Spatial Relationships Between Carpool Members' Trip Ends

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The potential for carpool formation is a function of the density of common trip ends, both spatially and temporally. It is also a direct function of the deviation from a direct route that carpool drivers will tolerate in order to pick up and deliver carpool passengers. This paper examines the spatial relationships between the origins and destinations of members of the same carpool. The relationships are reported in terms of carpool trip lengths, passenger pickup and delivery radii and deviations, total deviations from a direct route, and deviations as a function of the direct route distance for the carpool driver. Data for this study were obtained by means of roadside questionnaire surveys at 20 sites in the metropolitan area of Melbourne, Australia.

The last decade has seen a considerable change in emphasis in the area of transportation planning. The former emphasis on substantial capital expenditure for the provision of new transport facilities has been replaced with a much greater emphasis on the efficient management of existing transportation systems. In such an environment, there has been a marked increase in interest in providing for and encouraging the use of high-occupancy vehicles for urban travel during peak hours. Such high-occupancy vehicles may generally be thought of as buses or some form of carpool.

Greater interest in the use of buses for peak-hour travel has been fairly widespread. Comprehensive reports have emanated from the United States (1), the United Kingdom (2), Europe (3), and Australia (4). The predominant increase in interest in carpooling, however, has been in the United States (e.g., 5-7), although recently a number of papers have emerged from the United Kingdom to describe their experiences with ridesharing (8-11). Australia has also produced a limited number of studies over the past few years (12-18).

Most of the reports have, with a few exceptions, been descriptive in nature, and many have simply discussed the application of ridesharing to a specific site. Few of the papers have attempted to investigate the basic characteristics of carpool participants or the way in which carpools form and operate. [Some notable exceptions in this respect are the works of Margolin and Misch (6), Dueker and Levin (19), Bonsall (11), Cousins (14), and Johnson, Sen, and Galloway (20).] In particular, little research has been directed at investigation of the spatial structure of carpools (i.e., the relationships between origins and destinations of members of the same carpool).

The study described in this paper is primarily concerned with determining such carpool spatial structures for a sample of carpool journeys to and from work in Melbourne, Australia. The results are reported in terms of the length of carpool trips, the relationships between carpool members' origins and destinations, and the deviations from a direct route that carpool drivers will tolerate in order to participate in a carpool.

STUDY METHOD

The data on which this paper is based were collected by means of roadside reply-paid questionnaire surveys conducted in April 1978 at several sites in the Melbourne metropolitan area (21). In all, 20 separate surveys were conducted at 11 different locations, as shown in Figure 1. The survey sites were selected to yield a variety of radial and circumferential routes in various sectors of the metropolitan area. Sixteen of the surveys were conducted in the morning peak period and four were conducted in the evening peak period.

Each survey was performed by handing a questionnaire to the drivers of both carpool and noncarpool vehicles as they waited at a red traffic signal. Only one questionnaire was handed to each vehicle since the details for all members of the carpool were to be recorded on the one survey form [see Richardson and others (21) for further details of the questionnaire]. Although this resulted in a slightly crowded format for the questionnaire, previous experience with carpool surveys (22) had shown that considerable difficulty existed in obtaining details for a complete carpool if each member in the carpool is given a separate survey form. By obtaining all details for one carpool on the one survey form, although the total number of returns may decrease, the amount of useful information on carpool formation and spatial structure (the object of the study) would increase because of increased complexity of the questionnaire. Over all sites, the questionnaire distribution rate was 22 percent (i.e., 22 out of every 100 private-passenger vehicles were handed questionnaires). The return rate was 33 percent. This response was considered adequate for the purposes of the analysis.

SURVEY RESULTS

This paper is concerned with carpools that are used for journeys to and from work. Such a distinction is necessary because a large number of trip purposes are being fulfilled by carpools observed on major roads during peak periods. To illustrate this multiplicity of carpool trip purposes, consider Table 1, which shows the distribution of trip purposes for carpools observed on radial routes in the morning and evening peak periods and on circumferential routes in the morning peak period.

