# EFFECT OF ZONE SIZE ON TRAFFIC ASSIGNMENT AND TRIP DISTRIBUTION

Bruno R. Wildermuth, Wilbur Smith and Associates;
D. J. Delaney, Transport Planning Division, Commonwealth Bureau of Roads, Melbourne, Australia; and
K. E. Thompson, Bureau of Transport Economics, Canberra, Australia

The analysis in this paper of the effect of zone size on traffic assignment and trip distribution was based on the results of a research study initiated by the Australian Commonwealth Bureau of Roads. This investigation was concerned with identifying criteria for zone size selection, based on the results of applying standard trip distribution and traffic assignment procedures to an actual road network and vehicle trip matrix. Vehicle trips were aggregated to 5 test systems, ranging from 40 to 263 zones, and assignments were made to the basic 1964 road network. The effect of different zone systems on traffic assignment was evaluated statistically by comparing assignments with those for the study area's 607-zone trip matrix and with 1964 traffic counts at 16 check lines located throughout the study area. The effect of zonal aggregation on the simulation of trip distributions was also tested, both for a 1-purpose and a 4-purpose distribution. Distribution errors attributable to the aggregation of zones and to the grouping of trip purposes were evaluated for 3 zone plans by comparing assignments of the resulting trip matrices with the 607-zone system assignment and with the 1964 check-line volumes. It is concluded that for many aspects of transport planning, zone plans with an average of 30,000 trip ends per zone will yield traffic assignments sufficiently accurate for predictions of traffic growth within transportation corridors.

• TRAFFIC assignments for many aspects of transportation planning are not required to be so accurate as those required for design purposes. Rather, emphasis may be placed on the reliable prediction of traffic growth for travel corridors or for subareas of metropolitan areas. Such predictions may be desirable for evaluating a number of alternative urban development schemes for a range of time periods. Substantial savings in efforts and computer costs could be expected if estimates could be made with fewer analysis zones. The Commonwealth Bureau of Roads, therefore, initiated a research study to identify and measure the likely traffic assignment errors that would result from the use of fewer zones than normally used in transportation studies.

The basic approach in the investigation was to devise a number of alternative zone plans and to assign the resulting rearranged trip matrix to a common road network. The original origin-destination survey trip matrix for all vehicle trips was used for the purpose. Traffic assignments were performed by utilizing 2 noniterative techniques, the all-or-nothing method and a multiple-route method. (The multiple-route method is based on the assumption that the user of a network does not know the actual link times he is going to encounter but that he associates with each link in the network a probable link time based on past travel experience. In assignments, the probable link time is drawn at random from a normal distribution of times for that link every time it is considered in path building. The mean of the normal distribution is equal to the initial estimate of link time, and the standard deviation of the distribution is assumed to be 18 percent of the value of the mean.)

An analysis was made of those trips that became intrazonal trips under different zone plans. Trip matrices containing only those trips were prepared and assigned to the basic network to determine average vehicle-miles and vehicle-hours of travel for intrazonal trips.

Standard gravity or interactance trip distribution models were calibrated for 3 alternative zone plans. Both a 4-purpose model and a 1-purpose model were developed, and the resulting trip matrices were assigned to the basic road network. A unique feature of the trip distribution model was the use of separate distribution functions for central business district trips, external trips, and the remaining internal trips.

Statistical tests were made to compare assigned link volumes with traffic counts at 16 check lines located throughout the study area. In addition, vehicle-miles and vehicle-hours of travel were summarized for 56 districts, identical to one of the test zone systems. Comparisons were made with the assignment that had the smallest differences from the traffic counts on all links crossing the 16 check lines. Finally, the frequency distribution of the assigned volumes on the links of each zone system were determined. Particular attention was given to the links that were not assigned any trips under alternative zone plans.

## STUDY DATA

The source of data used for the research was the 1964 Melbourne Metropolitan Transportation Study, which used 607 internal traffic zones and 32 external cordon stations. A home interview survey of about 30,000 households (5 percent sample) provided most of the origin-destination data. Also surveyed were drivers of 9,000 trucks (10 percent sample) and nearly 600 taxis (25 percent sample). Roadside interviews at 32 external cordon stations provided travel data on approximately 90,000 vehicle trips. Some trips had both ends inside. Table 1 gives the internal and external trips by 4 trip-purpose categories.

The 1964 road network coded for study purposes comprised 4,936 one-way links representing 1,085 miles of arterial and collector roads. The network contained 2,440 centroid connector links and 2,519 nodes, including the 639 centroids.

Travel time studies made in 1964 provided estimates of average daily running speeds for the network. Subsequently, some of the link speeds were modified to achieve better correspondence between actual volumes and volumes obtained from the all-or-nothing assignment.

## ALTERNATIVE ZONE SYSTEMS

Various criteria, sometimes conflicting, were used in the selection of the 607 zones (hereafter referred to as system 607). These criteria included uniformity of land use, presence of physical barriers to travel, existing area subdivisions, and a requirement that the diameter of the zones should generally have a travel time of 3 to 6 min. For the purpose of statistical comparison, zone systems were defined as combinations of the original 607 zones. All of these criteria were observed, to the extent practicable, in defining the various test zone plans.

The following ranges of internal zones were initially defined for investigation: 30 to 50, 100 to 150, and 250 to 300 zones. The zones would have average areas of 12 to 20, 4 to 6, and 2 to 2.5 square miles and average widths of 5, 2.5, and 1.5 miles respectively. These average values were used only as a general guide in defining zones. Each of the zonal systems had smaller zones near the center and larger zones in the outlying parts of the study area.

The central business district and several suburban centers have trip-end densities far higher than those found elsewhere in the study area. These centers were retained as separate zones in systems 136, 144, and 263 but necessarily were combined with immediately adjacent areas in the test plans with the largest zones (systems 040 and 056).

In addition to the reduction in the number of internal zones, external stations were also combined, where possible, on the basis of physical proximity. Traffic entering from different external stations had to use the same general travel corridors to justify the use of a combined external centroid.

The criteria selected were consistent with those generally adopted in transport planning; therefore, the conclusions of this study would be applicable to other cities. In accordance with these criteria, test systems 040, 136, and 263 were initially established.

After the analysis of assignment results from the initial test systems, it was concluded that a limit for the maximum number of trip ends per zone would substantially improve assignment accuracy without materially increasing the number of zones. Consequently, test systems 056 and 144 were established as modifications of the initial systems 040 and 136. Accordingly, assignment errors were investigated for the range of test plans given in Table 2.

## ANALYSIS OF INTRAZONAL TRIPS

The amount and percentage of intrazonal trips depend primarily on the size and type of land use within zones. Because intrazonal trips were not assigned to the network by the normal traffic assignment process, the magnitude of travel caused by these trips must be considered in connection with changing zone sizes. Figure 1 shows the relation between the percentage of intrazonal trips and the average number of trip ends per zone for the zone plans tested.

To determine the magnitude of intrazonal travel in terms of vehicle-miles and vehicle-hours, the intrazonal trips associated with each test system were assigned to the system 607 network. In this way, it was possible to isolate the link loadings resulting from intrazonal trips in addition to the 220,124 trips that were intrazonal for system 607. The all-or-nothing method was used for this purpose. (This method was selected to eliminate effects of the stochastic process associated with the multiple-route method. However, because such trips would generally travel relatively short distances, few alternative paths would be identified in a multiple-route assignment.) Table 3 gives the resulting vehicle travel from these assignments for the major arterial and collector road links (i.e., all links except centroid connectors). Table 4 gives the average and incremental vehicle-miles and vehicle-hours for intrazonal trips. Incremental value are computed from travel generated by intrazonal trips that were not intrazonal in the system with which the comparison is drawn.

