1320-space lot and a direct flyover ramp were added, but the effects of these improvements are not included in this report. Also, 30 specially equipped 47-passenger buses were purchased for the Orange Streaker service.

The Orange Streaker provided express bus service between the residential area north of the park-and-ride lot and three major employment areas: downtown Miami, the Miami Civic Center, and Miami International Airport (with limited continuing service to downtown Coral Gables).

Transit users and car poolers who formed their car pool at the park-and-ride lot used several modes of access to the priority system: park-and-ride, kiss-and-ride, Orange Streaker feeder bus, or local bus. Walking was not a feasible mode because of the isolated location of the lot.

Traffic control of the priority lanes was provided through the use of overhead fixed-message signs such as the one shown in Figure 1a and was reinforced by the standard restricted-lane diamond symbol painted at 76.2-m (250-ft) intervals on the pavement of the priority lanes. Operating hours were originally 6:00-10:00 a.m. (southbound only) and 3:00-7:00 p.m. (northbound only), but when the required car-pool occupancy was reduced, these times were changed to 7:00-9:00 a.m. and 4:00-6:00 p.m. respectively.

THEORETICAL CONSIDERATIONS

The original decision to require three or more persons to qualify for the priority treatment was based on two factors. First, the observed number of vehicles carrying two or more passengers was high enough that it was feared that no travel-time benefit would result if all of these vehicles actually used the lanes. Second, the prevailing tendency on a national basis is to specify three or more persons per vehicle (PPV) as a car-pool occupancy requirement. But after nearly a year of operation of express buses and three-PPV car pools, it was found that the anticipated degree of car-pool attraction did not materialize de-

Figure 1. Views of I-95 priority-lane system.

spite a travel-time advantage of about 3 min (during average morning and afternoon peak periods). Indeed the priority lanes were carrying fewer persons than the average general lane.

The underuse of the lane and the high violation rate generated substantial public pressure for relaxation of the priority-lane regulations. Two approaches were used to determine the probable effects of such a change. A theoretical approach was used to determine the optimum car-pool definition. A car-pool definition model was developed (7) that uses a two-stage traffic assignment technique. The model considers a system that consists of a freeway section that has both priority and general lanes and vehicular demand that is stratified by level of occupancy and origin-destination patterns. Demand is then assigned to the facility such that preferential treatment is given to HOVs, and the overall or passenger hours of travel. Both violation and nonuse rates are assigned to reflect actual conditions, and the model is iterated until equilibrium is established between the estimated average vehicular (or person) flow and the assigned vehicular demand. Assignments are constrained by internal capacities.

It was found that, in practically all freeway subsections, the preferred minimum car-pool requirement was between two and three PPV, as is shown in Figure 2. Additionally, these analyses indicate that a car-pool definition of two PPV would result in both minimum vehicle hours and minimum passenger hours of travel. However, it was also found that the 2-PPV requirement would fail to provide a significant level of preferential treatment for priority vehicles, as shown in Figure 3 (degree of priority is defined as the ratio of the general-lane demand-to-capacity and priority-lane demand-to-capacity ratios and should be greater than unity if preferential treatment exists). In fact, it was evident that, at this lower requirement, the priority lane could be expected to effectively operate as a general-use freeway lane that has developed user equilibrium. [Further investigation showed that the degree of priority could be improved by providing access-egress restrictions on the lane by using discrete entry-exit strategies (7)].

These findings tended to justify the use of three PPV over two PPV for preferred priority treatment, but, as seen in Figure 2, there was some indication that a surplus person-moving capacity was available for a car-pool definition of fewer than three PPV.

The Florida Department of Transportation (FDOT) conducted a further analysis to test the feasibility of reducing the car-pool definition (8). The significant findings were as follows:

1. When operating with the three-PPV requirement, the priority lane was carrying only about 44 percent as many persons as the average general lane (although in only 5 percent of all vehicles using the freeway).
2. The violation rate was about 63 percent of the priority-lane traffic and steadily deteriorated because of the lack of effective enforcement (and ultimately reached 78 percent in the afternoon peak hour).
3. Only about 32 percent of all vehicles eligible to use the reserved lanes actually did so.

It was then estimated that, by assuming a 50 percent increase in two-PPV car pools the probability of demand versus capacity approaching equilibrium with the general lanes would not exceed 40 percent in any 0.5-h period in the most critical section of the freeway. Overall, the probability of breakdown was estimated at less than 25 percent in the critical half hour.

Based on these estimates and accepting the risk of some deterioration in priority operations, the Florida DOT decided to reduce the occupancy level (and simultaneously, the periods of operation).