Several features of this table are worth noting. First, for the morning trips in particular, a large number of nonwork carpools are primarily concerned with ferrying children to school. To ensure some degree of homogeneity in the carpools considered in this study, all carpools associated with school trips are eliminated from further consideration, as are those that serve passenger trips and carpools that have other (nonspecified) trip purposes. Second, it is obvious from the table that there are two fundamentally different types of work carpools--those in which all carpool members come from the same household (hereafter referred to as internal carpools) and those in which carpool members come from at least two households (external carpools). Although external carpools are generally considered to be more relevant to transportation policy decisions, both types of carpools will be considered in this study. Where comparisons are made with drive-alone vehicles in this paper, such drive-alone-vehicle trips also refer only to journey-to-work trip purposes.

Trip Lengths

Many previous studies of carpooling behavior (e.g.,

Figure 1. Carpool survey sites.

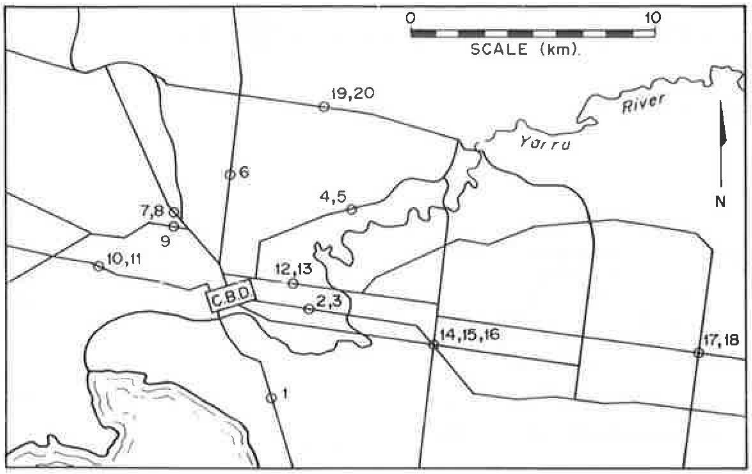


Table 1. Purpose of carpool vehicle trips.

	Morning Radials		Evening Radials		Morning Circumferentials	
Trip Purpose	No.	Percent	No.	Percent	No.	Percent
Work trip with occupants that come from more than one household	107	22	41	36	65	26
Work trip with occupants that come from same household	232	47	52	46	95	39
Trip with at least two work destinations and at least one school or nursery destination	27	5	1	1	13	5
Trip with only one work destination and at least one school or nursery destination	82	17	3	3	47	19
Serve passenger trip	10	2	2	2	2	1
Student or teacher carpools to university or college	9	2	0	0	8	3
Other trip purposes	27	5	14	12	17	7

23,24) have shown that the probability of carpooling is a function of the length of the trip in question. Generally, the probability of traveling in a carpool increases as the total trip length increases. However, at very large trip lengths, some studies (25) have found a tendency for this probability to decrease. Such trends may be explained by reference to two components of travel choice behavior: travel choice preferences and travel constraints. Thus, as the trip length increases, more people will prefer to travel by carpool since the financial savings to be had from reduced fuel consumption will, in absolute terms, be greater. Also, the effect of travel-time increases to pick up and deliver passengers will be relatively less noticeable. However, as the trip length increases, the residential density of potential carpool partners decreases and, hence, it is more difficult for a person to form a carpool (even though at such large distances, such a person may strongly prefer to travel by carpool). The combined effect of these two factors may therefore explain the trends outlined above.

Before proceeding to show the effect of trip length on the propensity to carpool, it is necessary to define the measure of trip length used in this study. Since no information was sought on the actual route traversed by carpools, the only information obtained in this study from which the trip distance could be estimated were the sets of (x,y) coordinates that describe the origins and destinations of each of the vehicle occupants. To find the distance between any two points by using this coordinate system, two possibilities exist:

1. Straight-line distance and
2. Rectangular-grid distance.

The simplest measure is the use of straight-line (or airline) distance between any two points, as given by

$$S_{12} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \qquad (1)$$

where

S_{12} = straight-line distance between points 1 and 2,
x_1 = x-coordinate for point 1, and
y_1 = y-coordinate for point 1.