An investigation was also made of the concentrations of intrazonal trips. Table 5 gives frequency distributions of 1-way links by volume prepared from the assignments of the intrazonal trips to the system 607 network. Depending on the number of zones, between 20 and 70 percent of all links will not carry any intrazonal trips. Only for the very coarse zone plans of systems 040 and 056 are more than 3,000 intrazonal trips concentrated on some links.

It was concluded that the volumes missed in the assignment process, because of intrazonal trips of systems 263, 144, and 136, were not significant enough to affect capacity evaluations. The higher volumes of intrazonal trips assigned to some links in systems 056 and 040 could affect design, but even so the effects throughout a system planned for capacity continuity would not be great.

## COMPARISON OF ASSIGNMENTS

The analysis and comparison of the traffic assignments resulting from alternative zone plans covered 2 primary areas of investigation. The first test evaluated the assignments with respect to actual traffic counts. Two-way link volumes for 16 check lines were available for this purpose. Three of these 16 ckeck lines represented the major screen lines used for the verification of the original origin-destination survey data, and the others were located throughout the study area. The second test involved the comparison of vehicle-miles and vehicle-hours of travel on a district basis. The results from the system 607 multiple-route assignment were used as a basis for these comparisons. The system 607 multiple-route assignment was selected because it showed the lowest root mean square (rms) error and chi-square error for the ckeck-line comparisons.

In addition to these major tests, comparisons were made of the frequency of links by volume range. Some line-printer plots were also produced for visual comparison of assignments from the different zone systems on a link-by-link basis.

**Table 1. 1964 internal and external vehicle trips.**

| Category | Internal | External | Total |
|---|---|---|---|
| Automobile drivers | | | |
| Non-home-based | 341,693 | 8,824 | 350,517 |
| Home-based, work | 518,578 | 19,443 | 538,021 |
| Home-based, other | 539,579 | 33,922 | 573,501 |
| Commercial vehicles | 631,666 | 25,407 | 657,073 |
| Total | 2,031,516 | 87,596 | 2,119,112 |

**Table 2. Zonal characteristics of alternative test systems.**

| System | Internal Zones | External Stations | Total Centroids | Maximum Number of Trip Ends per Zone |
|---|---|---|---|---|
| 607 | 607 | 32 | 639 | 35,894 |
| 263 | 263 | 23 | 286 | 124,422 |
| 144 | 144 | 17 | 161 | 79,176 |
| 136 | 136 | 23 | 159 | 217,355 |
| 056 | 56 | 17 | 73 | 124,422 |
| 040 | 40 | 23 | 63 | 342,813 |

**Figure 1. Intrazonal trips in relation to average number of trip ends per zone.**

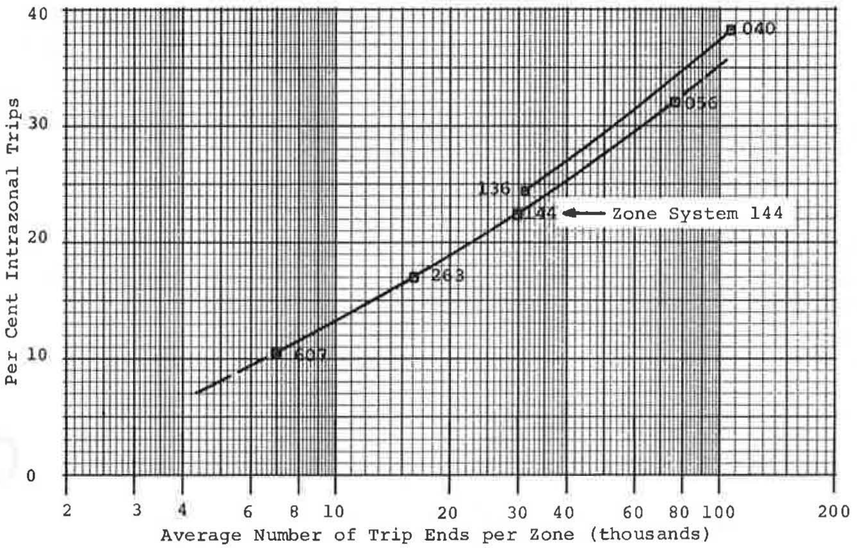


**Table 3. Vehicle-miles and vehicle-hours of intrazonal trips for alternative systems.**

| System | Additional Intrazonal Trips[a] | Vehicle-Miles: Number | Vehicle-Miles: Percent of System 607[b] | Vehicle-Hours: Number | Vehicle-Hours: Percent of System 607[b] |
|---|---|---|---|---|---|
| 263 | 139,373 | 104,584 | 1.17 | 4,194 | 1.19 |
| 144 | 254,742 | 234,929 | 2.63 | 9,009 | 2.56 |
| 136 | 297,504 | 277,471 | 3.11 | 11,479 | 3.27 |
| 056 | 454,840 | 540,992 | 6.05 | 20,242 | 5.76 |
| 040 | 594,044 | 793,704 | 8.88 | 31,120 | 8.85 |

[a] Intrazonal trips in addition to those already existing for system 607.

[b] System 607 vehicle-miles and vehicle-hours resulting from the minimum time path all-or-nothing assignment method.

**Table 4. Average and incremental vehicle-miles and vehicle-hours per intrazonal trip for alternative systems.**

| System | Average[a]: Vehicle-Miles | Average[a]: Vehicle-Hours | Incremental[b]: Comparison System | Incremental[b]: Vehicle-Miles | Incremental[b]: Vehicle-Hours |
|---|---|---|---|---|---|
| 263 | 0.75 | 0.030 | 607 | 0.75 | 0.030 |
| 144 | 0.92 | 0.035 | 263 | 1.13 | 0.042 |
| 136 | 0.93 | 0.039 | 263 | 1.09 | 0.046 |
| 056 | 1.19 | 0.045 | 144 | 1.53 | 0.056 |
| 040 | 1.34 | 0.052 | 136 | 1.74 | 0.066 |
| | | | 056 | 1.82 | 0.078 |

[a] Computed from Table 3, excluding intrazonal trips from system 607.

[b] Computed for intrazonal trips that were interzonal in the comparison system cited.

## Network Preparation

The original 1964 road network of the Melbourne Metropolitan Transportation Study was used for each assignment. This was accomplished by building a link data card image tape on which centroid connectors only were changed, or eliminated, as necessary.

For each zone system, one of the original system 607 zone centroids was designated to represent each new group of zones. All other centroids within the group were eliminated. The analysis of the initial assignments for systems 263, 136, and 040 indicated, however, that this method was not completely satisfactory because many of the original zones were connected with only 1 or 2 centroid connectors. Although this method is quite satisfactory for a large number of small zones, it proved to be a disadvantage for the zone plans with fewer large zones. The lack of an adequate number of alternative centroid connectors caused very large volumes of trips to be assigned to links in the immediate vicinity of the connectors and thereby caused gross overloadings on certain links. Increasing the number of connectors distributes interzonal trips more evenly onto the network, a detail that assumes increasing importance with decreasing numbers of zones. Consequently, additional centroid connecting links were coded for access to each zone in the preparation of networks for systems 144 and 056.

## Analysis of Check-Line Crossings

Sixteen check lines ranging in volume from 21,500 to more than 500,000 vehicles/day were used in this analysis. The number of 2-way network links involved ranged from 3 for check lines 8 and 13 to 24 for check line 1, the major north-south screen line. The total for all check lines was 194 links.