EFFECT OF CAR-POOL REDEFINITION

The effects of the change in car-pool occupancy were measured with respect to the following measures of efficiency:

Variable	Source of Data
Peak-period volumes and vehicle occupancies	Volume and occupancy studies
Bus travel times	Travel-time observations
Bus schedule adherence	Observations at Golden Glades terminal (provided by Metropolitan Transit Agency)
Automobile travel times and comfort measures	Instrumented moving-vehicle studies
Exclusive-lane-occupancy violators	Moving-vehicle observations
Weaving difficulties	Instrumented moving-vehicle studies
Transit ridership	Metropolitan Transit Agency records
Accident history	Dade County accident records

Effect on Transit Operations

The effects of the two-PPV car-pool definition on bus speeds and travel times in the reserved lane section of I-95 are summarized below (1 km/h = 0.62 mph).

	Car-Pool Definition		
Item	Three PPV	Two PPV	Change (%)
Morning peak			
Travel time, min	8.22	8.22	0
Speed, km/h	78.4	78.4	0
Afternoon peak			
Travel time, min	7.77	9.38	+21
Speed, km/h	83.0	68.7	-21

Figure 2. Optimum car-pool definitions for minimizing passenger hours: 3:30 to 6:30 p.m.

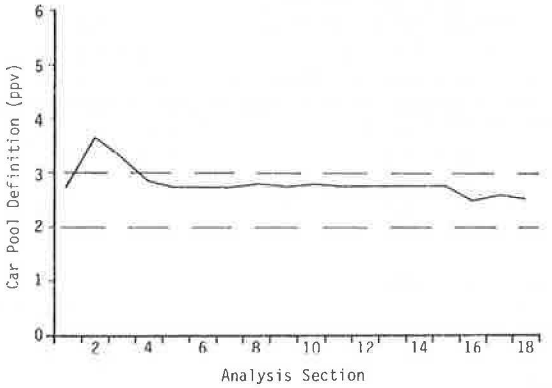


Figure 3. Degree of priority for minimizing passenger hours: 3:30 to 6:30 p.m.

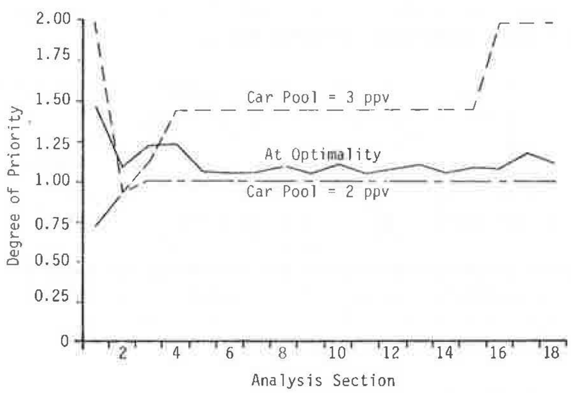


Figure 4. Variation in express bus travel times during peak periods.

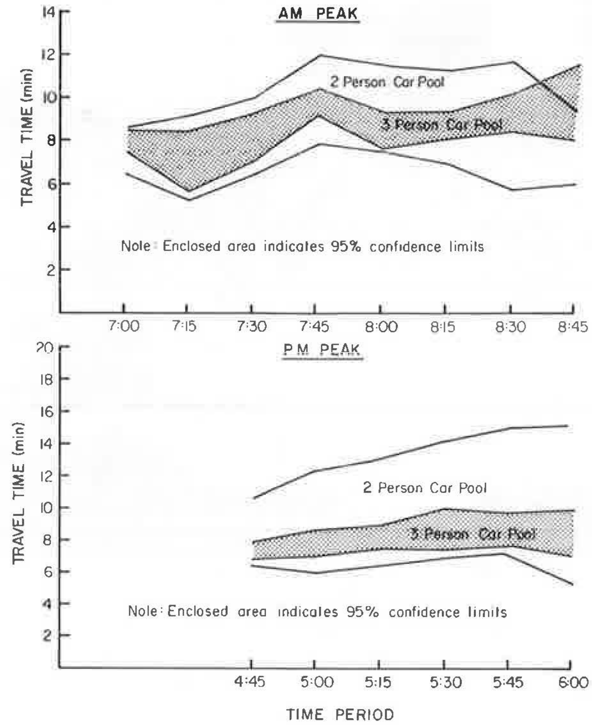
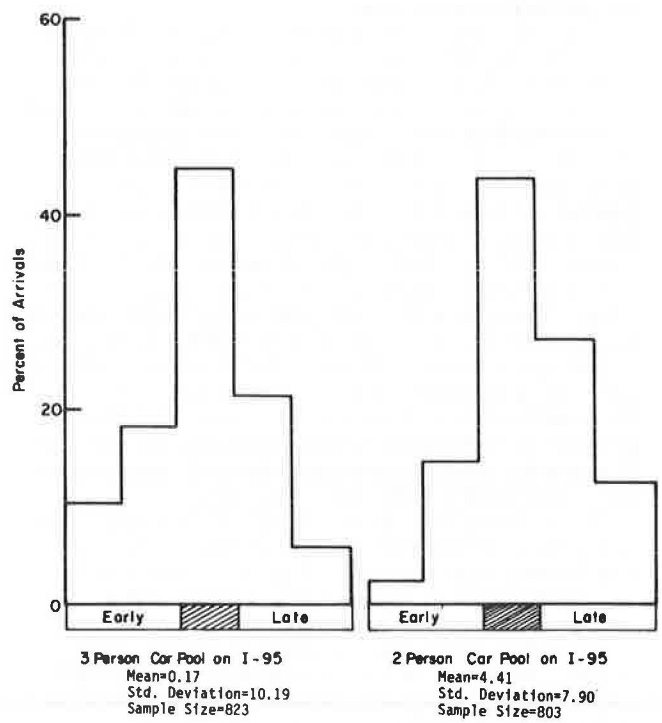