Although straight-line distance may be a reasonable representation of actual distance traveled in an abstract city with no knowledge of the specific street system, it is likely that, in a grid system of streets, it may be more appropriate to calculate the distance between two points by moving along the sides of a rectangle (aligned in the direction of the grid street system) rather than across the diagonal of the rectangle. In such a case, and when the grid is aligned north-south, the grid distance between any two points is given by

$$G_{12} = |x_1 - x_2| + |y_1 - y_2| \qquad (2)$$

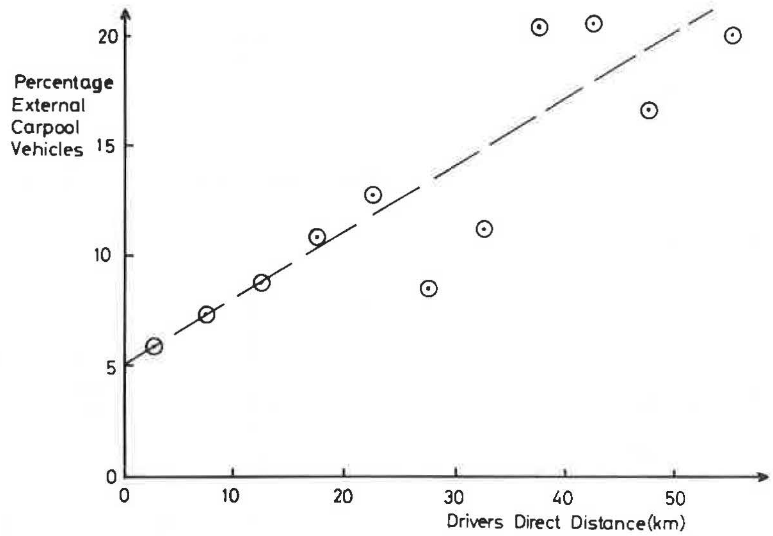
Because of the grid system of streets (aligned roughly north-south), which does occur in much of suburban Melbourne, grid distances were used in this study. As shall be seen later, grid-distance calculations are also more appropriate when calculating deviations from a route in a grid street system.

By using such grid-distance calculations, the distance between the driver's origin and destination was calculated for all three types of vehicle (i.e., drive alone, internal carpool, and external carpool) for the three different categories of survey site

Table 2. Trip length statistics.

	Carpool								
	Drive Alone			Internal			External		
Trip	Mean (km)	SD (km)	N	Mean (km)	SD (km)	N	Mean (km)	SD (km)	N
Morning radial	17.7	10.1	688	18.4	11.1	204	22.4	11.2	99
Evening radial	16.8	14.3	193	16.6	10.1	47	20.7	13.7	39
Morning circumferential	19.2	10.8	642	17.9	9.0	96	20.2	11.0	75
All sites	18.2	11.1	1523	18.0	10.5	347	21.3	11.7	213

Figure 2. Probability of carpooling as a function of driver's direct distance.



(i.e., morning radials, evening radials, and morning circumferentials). The results of these calculations are shown in Table 2. For each of the three types of vehicle, no significant difference (at the 5 percent level) is found between the trip lengths obtained for each of the three survey site categories. For this reason, the trip length values were combined to produce an all-sites trip length value (in all subsequent analyses, no differences were found among survey site categories and, hence, all-sites values are used in all analyses).

By using a z-statistic on these all-sites values, it can be shown that there is no significant difference (at the 5 percent level) between the mean trip distance for drive-alone vehicles and internal carpools. However, the mean distance for external carpools is significantly greater (again at the 5 percent level) than the mean distance for internal carpools (or drive-alone vehicles).

This increased length of external carpool trips can be examined a second way by noting the probability of a vehicle trip being an external carpool as a function of the driver's direct trip length. This relationship is shown in Figure 2. A strong trend is shown for the proportion of external carpools to increase with increasing trip length (although this trend becomes more variable at higher trip lengths because of reducing sample sizes). It therefore appears that increased trip length does favor the formation of external carpools, as noted in previous studies. This trend does not exist, however, for internal carpools where the proportion fluctuates randomly about a mean value of 17 percent, irrespective of trip length.

Radii of Pickup and Delivery

A previous study (13) showed that substantial potential benefits could accrue from carpooling if residents of Melbourne were willing to pick up and deliver other travelers within a radius of 500 m of their own residence and work place. The present study offers the chance to determine whether such radii of pickup and delivery are feasible, at least in terms of existing carpool arrangements.