The rms error, a measure of the average error on individual links, and the chi-square error, a cumulative measure of the error terms with emphasis on the large errors, were selected for the analysis.

$$\text{rms error} = \sqrt{(1/n) \sum_{i=i}^{n} (G_i - A_i)^2}$$

$$\text{chi-square error} = \sum_{i=i}^{n} [(G_i - A_i)^2]/G_i$$

where

$G_i$ = ground count volume for link i,
$A_i$ = assigned volume for link i, and
n = number of links.

Table 6 gives the assignment errors, measured on links crossing the 16 check lines, for each alternative zone system and for the 2 assignment methods. These comparisons show somewhat better results for the multiple-route assignment method than for the all-or-nothing method or the networks that were coded to allow an adequate range of alternative paths to be selected. The results illustrate that overall assignment errors at check lines increased relatively slowly as the number of zones was decreased. Systems 263 and 144, in which the original number of zones was reduced to less than one-half and one-fourth respectively, produced highly acceptable assignment results at all check lines. Chi-square errors for these 2 systems were 7 and 9 percent greater than for the lowest errors measured, which were for the multiple-route assignment to system 607. The error for system 144 was 6 percent greater than the lowest error, and the increase in error for system 263 was negligible. The rms errors measured for all 16 check-line crossings were nearly identical for systems 607 and 263, and the corresponding chi-square errors increased between 7 and 10 percent. This indicates that errors for some individual links were increased by the coarser zoning but that the average error remained unchanged.

Table 5. Frequency of 1-way links by volume for intrazonal trips assigned to system 607 network.

| Link-Volume Range | System 263 | System 144 | System 136 | System 056 | System 040 |
|---|---|---|---|---|---|
| 0 | 3,514 | 2,371 | 2,242 | 1,379 | 1,038 |
| 1-1,000 | 1,408 | 2,529 | 2,546 | 3,207 | 3,059 |
| 1,001-2,000 | 14 | 36 | 142 | 310 | 683 |
| 2,001-3,000 | 0 | 0 | 6 | 32 | 134 |
| 3,001-4,000 | 0 | 0 | 0 | 6 | 20 |
| 4,001-5,000 | 0 | 0 | 0 | 2 | 2 |
| Total | 4,936 | 4,936 | 4,936 | 4,936 | 4,936 |

Table 6. rms and chi-square assignment errors for links crossing 16 check lines.

| | Multiple-Route Assignment | | All-or-Nothing Assignment | |
|---|---|---|---|---|
| System | rms Error | Chi-Square Error | rms Error | Chi-Square Error |
| 607 | 7,022 | 591,928 | 7,596 | 648,321 |
| 263 | 7,047 | 635,564 | 7,494 | 714,428 |
| 144 | 7,454 | 647,452 | 8,940 | 850,789 |
| 136 | 8,722 | 800,039 | 8,635 | 723,685 |
| 056 | 9,618 | 1,189,126 | 10,553 | 1,327,603 |
| 040 | 12,510 | 2,105,617 | 12,255 | 1,895,987 |

Table 7. Vehicle-miles and vehicle-hours measured by 2 assignment methods.

| | Multiple-Route Assignment | | All-or-Nothing Assignment | |
|---|---|---|---|---|
| System | Vehicle-Miles | Vehicle-Hours | Vehicle-Miles | Vehicle-Hours |
| 607 | 9,145,191 | 360,992 | 8,934,996 | 351,487 |
| 263 | 9,127,628 | 361,396 | 8,912,493 | 351,564 |
| 144 | 8,710,338 | 343,250 | 8,460,635 | 330,922 |
| 136 | 8,965,009 | 357,042 | 8,765,627 | 348,187 |
| 056 | 8,532,841 | 329,620 | 8,313,325 | 327,089 |
| 040 | 8,895,391 | 352,889 | 8,701,668 | 342,589 |

Note: Travel on major arterial and collector roads only, i.e., excluding centroid connectors.

Table 8. rms errors for district comparisons by multiple-route assignment.

| | rms Error | | Coefficient of Variation[a] | |
|---|---|---|---|---|
| System | Vehicle-Miles | Vehicle-Hours | Vehicle-Miles | Vehicle-Hours |
| 263 | 9,826 | 411 | 6.0 | 6.4 |
| 144 | 16,244 | 637 | 10.0 | 9.9 |
| 136 | 15,818 | 778 | 9.7 | 12.1 |
| 056 | 22,160 | 879 | 13.6 | 13.6 |
| 040 | 38,307 | 1,594 | 23.5 | 24.6 |

[a] rms error expressed as the percentage of the mean vehicle-miles (163,307) and the mean vehicle-hours (6,446) for the system 607 multiple-route assignment.

Table 9. Cumulative difference by district of vehicle-miles by multiple-route assignment for system 607.

| Percentage Difference Range | System 263 | System 144 | System 136 | System 056 | System 040 |
|---|---|---|---|---|---|
| ± 0.00- 2.49 | 19 | 11 | 14 | 12 | 7 |
| ± 2.50- 4.99 | 37 | 24 | 23 | 21 | 12 |
| ± 5.00- 7.49 | 44 | 31 | 28 | 26 | 20 |
| ± 7.50- 9.99 | 51 | 40 | 37 | 35 | 22 |
| ±10.00-12.49 | 54 | 43 | 43 | 38 | 25 |
| ±12.50-14.99 | 54 | 48 | 47 | 41 | 32 |
| ±15.00-19.99 | 55 | 50 | 50 | 48 | 35 |
| ±20.00-24.99 | 56 | 54 | 53 | 48 | 41 |
| ±25.00-29.99 | 56 | 55 | 53 | 52 | 44 |
| ±30.00-34.99 | 56 | 55 | 56 | 54 | 49 |
| 35.00-39.99 | 56 | 55 | 56 | 54 | 54 |
| 40.00 and more | 56 | 56 | 56 | 56 | 56 |

## Analysis of Total Vehicle Travel

From the analysis of intrazonal trips, it would be expected that reductions in the number of zones would be accompanied by a reduction in the assigned vehicle-miles and vehicle-hours of travel. Table 7 gives these travel measures for each alternative zone system for each of the assignment methods.

The reduction in vehicle-miles for system 263 from those for system 607 was less than 0.2 percent; the vehicle-hours showed a small increase. The largest decrease in vehicle-miles, registered for system 056, was almost 7 percent of the total travel mileage for system 607. The consistently higher amounts of travel for the multiple-route assignments would be expected because of the selection of alternative paths, which would be longer than the minimum paths.

The loss of vehicle travel on the network generally was less than the travel lost in intrazonal trips for the networks that did not have sufficient centroid connectors. Systems 056 and 144, for which additional connectors were coded, had travel losses only slightly larger than losses due to intrazonal trips. However, even for system 056, which had less than one-tenth original number of zones, the loss in vehicle-miles and vehicle-hours of assigned traffic was only 7 percent of the system 607 travel. For many aspects of transportation planning, errors of such small magnitude would be acceptable.

Further analysis of the assignments was concerned primarily with identifying the range of assignment errors in sections of the metropolitan area. System 056 was used as a basis for this analysis, and each link on the arterial and collector road system was identified by the district in which it was located. Vehicle-miles and vehicle-hours of travel from the multiple-route assignments for each test system were summarized, by each of the 56 districts, and compared with the travel summaries from the multiple-route assignment for system 607. The resulting rms errors are given in Table 8.