Figure 5. Distribution of differences between actual and scheduled arrival times of Orange Streaker buses at Golden Glades terminal.



The travel times are for the portion of the bus trip on I-95 between NW 36th Street and NW 151st Street, which represents most of the exclusive-lane section. These results indicate that the change in regulations had no measurable effect on the average bus travel time in the morning but that travel times were increased by approximately 21 percent during the afternoon peak period.

A more detailed analysis of the bus travel times—the effect of time of day on the variation of travel times—is shown in Figure 4. For example, in the morning peak the travel times remained more or less constant during the entire peak period. It is interesting that, although the average travel times were not altered by the change in regulations, the variation in travel time (as indicated by the width of the confidence limits) was noticeably greater when two-person car pools were allowed in the exclusive lane.

In the afternoon peak, on the other hand, the two-person regulation resulted in increases in both the average travel time and the variability of travel time. Furthermore, a strong peaking trend is evident in the two-PPV case during the more congested portion of the afternoon period.

Bus schedule-adherence studies were conducted during the afternoon peak period. The primary measure of effectiveness used was the difference between the scheduled and the actual arrival times for buses at the Golden Glades terminal. This measure is termed the arrival-time discrepancy. The distributions of arrival-time discrepancies representing the three-PPV and two-PPV car-pool stages are shown in Figure 5. The dispersion of the distribution reflects the degree of schedule adherence (a more dispersed distribution represents a lower degree of adherence). Another measure of schedule adherence used was expressed in terms of the average lateness of buses. It is observed, for example, that the average bus arrived 4.4 min late at

Table 1. Effect of two-person car-pool definition on automobile travel times and speeds.

Item	Priority Lanes Three PPV	Priority Lanes Two PPV	Change (%)	General Lanes Three PPV	General Lanes Two PPV	Change (%)
Morning peak						
Travel time, min	7.51	7.50	0	10.52	10.73	+2
Speed, km/h	85.9	85.9	0	60.2	60.0	-2
Afternoon peak						
Travel time, min	8.02	7.94	Negligible	11.26	9.63	-14
Speed, km/h	80.5	81.3	Negligible	57.3	66.9	+14

Note: 1 km/h = 0.6 mph.

Table 2. Comparison of traffic volumes.

Time Period	Car-Pool Volume (vehicles/h) Three PPV	Car-Pool Volume (vehicles/h) Two PPV	Change (%)	Violator Volume (vehicles/h) Three PPV	Violator Volume (vehicles/h) Two PPV	Change (%)	Total Volume (vehicles/h) Three PPV	Total Volume (vehicles/h) Two PPV	Change (%)
Morning peak	106	623	488	182	352	93	288	974	238
Afternoon peak	110	638	480	188	380	102	298	1017	241

the Golden Glades terminal with two-person car-pool operation and 0.2 min late with three-person car pools. This difference agrees generally with the difference in travel times observed on the freeway. The dispersion of arrival-time discrepancies between these two stages of operation dropped by approximately 20 percent. This indicates that, although travel times were longer, the predictability was improved, primarily because fewer buses arrived earlier than scheduled.

Effect on Automobile Operations

The effects of the two-person car-pool definition on automobile travel on I-95 are summarized in Table 1. The only comparison in the above summary that proved to be statistically significant (95 percent level of significance) was the improvement in travel time in the general lanes during the afternoon peak period. The automobile travel-time comparisons during the morning peak were consistent with the bus travel-time comparisons; i.e., no noticeable change occurred with the reduced car-pool requirement. It may therefore be concluded that morning peak operations were not substantially affected by the operational changes that were implemented.

During the afternoon peak, on the other hand, noticeable changes were observed in the bus travel times, which increased by 21 percent, and in the automobile travel times in the general lanes, which decreased by approximately 14 percent. Some increase in automobile travel times in the exclusive lane would be anticipated in view of the relatively large increase in bus travel times; however, no such increase was recorded in the field. The average speed for automobiles in the exclusive lane remained at approximately 80.5 km/h (50 mph) throughout both stages of the study. This is generally consistent with a level of service B operation. The corresponding travel time in the general lanes was 67.6 km/h (42 mph), which represents level of service C.