Because this study considers both morning and evening work trips, we must redefine the radii used in this analysis. Thus, instead of considering pickup and delivery radii, this study will consider home-end and work-end radii. This redefinition overcomes the problem that the work-end radius is a delivery radius in the morning and a pickup radius in the evening. The work-end radius is therefore defined as the maximum straight-line distance between the driver's work place and any one of the work places of his or her passengers. Similarly, the home-end radius is the maximum straight-line distance between the driver's home and any one of the homes of the passengers.

Obviously, the home-end radius for an internal carpool must be zero because all carpool members must, by definition, come from the same household. The distribution of home-end radii for external carpools is shown in Figure 3. The distributions of work-end radii for both internal and external carpools are shown in Figure 4.

Several features of Figures 3 and 4 are worth noting. First, both the average home-end and work-end radii for external carpools are greater than the value of 500 m proposed in the earlier study (13). This suggests that the benefits derived in that study may be realistic estimates of the potential benefits of carpooling in Melbourne.

Second, the average home-end radius for external carpools is significantly and substantially greater than the average work-end radius for external car-

Figure 3. Distribution of home-end radii.

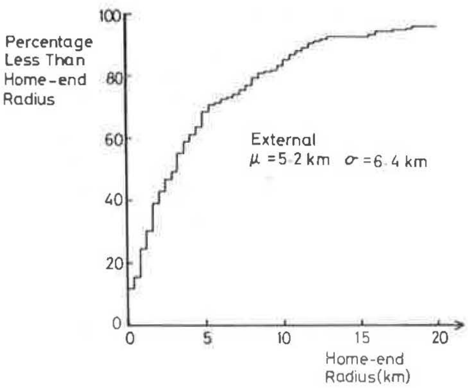


Figure 4. Distribution of work-end radii.

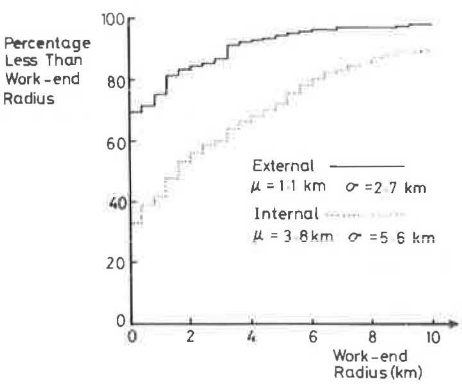


Figure 5. Distribution of home-end deviations.

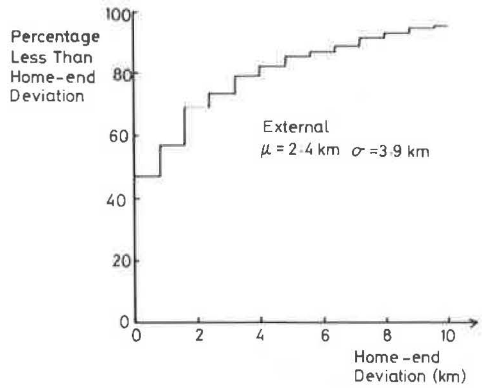
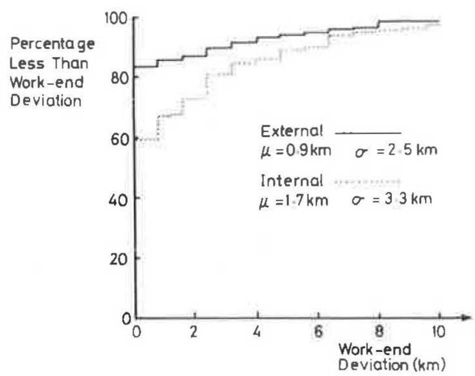


Figure 6. Distribution of work-end deviations.



pools. This indicates that most existing external carpools are work-based carpools. That is, such external carpools are mainly comprised of people who work together (or near each other). This is also demonstrated by the fact that 70 percent of external carpools have a zero work-end radius (i.e., all carpool members work together or at least within 0.4 km of each other), but only 12 percent of external carpools have a zero home-end radius. This natural tendency of travelers to form work-based carpools should be noted very strongly with respect to the encouragement of carpool matching schemes at work sites rather than within residential areas (7,18).