Table 9 gives the cumulative frequency of districts by percentage difference of vehicle-miles for the alternative zoning system. Vehicle-miles for system 263, for instance, differed from those of system 607 by 10 percent or more in only 5 districts. In only 2 of these 5 districts was the difference more than 12 percent. Thus, in 95 percent of the districts, assigned travel for system 263 would be in error by no more than 12 percent. For systems 144 and 136, however, an error larger than 12 percent occurs in 13 districts, or 23 percent of all districts.

A typical spatial distribution of percentage differences in vehicle-miles of travel by district is shown in Figure 2. Visual inspections of such distributions for all systems indicated that the spatial pattern of errors did not seem to be systematic from one test system to the next. Only 6 districts (2, 8, 9, 30, 41, and 46) were found to have an error greater than 5 pecent in all test systems. District 33 was the only district that had less than 5 percent error in each test plan.

## Comparisons of Assignments by Link Volumes

Analyses were also made of frequency distribution of link volumes. Of particular interest was the number of links that were assigned either no volumes or very low volumes. The number of such links would be expected to increase as the number of zones decreased. Analysis of the frequency tabulations indicated that with the multiple-path assignment fewer links were unused. In fact, the number of links with 0 volumes was generally half that for a minimum time path assignment. Because only the major arterial and collector roads were represented by the network, the multiple-path assignment was more realistic in this aspect.

Figure 3 shows that a consistent relation existed among the number of low-volume links (0 to 2,000) the number of zones used, and the assignment technique applied.

Links with excessively high volumes could also constitute a problem in zone aggregation. However, most of the extremely high-volume links were found to be located immediately in the vicinity of centroid connections. With the limitation of the maximum number of trip ends and the provision of adequate alternative connections to centroids, as used for systems 056 and 144, these extremes did not occur.

Figure 2. Differences in vehicle-miles by multiple-route assignment for systems 263 and 607.

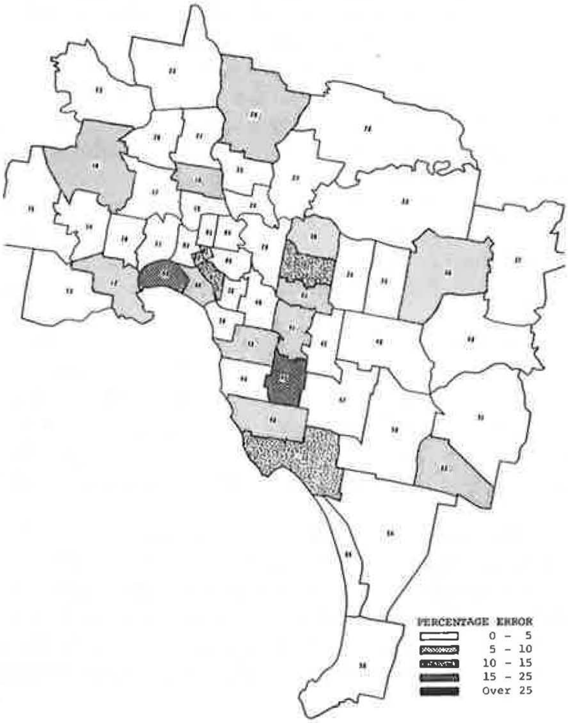
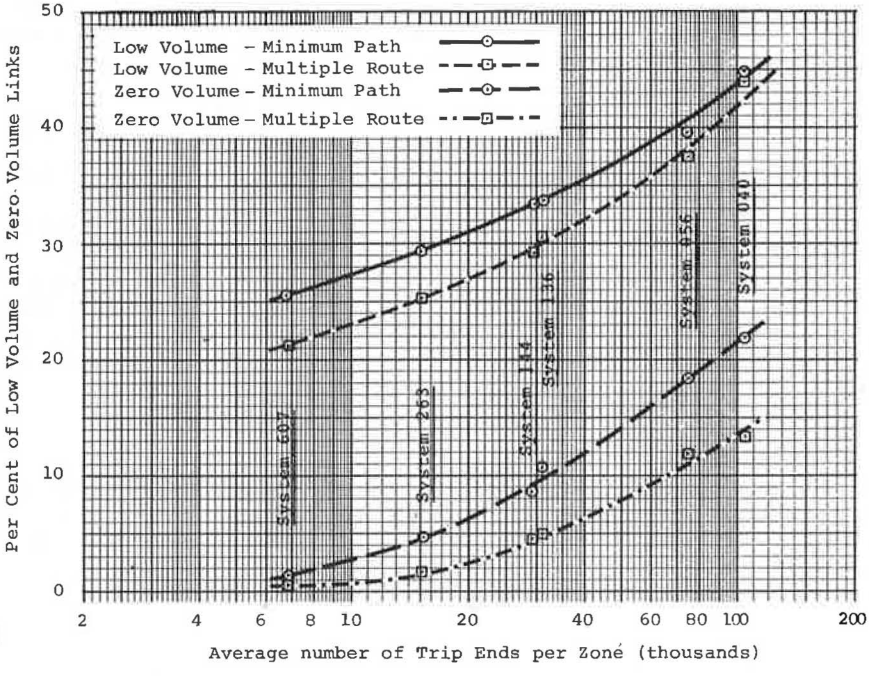


Figure 3. Low-volume lines and 0-volume lines for 2 assignment methods related to average number of trip ends per zone.



## ASSIGNMENT TEST FINDINGS

The investigation established measures of traffic assignment errors resulting from tests of widely varying zone plans. Also analyzed were the percentage of intrazonal trips and the corresponding magnitude of travel lost in zone aggregation.

The amount of travel lost because of intrazonal trips was relatively small, even though these trips may constitute a sizable percentage of total trips. Intrazonal trips lost ranged from 17.0 percent for system 263 to 38.6 percent for system 040. However, these trips accounted for only 1.2 and 8.9 percent respectively of assigned vehicle-miles of travel. Such losses could easily be tolerated for many planning purposes, especially because the study found that these trips are not concentrated to any significant degree.

Comparisons of assigned volumes with traffic counts at 16 check lines indicated that the number of zones could be reduced to less than half of the original number before increases in rms errors occurred. The multiple-route assignment produced lower errors than the all-or-nothing assignment.

Within sections of metropolitan Melbourne, the comparison of alternative assignments could be made only against the system 607 multiple-route assignment that, of course, was affected by some errors of its own. rms errors for 56 districts for multiple-route assignment to systems 263, 144, and 136 were within 10 percent of the average vehicle-miles and 12 percent of the average vehicle-hours for system 607. All-or-nothing assignment increased these errors by between 1 and 2 percent for vehicle-miles and up to 3 percent for vehicle-hours.

The analyses undertaken in this study indicated that the number of zones commonly selected for metropolitan transportation studies may be reduced to a third or even a fourth and still produce traffic assignments with adequate reliability for many planning purposes. It was further shown that additional traffic assignment errors can be minimized by the use of multiple-route assignment, the provision of adequate centroid connections, and reasonable limitations on the maximum number of trip ends concentrated within any one analysis zone.

## ANALYSIS OF TRIPS BY PURPOSE

In the transportation planning process, trips are generally categorized by a number of different purposes, and trips made by different vehicles, such as passenger cars, trucks, and taxis are usually treated separately. There are valid reasons for this separation, including differences in trip length, peak-hour concentration, and spatial distribution. However, each additional category increases the cost of data preparation and computer processing. Thus, substantial economies would result if categories could be combined for the purpose of trip distribution.

The study investigated the effect of reducing the number of purposes normally used in a transportation study and the effect of zone aggregation on trip distributions. A 4-purpose model and a 1-purpose trip distribution model were considered, each being calibrated for 3 different zone plans: systems 263, 144, and 056.