The difference between the bus travel times and the automobile travel times in the exclusive lane may be due to a number of factors, including the concentration of bus travel during the more heavily congested portion of the peak period and the difference in general maneuverability between the two classes of vehicles. It is interesting that, during the afternoon peak period, the average bus travel time with two-person car-pool operation was nearly the same as the average automobile travel time in the general lanes. This suggests that, with the reduced car-pool requirement, the system fell into user equilibrium during the congested portion of the peak period, and therefore the potential benefits of the exclusive lane did not materialize during that period.

Trip comfort was measured in this study as speed noise. This measure, defined as the coefficient of variation of individual vehicle speeds, provides an indication of the variability of speed as the vehicle proceeds along the route. A trip that is made at constant speed will experience no speed noise. A value that exceeds 1.0 generally reflects a noticeably stop-and-go type of operation.

Speed-noise measurements were carried out for automobiles using both the general and the reserved lanes on I-95 during both peak periods. The results followed the same pattern as the travel-time studies; i.e., no statistically significant differences were observed, except in the general lanes during the afternoon peak period when speed noise was reduced by 35 percent with the two-person car-pool regulations. This indicates that a generally more comfortable trip was experienced under this condition.

Bus travel-time measurements were made by direct observations of departure and arrival times. It was not therefore possible to provide a quantitative speed-noise comparison. Some deterioration in transit-passenger trip comfort would, however, be anticipated during the afternoon peak period because of the increased travel times experienced by buses when the car-pool regulations were relaxed.

The reduction in passenger-occupancy requirements for the exclusive lane changed the definition of a violator substantially. A reduction in violation rates would, therefore, be anticipated.

A comparison of car-pool volumes, violator volumes, and total traffic volumes violation rates is given in Table 2, and a comparison of noncompliance ratios for both peak periods is given below.

Time Period	Violation Rate (%) Three PPV	Violation Rate (%) Two PPV	Noncompliance Rate (%) Three PPV	Noncompliance Rate (%) Two PPV
Morning peak	63	36	2.8	5.8
Afternoon peak	63	37	3.1	7.3

The violation rate is the percentage of vehicles using the reserved lane that are ineligible to do so. The noncompliance rate is the percentage of all ineligible vehicles that use the reserved lanes. Thus, these measures are two methods of measuring violations.

Table 3. Comparison of time and distance required for entry to and exit from exclusive lane.

Item	Weaving Time (s)			Weaving Distance (m)		
	Three PPV	Two PPV	Change (%)	Three PPV	Two PPV	Change (%)
Morning peak						
Entry	46	36	+22[a]	732	671	+8
Exit	46	53	-15	792	762	+4
Afternoon peak						
Entry	62	45	+27[b]	1006	701	+30[b]
Exit	47	29	+38[b]	945	457	+52[b]

Note: 1 m = 3.3 ft.
[a]Comparison between stages significant at 95% level.
[b]Comparison between stages significant at 99% level.

Table 4. Summary of system performance measures on I-95.

Performance Measure	Morning Peak		Afternoon Peak	
	Three PPV	Two PPV	Three PPV	Two PPV
Vehicle demand, km	171 219	194 230	199 702	237 035
Vehicle travel time, h	2 630	2 960	3 210	3 250
Avg vehicle speed, km/h	65.2	65.7	62.3	72.9
Passenger demand, km	227 380	255 380	279 840	344 047
Passenger travel time, h	3 450	3 810	4 440	4 720
Avg passenger speed, km/h	66.0	66.9	62.9	72.9
PMI, km/vehicle-h	86.6	86.6	87.2	105.7
HOV priority index	1.011	1.020	1.012	1.000

Note: 1 km = 0.6 mile.

The same trends were evident during both peak periods; specifically,

1. Car-pool volumes more than quintupled,
2. Violator volumes increased by an average of 97 percent, and
3. Violation rates decreased by an average of 41 percent.

The net result was an appreciable increase in total exclusive-lane volumes (approximately 24 percent on the average), indicating substantially greater use of the exclusive lane. All of the comparisons given above were statistically significant at the 99 percent level.

One of the potential problems of the HOV priority-lane concept is the difficulty of crossing several congested lanes of traffic to gain access to the priority lane. Studies were carried out to assess the degree of difficulty of the weaving maneuver under both conditions of car-pool definition. The measures of effectiveness, obtained by moving-vehicle studies that used an instrumented vehicle, were the time and distance required to complete the weaving maneuver. The entry movements were studied downstream of an entrance ramp in the most congested area of the freeway during each peak period, and the exit movements were studied upstream of the last exit ramp in the system (these are the locations where the majority of weaving activities are concentrated).

The results, as summarized in Table 3, indicate that reducing a car-pool requirement from three to two PPV significantly decreased both the time and distance required for executing the lane-changing maneuver during the afternoon peak. The morning peak showed a slight reduction in the time necessary to complete the weaving maneuvers but not the distance.