Third, note that the average work-end radius for internal carpools is significantly greater (at the 5 percent level) than the average work-end radius for external carpools. This is to be expected because all internal carpools are home-based and, as a result of family obligations, the driver is committed to delivering or picking up the passenger at the passenger's place of employment, irrespective of the location of that place of employment.

Home-End and Work-End Deviations

Home-end and work-end radii are but one way of specifying the inconvenience suffered by carpool drivers in forming carpools. A more realistic measure of inconvenience is the deviation from a direct route that a carpool driver will tolerate to pick up and deliver passengers. Thus, for example, a carpool driver may have a large home-end radius but if all of the passengers live along the normal route to work then he or she will have little or no route deviation to pick them up. On the other hand, if the carpool driver must first travel away from a final destination in order to pick up passengers, then the route deviation may well be greater than his or her home-end radius.

In this study, the home-end deviation is defined as the grid distance covered in traveling from the driver's home to each of the passengers' homes (in correct order) and then to the driver's work place minus the direct grid distance from the driver's home to the driver's work place (or vice versa for evening trips). The work place deviation is similarly defined as the grid distance covered in traveling from the driver's home to each of the passengers' work places (in correct order) and then to the driver's work place minus the direct grid distance from driver's home to work place.

Once again, the home-end deviation for internal carpools must, by definition, be equal to zero. The distribution of home-end deviations for external carpools is shown in Figure 5. The distributions of work-end deviations are shown in Figure 6.

Comparison of Figures 3 and 5 shows that the average home-end deviation is significantly less than the average home-end radius (2.4 km compared with 5.2 km). This indicates that carpool drivers tend to pick up passengers who live along their normal route to work. However, this implication should be drawn with some care, since the use of grid-distance calculations (and in fact the existence of the grid street system) ensures that many deviations will be zero even though the driver no longer traverses his or her normal route. The existence of this situation is borne out in the results of this study because, although only 12 percent of external carpools have home-end radii equal to zero,

Figure 7. Distribution of total deviations.

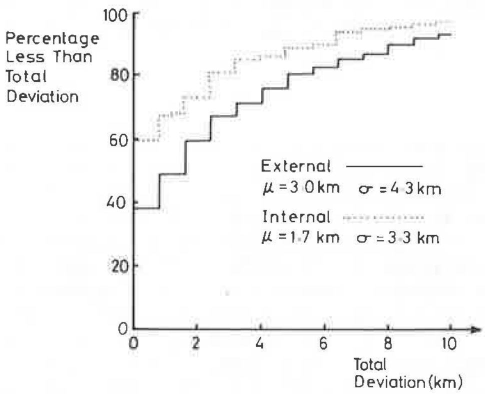
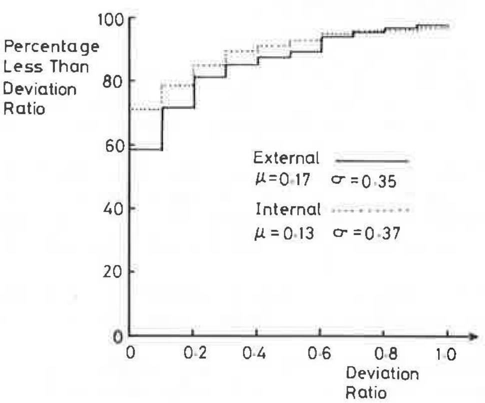


Figure 8. Distribution of deviation ratios.



47 percent of external carpools have home-end deviations equal to zero. The forgiving nature of grid street systems with respect to route deviations means that such grid street systems are more suited to carpool formation than the more recent types of hierarchical street systems where it is necessary for the driver to backtrack in order to continue the journey.

The average home-end deviation for external carpools is significantly greater (at the 5 percent level) than the average work-end deviation for external carpools. This reflects the work-based nature of external carpools, as noted earlier, but may also reflect the relative ease of making deviations at the home and work ends of the trip in terms of traffic congestion levels. Finally, the average work-end deviation for internal carpools is significantly greater than the average work-end deviation for external carpools even though the difference in work-end deviations is far smaller than the difference in average work-end radii.