The 1-purpose model was calibrated against the all-vehicle trip matrix used for the assignment test phase of the study. The 4-purpose model consisted of 3 categories of automobile driver trips (non-home-based, home-based work, and home-based other) and 1 category of commercial vehicle trips. Home-based trips were arranged so that trip production was always from the same zone as the home of the driver. Origins and destinations of non-home-based and commercial vehicle trips were assumed to correspond to production and attraction zones respectively.

### Trip Length Distributions

Trips of different purposes and vehicle types are generally found to have significant variations in trip length characteristics. Average trip lengths for the categories of trips used in the study are given in Table 10. Average trip lengths were affected to some degree by reductions in the number of zones because of different locations of zone centroids and changes in the proportion of intrazonal trips.

### Stratification of Trips by Area

Early in the calibration process it was found that, despite excellent overall correspondence between observed and estimated trip-length frequency distributions, large differences in trip-length characteristics existed for trips associated with the CBD and with external stations. Accordingly, the trip matrices were partitioned for separate analyses of each of these 2 classes of trips and for all other trips.

It was found that the percentage of CBD trips was highest (15.4 percent) for non-home-based trips and lowest for home-based other trips (4.9 percent). For external trips, the order was reversed with 5.6 percent for home-based other trips and 2.3 percent for non-home-based trips. For all trips, the distribution included 9.1 percent CBD trips and 4.0 percent external trips. Of all CBD trips, 37 percent were made by commercial vehicles.

Average trip lengths for trips of the selected spatial classes are given in Table 11. For all categories of trips, CBD and external trips were substantially longer than internal non-CBD trips. Thus, although these 2 trip classes constituted only a small percentage of all trips, they accounted for a substantially larger portion of the total vehicle-hours of travel, ranging from 17 percent for home-based work trips to 25 percent for non-home-based and commercial vehicle trips. If all trips are processed in 1 group, the trip distribution does not adequately reflect the length and special orientation of these trips. However, with the calibration of separate distribution functions for each of the 3 spatial classes, as was done in the study, a satisfactory trip distribution was achieved.

### Intrazonal Trips

The number of intrazonal trips increased substantially as the number of zones was reduced. Figure 4 shows the variation in the percentage of intrazonal trips of different trip categories plotted against average trip densities as obtained from the analyses of systems 263, 144, and 056. The proportion of intrazonal trips is best for home-based work trips, ranging from 3.3 percent for system 607 to 10.3 percent for system 056. Home-based other trips and commercial vehicle trips have the largest proportion of intrazonal trips, ranging from 13.3 and 14.0 percent to 30.5 and 26.1 percent respectively.

## TRIP DISTRIBUTION MODEL CALIBRATIONS

Trip distribution models, using the 3 area stratifications, were calibrated for systems 263, 144, and 056 for 5 categories of trip. Four calibration cycles were applied in each case to determine the proper impedance function. No particular difficulties were experienced with the calibration of any of the distribution models. The average estimated trip length for each completed calibration differed from the observed trip length by no more than 0.1 min, the largest discrepancy between values of the cumulative trip-length frequencies being approximately 1 percent.

The differences between the impedance functions for trips associated with the spatial classes are shown in Figure 5 for the all-vehicle category and system 144. For long trips, impedance to travel tends to be greater for internal trips than for CBD or external trips. This same relation was observed for each of the categories considered in the study.

Variations among impedance functions for each of the 3 test systems are shown in Figure 6 for the all-vehicle category of trips. The curves were markedly similar, especially for the middle range of travel times into which most of the trips fall: Fewer than 2 percent of the trips were longer than 50 min, the value beyond which the curves diverge. At the other extreme, the variation among impedance values for the very short trips would be expected because of the differing numbers of intrazonal trips. However, for most of the range, the curves followed one another closely and demonstrated that the impedance function described trip-maker characteristics that, of course, were independent, for this range, of the number of zones into which the study area was divided.

Table 10. Average trip length in min by category.

| Category | System 263 | System 144 | System 056 |
|---|---|---|---|
| Automobile drivers | | | |
| Non-home-based | 15.4 | 14.9 | 14.6 |
| Home-based, work | 19.6 | 19.0 | 19.0 |
| Home-based, other | 13.5 | 13.0 | 13.4 |
| Commercial vehicles | 15.0 | 14.7 | 14.4 |
| Total | 15.8 | 15.4 | 15.4 |

Table 11. Average trip length in min by category and spatial class for system 263.

| Category | CBD | Internal | External | Total |
|---|---|---|---|---|
| Automobile drivers | | | | |
| Non-home-based | 21.2 | 14.0 | 24.9 | 14.3 |
| Home-based, work | 29.3 | 18.5 | 23.9 | 19.6 |
| Home-based, other | 29.5 | 11.8 | 27.1 | 13.5 |
| Commerical vehicles | 18.7 | 14.0 | 26.8 | 15.0 |
| Total | 23.4 | 14.5 | 26.1 | 15.8 |

Figure 4. Intrazonal trips by category related to average number of trip ends per zone.

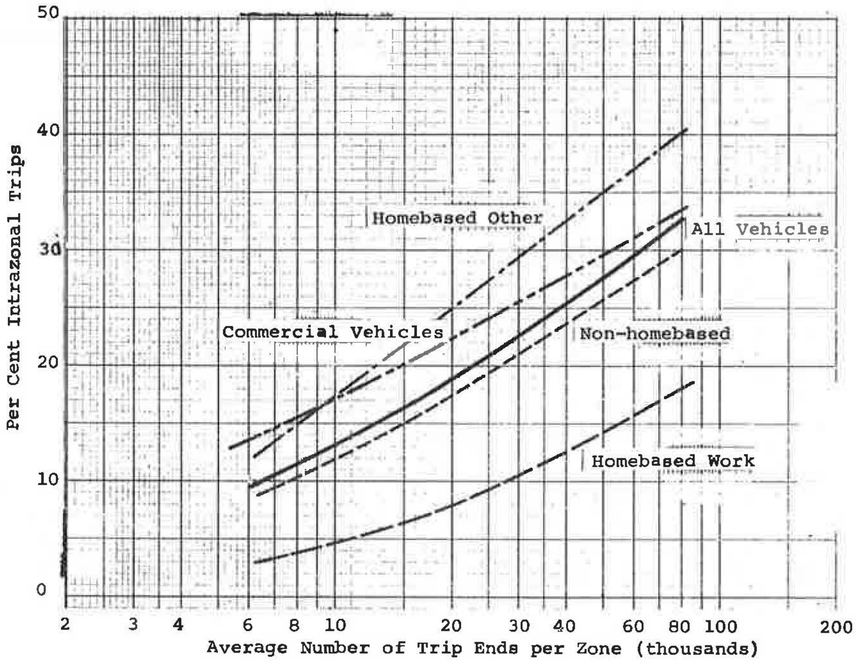


Figure 5. Impedance functions by spatial class for all vehicles and system 144.