There appears, therefore, to be a strong indication that, during the evening peak, a reduction in car-pool requirements from three to two PPV altered the lane distribution to the point that weaving maneuvers were significantly easier to perform. This conclusion is based on the significantly lower times and distances required to perform weaves from an entrance ramp to the exclusive lane or from the exclusive lane to an exit ramp.

The same phenomenon did not hold true for the morning peak when the times and distances associated with weaving across the freeway generally showed no statistical differences. The lack of differences during the morning period was due primarily to the fact that the change in car-pool definition had generally little effect on the morning peak operations.

Effect on System Operating Characteristics

The operating characteristics were compared for the two stages of the pool demonstration project. To develop these comparisons, field data were collected to determine

1. Average traffic volumes on I-95 during each of the peak periods,
2. Average passenger occupancy for exclusive-lane automobiles and automobiles traveling in the general lanes,
3. Travel times for each mode of travel, and
4. Bus passenger volumes.

From the field data, the following measures of effectiveness were calculated for each peak period:

1. Total vehicular demand on the freeway (vehicle kilometers),
2. Total passenger demand (passenger kilometers),
3. Total vehicular travel time on the freeway (vehicle hours),
4. Total passenger travel time on the freeway (passenger hours),
5. Average vehicle speed (vehicle kilometers divided by vehicle hours),
6. Average passenger speed (passenger kilometers divided by passenger hours),
7. Passenger movement index (PMI) (passenger kilometers divided by vehicle hours), and
8. HOV priority index (average passenger speed divided by average vehicle speed).

The vehicle and passenger speeds are relatively simple from a conceptual point of view. The PMI is defined

Table 5. Accident analysis data.

Item	Morning Peak		Afternoon Peak	
	Three PPV	Two PPV	Three PPV	Two PPV
No. of accidents	75	33	92	27
No. of days	211	101	211	101
No. of accidents per day	0.36	0.33	0.44	0.27
Vehicle demand, 10^6 km	34.1	18.8	30.3	17.4
No. of accidents per million vehicle kilometers	2.20	1.75	3.04	1.55
Passenger demand, 10^6 km	45.4	24.3	42.8	25.3
No. of accidents per million passenger kilometers	1.65	1.36	2.15	1.07

Note: 1 km = 0.6 mile.

for purposes of this study as the number of passenger kilometers of travel per vehicle hour of travel time. It is suggested that this measure provides the most meaningful relationship between the service provided by the facility, in terms of passenger throughput, and the cost of providing that service, in terms of traffic congestion.

Another derived measure of effectiveness is the HOV priority index. This measure is defined for purposes of this study as the ratio of average passenger speed to average vehicle speed. An HOV priority index of 1.0 would indicate that no travel-time advantage was experienced by high-occupancy vehicles. To achieve an index greater than 1.0, it would be necessary to move vehicles carrying larger number of passengers at higher speeds than vehicles carrying fewer occupants.

The results of each of the operational stages are summarized in Table 4. In general, the system performance measures were not changed substantially in the morning peak period. The HOV priority index increased by 1 percent, and the PMI was unchanged. The improvement in the HOV priority index resulted primarily from the ability of the system to accommodate the transfer of additional two-person vehicles to the priority lane during this period without adversely affecting speeds in the lane.

In the afternoon peak, the changes were more pronounced. A 21 percent improvement in the PMI for the two-person car-pool stage was observed. This improvement was, however, achieved at the expense of the degree of priority given to HOVs. Thus, the HOV priority index for the two-person car-pool stage was reduced to 1.0, indicating that the system was in user equilibrium. Some advantages were gained by car pools using the priority lane during the afternoon peak, but this advantage was offset by the operating difficulties apparently experienced by the buses, whose scheduled movements tended to concentrate in the more congested portion of the peak period.

The accident rates were examined during the peak periods (using the 2-h peaks for consistency) in terms of accidents per day, accidents per million vehicle kilometers (MVK) and accidents per million person kilometers (MPK). Data were obtained from computerized records of the Dade County Public Safety Department. The data are given in Table 5 (6), and the effects are summarized below (1 km = 0.6 mile).

Item	Change (%) Morning Peak	Afternoon Peak
Accidents per day	-8	+39
Accidents per million vehicle kilometers	-20	-49
Accidents per million passenger kilometers	-18	-50

The results indicate a negligible change in the accident frequency during the morning peak, although the accident rates per MVK and MPK decreased by about 20 percent (which was not statistically significant). The more substantial improvement in safety occurred in the afternoon peak when accident frequency decreased by 39 percent and the accident rates decreased about 50 percent (both statistically significant). Overall, the accident frequency and both rates decreased significantly in the combined peak periods. This indicates that the improved quality of general traffic flow in the two-PPV car-pool operation was much safer than that in the three-PPV car-pool operation.