Total Deviations

A further advantage of using deviations rather than radii as a measure of carpool inconvenience is that it enables the calculation of a total measure of inconvenience for the trip, namely the total deviation. This total deviation is defined as the grid distance covered in traveling from the driver's origin to all the passengers' origins and destinations (in correct order) and then to the driver's destination minus the direct grid distance from driver's origin to destination. The total deviation therefore accounts for both the home-end and work-end deviations and also for the dependence between home-end and work-end deviations. It is therefore unnecessary to try to apportion the total deviation to separate home-end and work-end components.

Because internal carpools have no home-end deviation, the total deviation for internal carpools is the same as the work-end deviation. The distributions of total deviations for both internal and external carpools are shown in Figure 7.

The average total deviation for external carpools is significantly greater (at the 5 percent level) than that for internal carpools, as expected. However, the total deviation for external carpools is not simply the sum of the home-end and work-end deviations. Rather, it is slightly less to account for the degree of dependence between the deviations at the home end and the work end. The average total deviation for external carpools is 3.0 km; 38 percent of the deviations are equal to zero and 10 percent are greater than 8 km.

Deviation Ratios

A measure of inconvenience that is perhaps more readily understood is given by the deviation ratio that relates the total deviation to the total direct distance for the carpool driver. It gives a percentage increase in total trip distance that the carpool driver will tolerate in order to form a carpool. Not only is the nondimensional nature of the ratio easily understood but the ratio also takes account of the different trip lengths of carpool types. Thus, although the total deviation for internal carpools is smaller, remember from Table 2 that the driver's direct distance for internal carpools is also smaller and hence these two factors will tend to even out, with the deviation ratios for internal and external carpools tending to be more equal.

The distributions of deviation ratios for all sites are shown in Figure 8. To some extent, the expectation of more equal deviation ratios for internal and external carpools is borne out by examination of Figure 8. Thus, although the ratio of average total deviations for external and internal carpools was 1.76 to 1, the ratio of the average deviation ratios is only 1.31 to 1. However, by using a Mann-Whitney rank-sum test, the deviation ratio for external carpools is still greater than the deviation ratio for internal carpools (at the 5 percent level).

The mean value of the deviation ratio for external carpools of 0.17 compares reasonably well with previous reported findings. Pratsch (26) suggests that a ratio of 0.25 (albeit measured in time) generally constitutes an acceptable carpool. Approximately 80 percent of the external carpools in the present study have deviation ratios less than Pratsch's value of 0.25.

Johnson, Sen, and Galloway (20) present empirical evidence from two pooling schemes that suggests a ratio between 0.25 and 0.33 (measured in distance). Two factors, however, need to be considered with respect to this study before comparisons can be made with the present study. First, the study by Johnson and others (20) is concerned with vanpools that have up to 12 passengers. This greater number of passengers would obviously tend to increase deviation ratios. Second, the deviation ratio was calculated in a slightly different manner, with the collection distance (i.e., the grid distance traveled to the last pickup) being divided by the line-haul distance (i.e., the grid distance from the last pickup to the final destination, which in that study was common for all passengers). Therefore, although the orders

Figure 9. Deviation ratio as a function of driver's direct distance for internal carpools.

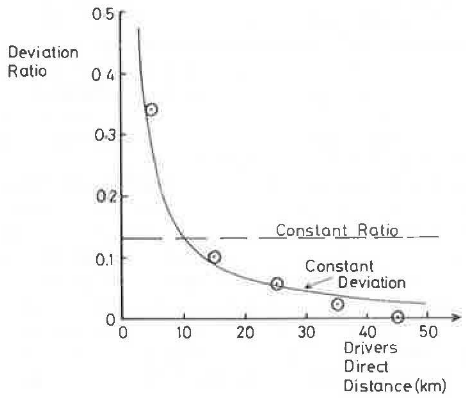
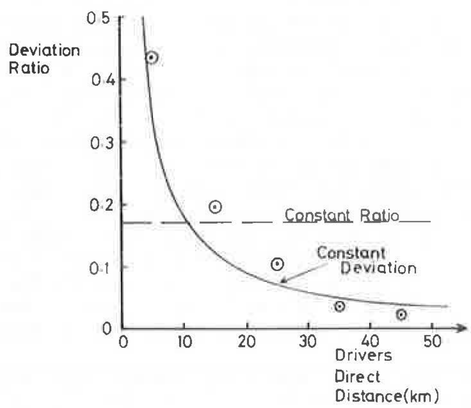


Figure 10. Deviation ratio as a function of driver's direct distance for external carpools.



of magnitude of the deviation ratios from both studies are similar, a detailed comparison cannot be made.