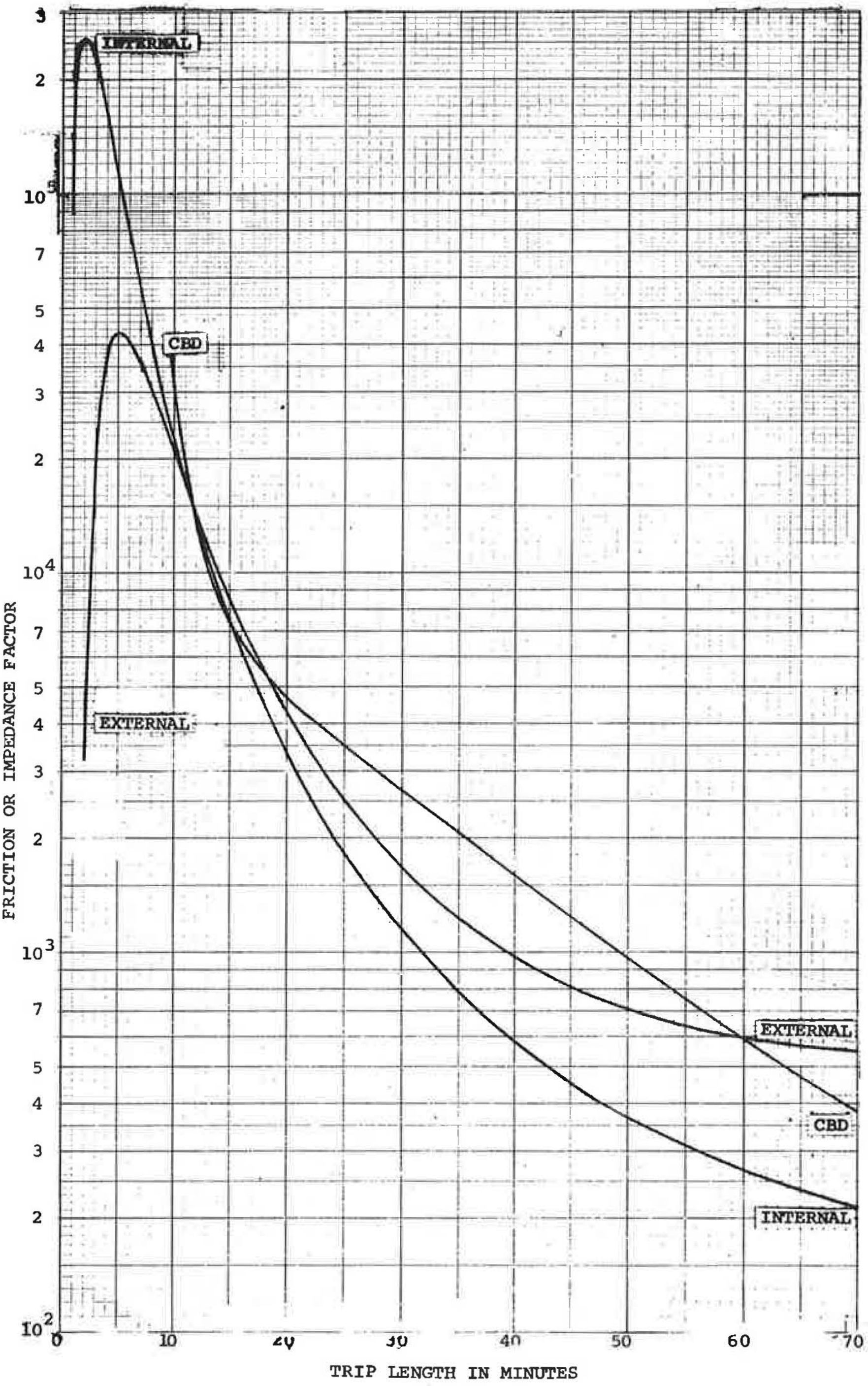
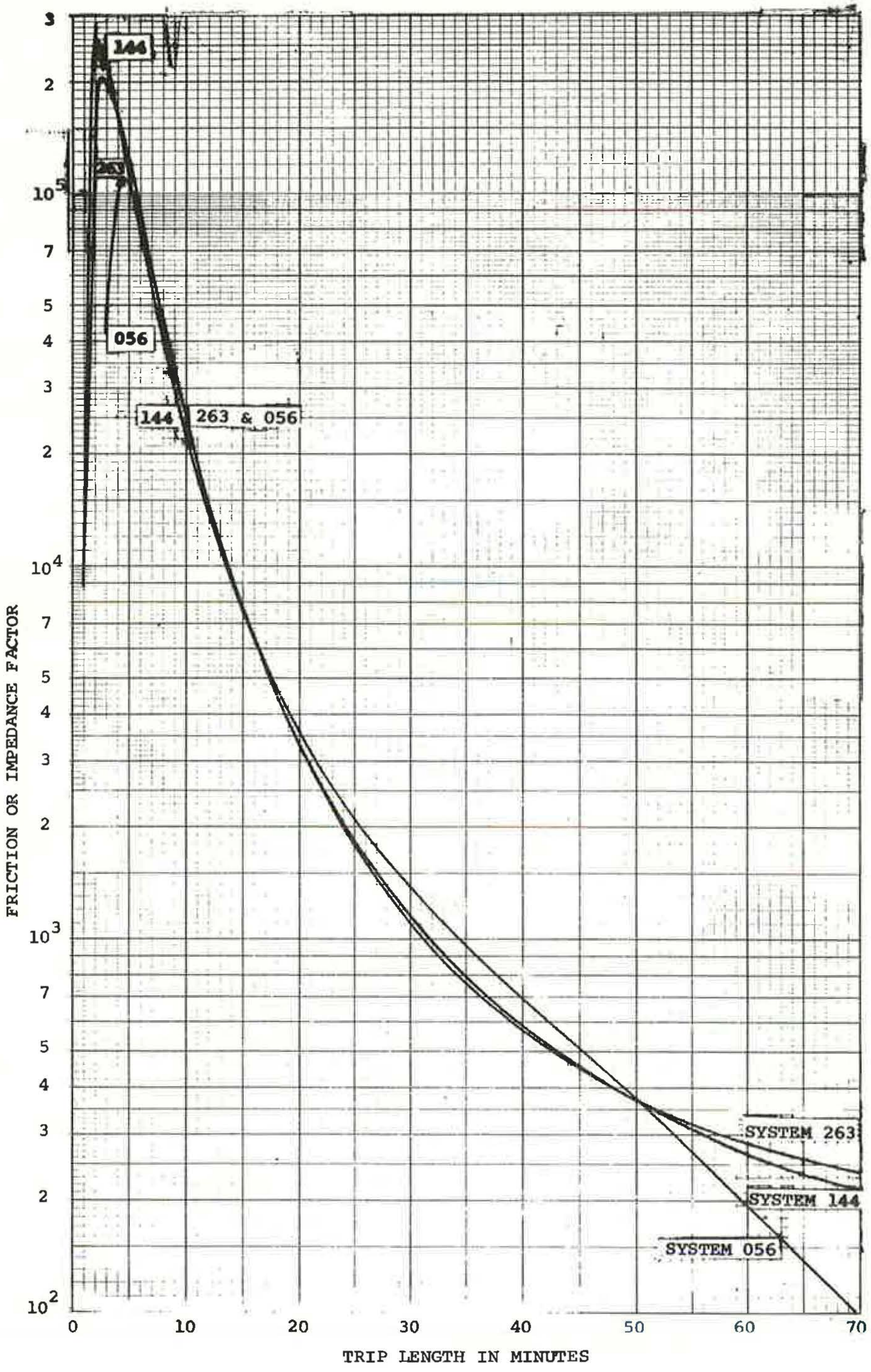


Figure 6. Impedance functions by system for all vehicles and internal trips.



Of the 3 impedance functions shown in Figure 6, the curves for systems 144 and 263 showed the most striking resemblance. Although the system 056 curve is similar, it seems that the drastic reduction in number of zones caused some loss of sensitivity. This tends to suggest that system 056 partitioned the study area into too few zones.