On the other hand, an examination of the accident severity rates indicated that the percentage of all accidents that involved injuries increased from 27 to 39 between the two stages in the morning peak period (there was no change in the afternoon). Although this change does not represent an increase in the injury-accident rate, it does suggest that there was a higher probability of more severe accidents in the two-PPV car-pool operation in the morning peak.

SUMMARY AND CONCLUSIONS

The operating changes on the I-95 bus and car-pool priority system were implemented largely in response to public concern over the apparent underuse of the facility. The initial minimum car-pool requirement of three PPV was based on analyses that demonstrated that no substantial priority for HOVs would materialize if the car-pool definition was set at a lower level (because the analyses assumed no violations and that all car pools would use the priority lane). The same analyses indicated, however, that the lower level would result in a higher passenger-carrying capability due to more effective use of the freeway capacity by lower occupancy vehicles.

Field studies that compared the two operating strategies indicated that the degree of use of the exclusive lane by qualified vehicles was somewhat lower than had been anticipated. This factor has maintained a consistent travel-time advantage in the exclusive lane throughout the morning peak period and through the noncongested portions of the afternoon peak, even with the reduced car-pool requirement. During the more heavily traveled portion of the afternoon period, however, the system falls into user equilibrium (i.e., the general lanes became equally attractive from the user's point of view). The express buses experience particular difficulty under these conditions because their maneuverability is more limited than that of automobiles. Travel times, delays, and overall trip comfort deteriorated during the afternoon peak for HOVs in general and for buses in particular after the car-pool redefinition.

On the other hand, some appreciable benefits have resulted from the reduction in the car-pool-occupancy requirement. Overall travel times and delays were reduced. The passenger throughput per vehicle hour of travel was improved by 21 percent in the afternoon peak period. Lane-changing problems were significantly reduced. The problems of enforcement were greatly alleviated by eliminating the two-person car pool as a violator of the traffic-control regulations, and the accident rates were improved appreciably. Although the two-person car-pool requirement has compromised, to some extent, the HOV priority advantages, it has also improved system operation and safety.

ACKNOWLEDGMENT

We wish to acknowledge the support of the Florida Department of Transportation and the Federal Highway Administration and Urban Mass Transportation Administration, U.S. Department of Transportation, who sponsored this research. All opinions, findings, and conclusions expressed in this publication are ours and not necessarily those of the sponsoring agencies.

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Discussion

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It was a disappointment to see that the minimum occupancy that qualified an automobile as an HOV was lowered from three to two in the I-95 project, thus weakening its persuasive power to achieve the original objective of increasing transit patronage and car pooling. The disappointing move seems to be justified by Courage and others through an extensive evaluation study. However, the evaluation technique used does not seem to agree with the original project objective.

The most important point to be investigated in the evaluation process would be the impact on transit ridership of the move. Also, periodic counts of parked vehicles at the park-and-ride lot during the study period would be of interest. The parked vehicles are indeed the results of such a project. Drivers will leave their automobiles at the parking lot and take transit if the project measures are effective but take the reverse course if the measures are not convincing. The number of vehicles classified by the number of occupants before and after the change will be another significant statistic. Similar to the decision to take transit, occupants of low-occupancy vehicles may decide to form an HOV if such a tactic is perceived advantageous. A survey of the drivers of the parked vehicles and the occupants of HOVs might explain why and how they became project supporters, and the findings of the survey could suggest the future directions toward which the project effort should be aimed.

These are the points one would expect in an evaluation of this type. Unfortunately, none of them were discussed.

Courage and others showed that, by lowering the minimum requirement for an HOV from three occupants to two, more effective use of the freeway capacity had been achieved. Specifically, they say that "car-pool volumes more than tripled; violation rates decreased by 45 percent." These changes, according to them, were statistically significant at the 99 percent level. These seemingly striking statistics are in fact meaningless and can easily mislead readers. The changes occurred simply because vehicles carrying two persons on the HOV lane were counted as violators in one case and as legitimate users in the other. This does not at all mean that the average vehicle occupancy increased.

Generally, Courage and others were interested in the impact on operating conditions when different definitions of HOV were used rather than the impact of road-user behavior in choosing their mode. They investigated the numbers of vehicles and persons that passed the study location and the level of service that was provided. However, the fundamental objective of the I-95 project should be, rather than to provide the highest total vehicular capacity on the freeway section, to increase the average occupancy of automobiles and buses by discriminating against low-occupancy vehicles. This could be achieved through frustration of the users of low-occupancy vehicles, but such frustration will not necessarily occur simultaneously with the overall highest use of the road surface. One more frustrated automobile driver who decides to leave his or her vehicle at the park-and-ride lot and take transit is a greater sign of success of the project than is one more vehicle passed through during a peak period.