One problem with the use of the deviation ratio is that, although such a ratio is easy to understand and the ratio itself is easy to remember, there is the danger that the ratio may impute a generality that is unable to be substantiated. For example, it may be assumed that the deviation ratio is constant, irrespective of the carpool driver's total direct distance.

To test this assumption, the average deviation ratio for carpools that have driver direct distance that lie within 10-km intervals was calculated and plotted against the mean trip distance for that interval, as shown in Figure 9 for internal carpools and Figure 10 for external carpools. In general, the deviation ratio decreases with increasing driver direct distances. Thus, the constant deviation ratio hypothesis, as depicted by the dashed line in each figure, can be effectively discounted.

On the other hand, if a constant total deviation is assumed (of 3.0 km for external carpools and 1.7 km for internal carpools, as shown in Figure 7), then it is possible to postulate a theoretical curve to represent this hypothesis, as shown by the full line of Figures 9 and 10. In each case, there is reasonably good agreement between this constant deviation curve and the value calculated from the data sets.

It therefore appears that, even though the deviation ratio is a convenient conceptual measure of carpool inconvenience, the total deviation is a more stable measure of the inconvenience that will be tolerated by carpool drivers, irrespective of the driver's distance.

CONCLUSIONS

This paper has presented the results of a reply-paid questionnaire survey conducted at several sites on major roads in the morning and evening peak periods in Melbourne, Australia. It has concentrated on an analysis of the spatial relationships between the origins and destinations of members of the same carpool and has derived a measure of the inconvenience that carpool drivers will tolerate in order to form a carpool. Two types of work-trip carpool were identified and treated separately in the analysis: internal carpools, whose members all come from the same household, and external carpools, whose members come from at least two different households.

On the basis of the reported analysis, the following conclusions can be drawn about the spatial structure of carpool formation.

1. A substantial proportion of multioccupant vehicles could not be strictly classified as carpools; a large number of observed multioccupant vehicles were involved in ferrying schoolchildren to school.
2. No significant differences could be detected between the spatial structure of carpools observed on radial routes in the morning or evening peak periods and circumferential routes in the morning peak period.
3. Over all sites, external carpool driver-trip distances are significantly longer than drive-alone trip distances.
4. Internal carpool driver-trip distances exhibit the same distribution of trip distances as those of drive-alone trips.
5. The probability of a trip being made by an external carpool rises with increased trip distance, from 5 percent at distances less than 5 km up to approximately 20 percent at distances greater than 40 km.
6. The work-end radius for external carpools is significantly lower than the home-end radius, which indicates that most existing external carpools are organized around the work site.
7. The average home-end radius for external carpools is 5.2 km, and the average work-end radius for external carpools is 1.1 km.
8. The home-end and work-end deviations are smaller than the home-end and work-end radii, which indicates that pickups and deliveries can be made with minimal increase in the driver's direct distance.
9. The average total deviation for external carpools is 3.0 km, which is significantly greater than the average total deviation of 1.7 km for internal carpools.
10. The average deviation ratio for external carpools is 0.17, which is also significantly greater than the average deviation ratio of 0.13 for internal carpools.
11. The hypothesis of a constant total deviation appears to be more justified than the hypothesis of a constant deviation ratio (irrespective of driver's direct distance).

The results obtained should help to provide some objective measurements of the way in which journey-to-work carpools are formed and operated. The results should be of considerable assistance in determining the feasibility of carpool structures generated by carpool matching programs. They may also assist a work-site carpool coordinator, whose responsibility is to generate feasible carpools for employees at that site. Remember, however, that these results only assist in generating carpools that are physically feasible. The numerous influences that determine the overall feasibility of the carpool in terms of social acceptability must also be considered as described in other studies of carpooling behavior (6,11,19).

ACKNOWLEDGMENT

The data on which this paper was based were collected with financial assistance from an Australian Road Research Board (ARRB) research grant. We would like to thank the ARRB liaison officer for this project, D.P. Bowyer, for his considerable assistance in the conduct of the study. We would also like to thank J. Turney of Monash University for her diligent efforts in the computer processing of the data.

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