## ANALYSIS OF TRIP DISTRIBUTION ASSIGNMENTS

The statistical evaluation and comparison of the 1-purpose and 4-purpose distribution models for the 3 test systems were carried out in the same way as the investigation of the effects of zone aggregation on assignment. Two assignments were prepared for each of the 3 zone systems: one with the trip matrix from the 1-purpose model and one with the all-vehicle trip matrix resulting from the sum of the 4-purpose trip tables. All assignments were made by using the multiple-route technique. The following analyses were made:

1. Two-way link volumes were compared with traffic counts for the 16 check lines;
2. Vehicle-miles and vehicle-hours of travel were accumulated for 56 districts and compared with the basic results from the system 607 multiple-route assignment of the O-D survey trip matrix; and
3. The frequencies of links by volume ranges were compared.

The results obtained for both the 1-purpose and the 4-purpose trip distributions were compared with the corresponding zone plan assignments of the original O-D survey trip matrix. This was necessary to isolate the errors of the trip distribution process from those inherently associated with the zone plan and the O-D survey data used for calibration.

### Check-Line Comparison

rms errors and chi-square errors resulting from the 1-purpose and the 4-purpose trip distribution assignments are given for each test plan in Table 12. The results of both trip distribution assignments showed very close agreement with the O-D assignment for all zone systems tested. Both rms and chi-square errors were only slightly smaller for the 4-purpose trip distribution model than for the 1-purpose model. Increases in errors relative to the corresponding O-D assignment error decreased with reductions in the number of zones.

The check-line comparison indicated that reductions in the number of zones tended to reduce errors resulting from the trip distribution process taken alone. Furthermore, the elimination of separate-purpose and vehicle-type categories did not significantly affect the assignment results at any level of zone aggregation.

### District Comparison

The reliability of assigned travel throughout the network was assessed by accumulating traffic volumes from the assignments of 1-purpose and 4-purpose trip distributions for each of the 56 districts and by comparing them with the volumes from the multiple-route assignment for system 607. Table 13 gives the total vehicle-miles and vehicle-hours for the 3 test systems. Again, only marginal differences occurred between the 1-purpose model and the 4-purpose model. Both models produced total travel estimates within 3 percent of the estimates obtained from the assignment of the O-D trip matrix. Table 14 gives the comparisons for rms errors of vehicle-miles and vehicle-hours respectively. The errors were greater when comparison was made by district. Table 15 gives the cumulative frequency of districts by percentage difference of vehicle-miles. These data suggest that the 4-purpose distribution provided more added accuracy than was indicated by the check-line comparison.

### Link Volume Distribution

The analysis of individual link volumes for 1-purpose and 4-purpose distributions indicated only small differences for most volume ranges. Trip distribution assignments produced fewer low-volume links (0 to 2,000 volume range) than the O-D survey assign-

**Table 12. rms and chi-square assignment errors for links crossing 16 check lines.**

| System | O-D Survey Data<br>rms Error | <br>Chi-Square Error | 4-Purpose Distribution<br>rms Error | <br>Chi-Square Error | 1-Purpose Distribution<br>rms Error | <br>Chi-Square Error |
|---|---|---|---|---|---|---|
| 263 | 7,047 | 635,564 | 7,631<br>(8.3) | 774,738<br>(21.9) | 7,780<br>(10.4) | 785,465<br>(23.5) |
| 144 | 7,454 | 647,452 | 7,896<br>(5.9) | 741,073<br>(14.5) | 7,967<br>(6.9) | 748,603<br>(15.6) |
| 056 | 9,618 | 1,189,126 | 9,801<br>(1.9) | 1,228,486<br>(3.3) | 9,983<br>(3.8) | 1,263,340<br>(6.2) |

Note: Figures in parentheses indicate percentage increase in errors over O-D assignment errors.

**Table 13. Vehicle-miles and vehicle-hours by distribution assignment for 3 test systems.**

| | Vehicle-Miles (thousands) | | | Vehicle-Hours (thousands) | | |
|---|---|---|---|---|---|---|
| System | O-D | 4-Purpose | 1-Purpose | O-D | 4-Purpose | 1-Purpose |
| 263 | 9,128 | 9,357 | 9,362 | 361 | 367 | 365 |
| 144 | 8,710 | 8,955 | 8,896 | 343 | 349 | 346 |
| 056 | 8,533 | 8,787 | 8,745 | 330 | 345 | 342 |

**Table 14. rms errors for district comparison of vehicle-miles and vehicle-hours by distribution assignment for 3 test systems.**

| | rms Error | | | Coefficient of Variation | | |
|---|---|---|---|---|---|---|
| System | O-D | 4-Purpose | 1-Purpose | O-D | 4-Purpose | 1-Purpose |
| Vehicle-Miles | | | | | | |
| 263 | 9,826 | 18,141 | 22,179 | 6.0 | 11.1 | 13.6 |
| 144 | 16,244 | 19,348 | 22,412 | 10.0 | 11.8 | 13.7 |
| 056 | 22,160 | 27,551 | 31,601 | 13.6 | 16.9 | 19.4 |
| Vehicle-Hours | | | | | | |
| 263 | 411 | 692 | 839 | 6.4 | 10.8 | 13.0 |
| 144 | 637 | 779 | 903 | 9.9 | 12.1 | 14.0 |
| 056 | 879 | 1,021 | 1,181 | 13.6 | 15.8 | 18.3 |

**Table 15. Cumulative difference by district of vehicle-miles by distribution assignment for 3 test systems.**

| Percentage Difference Range | System 263<br>1-Purpose | <br>4-Purpose | System 144<br>1-Purpose | <br>4-Purpose | System 056<br>1-Purpose | <br>4-Purpose |
|---|---|---|---|---|---|---|
| ± 0.00- 2.49 | 11 | 12 | 9 | 11 | 5 | 8 |
| ± 2.50- 4.99 | 19 | 23 | 15 | 21 | 14 | 17 |
| ± 5.00- 7.49 | 29 | 31 | 26 | 28 | 20 | 22 |
| ± 7.50- 9.99 | 37 | 39 | 33 | 33 | 26 | 29 |
| ±10.00-12.49 | 39 | 46 | 35 | 38 | 32 | 37 |
| ±12.50-14.99 | 43 | 49 | 40 | 45 | 36 | 39 |
| ±15.00-19.99 | 50 | 53 | 47 | 50 | 44 | 46 |
| ±20.00-24.99 | 53 | 55 | 52 | 53 | 47 | 49 |
| ±25.00-29.99 | 54 | 55 | 53 | 54 | 50 | 50 |
| ±30.00-34.99 | 55 | 55 | 54 | 54 | 51 | 51 |
| ±35.00-39.99 | 55 | 56 | 54 | 54 | 52 | 53 |
| ±40.00 and more | 56 | 56 | 56 | 56 | 56 | 56 |

ment. This was to be expected because the trip distribution process generated trips for many cells of the matrix where the trip frequency is too small to get complete coverage in an O-D sample survey. There were also improvements relative to the O-D assignment for links with volumes of more than 30,000.

Figures 7 and 8 show assignments resulting from the 1-purpose and the 4-purpose distributions for systems 263 and 144. The line-printer graphs shown in these figures illustrate the high degree of correspondence between the 2 distributions for all link-volume ranges.

## TRIP DISTRIBUTION TEST FINDINGS

The study established that trip distribution models can readily be calibrated for analysis systems with widely varying numbers of zones. One-purpose and 4-purpose models were developed that reproduced the observed trip patterns within acceptable limits. It was found that the friction or impedance functions, which reflected the bahavior of tripmakers with regard to travel time, were not affected by zone aggregation, except for the intervals that applied to intrazonal trips. Even so, these trips did not cause any particular problem in the calibration process, provided that the intrazonal travel times for large zones were carefully determined. Even a small change in intrazonal times (e.g., 1 min) can have a significant effect on the number of trips leaving and entering a zone when 50,000 or more trip ends need to be distributed.