The other parameters used—the PMI and the HOV priority index—do not seem to be relevant for this evaluation task. The PMI is meaningful only when the minimum-occupancy requirement is unchanged. The use of this factor in evaluating the impact of the change of occupancy requirement is unfortunate. For example, if the project is completely abandoned and vehicles are not differentiated, the overall vehicle speed will be increased because of the wider use of the HOV lanes. This apparent failure will yield an increased value of PMI. At the same time, both vehicle and passenger speeds will be increased and the HOV priority index will not explain the impact clearly. Even when the minimum occupancy is held fixed, the conversion of low-occupancy vehicles to

HOVs will cause an increase of speed not only of the new HOVs but also of the remaining low-occupancy vehicles because there will be fewer vehicles on the general lanes. Therefore, this situation will not necessarily increase the HOV priority index.

Finally, the high number of violators on the HOV lane (78 percent in the afternoon peak periods) and the low rate of legitimate users on it (only 23 to 37 percent of the total qualified vehicles) make one think that stricter enforcement might have been more effective than lowering the minimum-occupancy requirement in making the I-95 project successful.

Authors' Closure

We appreciate the comments of Shin on our paper. Although some of his comments are well taken, many of them are addressed to points that are beyond the scope of our paper, which was expressly limited to the operating effects of the change in the minimum car-pool occupancy requirement on traffic stream characteristics. Many of these comments are addressed directly in the reports that were prepared as part of the complete evaluation of the demonstration project. In particular, the papers by Wattleworth and others (5, 6) and by Courage and others (7) will answer many of his comments.

Shin inquired about many important measures that were not included in the original paper; these will be presented in summary from here. He asked about the use of the park-and-ride lot and about transit ridership. The average number of vehicles using the lot and the average number of morning peak-period bus passengers are given below for each operational condition.

Condition	Average No. of Vehicles Using Parking Lot	Average No. of Express Bus Passengers
Base	418	726
Three PPV	464	816
Two PPV	525	870

It can be seen that both of these transit-use measures continued to improve when the car-pool definition was reduced from three to two PPV. Thus, the change in car-pool definition did not seem to have a serious effect on the use of the transit system.

Shin points out that the reduction in violation rates in the reserved lane from 63 percent when the three-PPV car-pool definition was used to 37 percent when the two-PPV car-pool definition was used represents, at least partially, the change in the base of vehicle types on which the definition of violator is based. This is certainly a valid observation and, in fact, Table 2 shows that the volume of violators actually increased when the car-pool definition was changed from three to two PPV. However, the violation rate is still an important measure from two points of view, enforcement and system operations. If the violation rate is high, it breeds disrespect for the system, which can lead to a further increase in violators and may foster disrespect for other traffic regulations.

Shin states that the objective of an HOV priority system should be to increase the average occupancy of automobiles. However, the average automobile occupancy is of less significance from a system operation point of view than is the passenger movement capability, and the low passenger movement capability when the three-PPV definition was used was the major reason for redefining the minimum car-pool requirement for the reserved lane. Table 6, Figure 6, and the percentage of total vehicles that are single-occupancy vehicles (SOVs) given below point this out quite dramatically.

Item	SOVs (percentage of total)	Item	SOVs (percentage of total)
Morning peak		Afternoon peak	
No. of vehicles		No. of vehicles	
Base	79.5	Base	76.1
Three PPV	76.6	Three PPV	70.7
Two PPV	79.0	Two PPV	68.2
No. of passengers		No. of passengers	
Base	62.0	Base	56.2
Three PPV	57.3	Three PPV	49.7
Two PPV	61.0	Two PPV	46.7

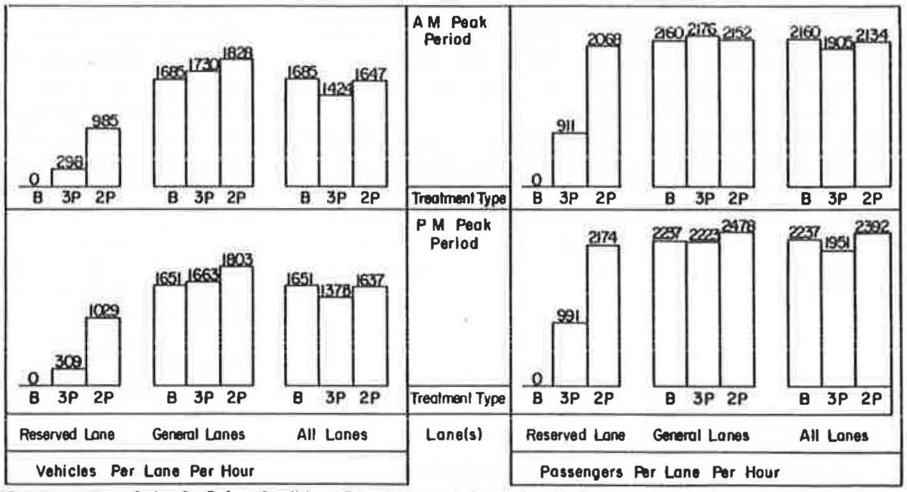
1. When three-PPV operation was used, the total number of automobiles that were eligible to use the reserved lane was extremely small (611 vehicles/2 h in

Table 6. Summary of vehicular and passenger movements.