The investigation evaluated assignment results from 1-purpose and 4-purpose trip distributions. It found that the rms errors resulting from both trip distributions for links crossing 16 check lines were only marginally larger than the errors from the assignment of O-D survey data. The errors ranged from 2 to 10 percent, the smallest errors being associated with the least detailed zone plan and the largest errors with the most detailed zone plan. The errors of 1-purpose distribution assignments were consistently larger than those of 4-purpose assignments for each test system; however, the increase in error was much less than the increase in error over the O-D assignments.

The analysis of vehicle-miles and vehicle-hours traveled in 56 districts indicated similar results although, with the exception of system 263, the increase in errors from the 4-purpose distribution to the 1-purpose distribution was similar to the increase in assignment errors between the O-D survey and the 4-purpose trip distribution. Close analysis indicated, however, that most large errors were due to the effects of the zone plan rather than the trip distribution process.

In summary, the findings indicated that reductions in the number of zones did not appreciably diminish the accuracy of trip distributions. Further, 1-purpose trip distributions were only very slightly less accurate than separate distributions of several trip purposes. This finding is of major importance because of the substantial reductions in computer time and analysis effort that would result from the use of a 1-purpose distribution model.

## CONCLUSIONS

The study has determined the levels of accuracy in traffic assignments and trip distributions that may be expected from the use of fewer analysis zones than normally used in conventional transportation studies.

Assignment tests with a total vehicle O-D survey trip matrix have identified the level of accuracy in traffic assignments for 5 widely varying zone plans, thus providing evidence to transport planners for the selection of zone numbers according to the objectives of their studies. For major route-planning purposes, adequate traffic assignments should be obtained from zone plans with an average of 10,000 to 15,000 trip ends per zone. For predictions of traffic growth within transportation corridors or segments of urban areas, zone plans with as many as 30,000 trip ends per zone should yield traffic assignments with sufficient accuracy.

The comparison of O-D traffic assignments with trip distribution output matrices indicated that the accuracy of the trip distribution process was not affected significantly by reductions in the number of analysis zones. Thus, decisions regarding the design

Figure 7. Comparison of 4-purpose and 1-purpose distribution assignments for system 263.

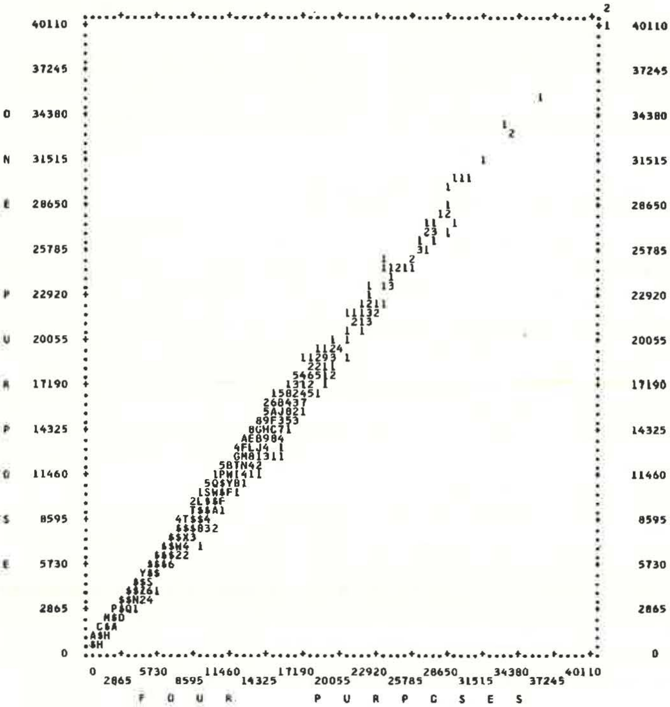
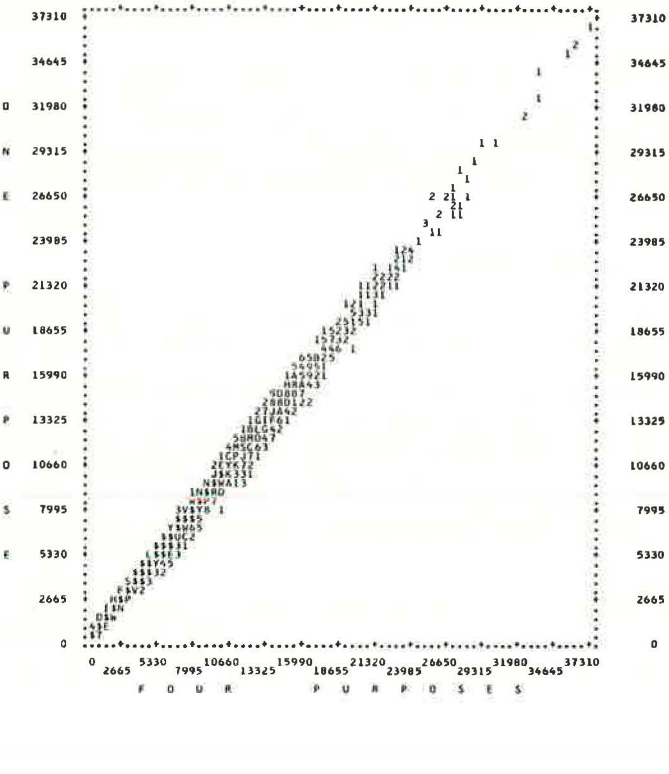


Figure 8. Comparison of 4-purpose and 1-purpose distribution assignments for system 144.



of zone systems should be based primarily on the level of acceptable accuracy for the traffic assignment phase alone. For the trip distribution phase of a study, the use of a 1-purpose trip distribution with partition of the matrix offers significant savings in computer processing and leads to little reduction in accuracy compared to the usual distribution of several trip purposes.

The data on traffic assignment errors presented in this study should serve as a guide for the selection of optimal zone size for transportation planning studies. The techniques developed are appropriate for testing the potential for aggregating the initial zone system of completed studies for use in continuing planning. Generally, zone aggregation offers significant reductions in the effort required to prepare input data and to analyze transportation study results. Particularly important savings may also be achieved in developing projections of land use activities for trip estimation. This could be welcomed by land planners, who prefer to work with larger zones than are normally used in transportation studies. Substantial savings can also be achieved in computer time for processing trip distributions and assignments.

We conclude from this study that for many aspects of transport planning, where accuracy at the level of individual arterial routes is not essential, standard traffic assignment and trip distribution methods can reliably be applied with substantially fewer zones and fewer trip purposes than used in conventional transportation studies.

In view of the potential savings resulting from the use of fewer zones, further research should be undertaken to investigate the effects of zone size on other aspects of the transportation planning process. For new or repeat studies, consideration should be given to the effect on the accuracy of trip-end estimations. Further work is also required to assess the effects with capacity-restraint assignments and with peak-hour assignments. Changes in the normal approach to assignment may prove feasible, so that individual route accuracy can be achieved while the advantages of large zones are retained. For example, intrazonal trips could be allocated uniformly to links within a zone as part of the assignment process. More fundamental innovations in traffic assignment may follow if it is appreciated that large numbers of zones are not necessarily basic to achieving acceptable levels of accuracy. This could open up new horizons for testing alternatives, for stage development planning, for economic evaluation, and for properly integrating road and public transport planning, if the present transport planning process is made less cumbersome, less time-consuming, and less costly.