		Morning Peak: I-95 Southbound						Afternoon Peak: I-95 Northbound					
		No. of Vehicles			No. of Passengers			No. of Vehicles			No. of Passengers		
Lanes	Type of Vehicle[a]	Base	Three PPV	Two PPV	Base	Three PPV	Two PPV	Base	Three PPV	Two PPV	Base	Three PPV	Two PPV
Reserved	SOV	0	225	703	0	225	703	0	241	759	0	241	759
	2OV	0	139	1 058	0	278	2 116	0	135	1 021	0	270	2 042
	3OV	0	211	187	0	691	613	0	219	254	0	734	849
	Buses	0	21	21	0	628	704	0	23	23	0	656	697
	Total	0	596	1 969	0	1 822	4 136	0	618	2 057	0	1 981	4 347
General	SOV	9 827	9 967	11 456	9 827	9 967	11 456	9 215	8 820	9 662	9 215	8 820	9 662
	2OV	2 185	2 325	1 656	4 370	4 670	3 312	2 230	2 846	2 789	4 460	5 692	5 778
	3OV	334	400	305	1 111	1 338	1 029	648	541	782	2 175	1 808	2 751
	Buses	21	0	0	548	0	0	24	0	0	572	0	0
	Total	12 367	12 705	13 417	15 856	15 975	15 797	12 117	12 207	13 233	16 422	16 320	18 191
All	SOV	9 827	10 192	12 159	9 827	10 192	12 159	9 215	9 061	10 421	9 215	9 061	10 421
	2OV	2 185	2 474	2 714	4 370	4 948	5 428	2 230	2 981	3 810	4 460	5 962	7 620
	3OV	334	611	492	1 111	2 029	1 642	648	760	1 036	2 175	2 542	3 600
	Buses	21	21	21	548	628	704	24	23	23	572	656	697
	Total	12 367	13 298	15 386	15 856	17 797	19 933	12 117	12 825	15 290	16 422	18 221	22 338
	Percent SOV	79.5	76.6	79.0	62.0	57.3	61.0	76.1	70.7	68.2	56.1	49.7	46.7

[a]SOV = single-occupant vehicle, 2OV = vehicle that has two occupants, and 3OV = vehicle that has three or more occupants.

Figure 6. Productivity of reserved lane, general lanes, and all lanes.



Treatment Type Code: B – Before Condition; 3P – Buses and Car Pools with 3 or more Persons in Reserved Lane; 2P – Buses and Car Pools with 2 or more Persons in Reserved Lane

the morning and 760 vehicles/2 h in the afternoon). Most people would consider these numbers too small to justify a reserved lane.

2. When two-PPV operation was used, the number of eligible automobiles that actually used the reserved lane was 1245 vehicles/2 h in the morning and 1275 vehicles/2 h in the afternoon.

3. The number of persons moved in the reserved lane was about 1900 persons/2 h when the car-pool definition was three or more, and the number of persons moved increased to about 4250 persons/2 h when the minimum car-pool requirement was two persons.

4. The number of persons moved in all lanes of I-95 was about 18 000 persons/2 h when the car-pool definition was three and increased to about 21 000 persons/2 h when the car-pool requirement was two persons.

Thus, if one considers the person-moving capability of the freeway, it can be seen that the freeway (and the reserved lane) was able to move many more persons when the lower car-pool requirement was used. Because the primary function of a freeway (or other transportation system) is to move people, it is believed that this is a significant point.

Figure 6 presents some of this information on a basis of persons moved per lane per hour. Some of the significant points from this figure include the following.

1. When the three-PPV car-pool definition was used, the reserved lane carried only about 300 vehicles/h and about 950 persons/h, and the general lanes carried 1700 vehicles/lane/h and about 2200 persons/lane/h. Thus, the productivity of the reserved lane was much less than that of the general lanes.

2. When the car-pool definition was changed to two PPV, the reserved lane carried about 1000 vehicles/h and about 2125 persons/h. This represents a significant increase in productivity.

3. When the car-pool definition was three PPV, the general lanes averaged about 1700 vehicles/lane/h and about 2200 persons/lane/h. When the car-pool definition was reduced to two PPV, the general lanes averaged about 1800 vehicles/lane/h and about 2300 persons/lane/h.

Thus, the reduction in the car-pool definition in the reserved lane increased the productivity of both the reserved lane and the general lanes.

In view of these results, it is difficult to conclude other than that the reduction in the minimum car-pool requirement for reserved-lane use from three to two PPV produced a much more efficient operation from almost every practical viewpoint. Perhaps from an academic point of view, the change represented some philosophical sacrifices but from a practical, engineering point of view the changes were extremely beneficial.

Publication of this paper sponsored by Committee on Freeway Operations.

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