Computational Issues in Increasing the Spatial Precision of Traffic Assignments

Alan J. Horowitz, Professor, Center for Urban Transportation Studies, University of Wisconsin – Milwaukee, PO Box 784, Milwaukee, WI 53201

Abstract. This paper demonstrates the practical feasibility of a method of traffic assignment, dubbed area spread assignment, that incorporates information on the spatial relationships between nodes, links and zone boundaries. Tests of area spread assignment were performed on networks from Fredericton, New Brunswick and Racine, Wisconsin. To eliminate the effect of errors from other model steps in the tests, comparisons were made to a “detailed” network of Fredericton that contained all streets in the city and extremely small zones. The tests indicated that there is a substantial difference between area spread assignment and a traditional assignment using centroid connectors. Area spread assignment did a better job at replicating volumes on the detailed network, although computation times were much longer.

INTRODUCTION

A constant concern among those performing traffic forecasts is the level of spatial precision of the models. This concern usually revolves around such issues as the size and placement of traffic analysis zones (TAZs). The selection of a set of TAZs is always a compromise between data preparation costs, computation costs and model accuracy. Spurred by advances in computer speed and geographic information systems (GIS), there has been a recent trend toward greater spatial precision in models. For example, FHWA’s TRANSIMS model has zones as small as a single dwelling unit.

Even with a standard set of zones, it is unclear whether a typical model is using all readily available geographic information. In the assignment step, paths are built and trips are loaded between centroids without any regard for the sizes of zones, shapes of zones, trip density characteristics across a zone or locations of streets and intersections within zones. Such information should be readily available through GIS technology.

While those planners coding networks try to locate centroids within zones to maximize model accuracy, the process remains hit-or-miss at best. Furthermore, centroid connectors, highly artificial network elements, are used to represent the mass of local streets and collectors that tie true trip ends to the nearest arterial street. The actual paths of access to the arterial system are not considered.

Assignment errors due to lack of spatial precision are especially problematic in small urban areas, rural parts of urban networks and across statewide networks. In these instances, many zones are large with the true trip origins or destinations being considerably distant from their zone’s centroid or from the point where the centroid connectors attach to the arterial network. A recent study of actual trip making (1) found that even small errors (< ¼ mile) in the placement of a trip end can have an affect on the model’s ability to replicated the chosen path of travel.
This paper investigates the improvements in assignment precision obtainable by creating subzones of TAZs strictly for the purpose of traffic assignment.

STRATEGIES FOR INCREASING SPATIAL PRECISION

There are four straightforward strategies for introducing greater spatial precision in traffic assignments.

**Smaller Traffic Analysis Zones.** The most obvious way to increase spatial precision in a traffic assignment is to increase the number of TAZs. Centroid connectors are still required, although many of them would be shorter and less arbitrary and therefore have less influence on the traffic assignment. The number of intrazonal trips decrease -- sometimes greatly, depending on the zone structure. Estimates of measures of effectiveness (MOEs) are more precise.

Smaller TAZs increase the computational effort for path building and for loading the network, roughly in proportion to the number of TAZs. Smaller TAZs also increase the amount of computational effort required for all other steps in the travel forecasting process. In addition, smaller TAZs potentially require more precision in data collection and in organizing data on the network, something that may not be warranted in low density areas. Networks with 5000 or more TAZs are being developed for Dallas and San Diego to increase spatial precision in those models.

**Microsimulation.** Microsimulation has gained credibility since the creation of TRANSIMS. In a TRANSIMS-like simulation, the spatial precision is at the level of a dwelling unit. Centroid connectors are not used and MOEs can potentially be calculated without biases from either centroid connectors or intrazonal trips. The amount of computation is unclear, but would be many times greater than the deterministic techniques discussed here.

**Subzoning around Nodes.** A way of introducing spatial precision in a traffic assignment without increasing the number of TAZs is to assign traffic to and from all (or nearly all) intersections in the network. Centroid connectors are not used, and most intrazonal trips can be assigned to the network. This author has had experience with this method in transit networks (2), and at least one commercial travel forecasting package (not associated with this author) has featured this method for highway assignment. Automatic subzoning, although not often used, is possible by observing the spatial relationships between intersections within a TAZ. Given that trips can only be loaded to the network at nodes, this method maximizes the use of network topology.

If subzoning is preformed automatically, network preparation costs are comparable to a traditional centroid-connector assignment. Data collection and preparation costs would be higher only if variations in the density of urban development are to be included. Computation times for path building and network loading increase in proportion to the ratio of intersections to zones. Automatic subzoning adds significantly to computation time, but all other model steps are unaffected.

**Subzoning around Links.** Subzoning around links is a variation of subzoning around nodes that maximizes the use of spatial information obtainable from networks. This type of subzoning
is similar to a method proposed for transit networks that is based on the concept of service area (2). Although it slightly increases the computational effort needed to develop the subzones around nodes, it does not add to the computation necessary to build paths or load trips. Subzoning around links recognizes that access to the network is made along links rather than at nodes, since driveways, local streets and small collectors always attach to streets in the network at midblock. The tests for this research use this method, and details are provided in the next section. This method will be referred to as “area spread” assignment.

DETAILS OF THE SUBZONING AROUND LINKS

Subzoning around links assumes that each link has a service area consisting of all land closest to the link. This assumption would be nearly exact for networks containing all local streets and collectors, but would be considerably less accurate for networks that contain only arterial streets. Behaviorally, travelers are assumed to access the arterial network somewhere along the link closest to their actual origin and leave the arterial network somewhere along the link closest to their destination. A major issue is the degree to which this assumption holds for typical arterial networks used for metropolitan planning.

Figure 1 illustrates the concept on a small TAZ like those in many urban networks. Solid lines are links, dots are nodes, and bold lines are TAZ boundaries. Dashed lines are boundaries of link service areas and dotted lines show how origins and destinations are split among the two link ends (nodes). This figure shows the service areas of all links connecting to Node A. Each link’s service area is seen to be a uniquely shaped polygon. For the most part, the dotted lines, showing how the link service area is split between the two ending nodes, are the perpendicular bisectors of links. The one exception is the dotted line near link 1. The dotted line extends just to the TAZ boundary, because one end of the link is outside the TAZ.

Figure 1. Illustration of Subzoning for One Intersection
Subzoning is conducted automatically for the tests performed here. To enable automatic subzoning, TAZs are drawn as polygons on top of the network, with each TAZ referenced to its corresponding centroid. A raster method is used for determining the size of subzones, with each square raster cell being equivalent in size to a single graphical pixel on the computer display. Raster methods are commonly used in GISs for analysis of complex areas. (3) The method proceeds through these steps for each raster cell.

a. Determine the list of TAZs to which the cell belongs. The majority of cells exist within only a single TAZ, but many cells occur on the border between two TAZs or at common vertices.
b. Apportion the raster cell’s area to each TAZ to which it belongs.
c. Determine the list of street links that are fully or partially contained within the cell’s TAZ.
d. For each full or partial raster cell compute the minimum airline distance to each street link. Ascertain the closest street link. Ignore links that have neither ending node within the zone.
e. If the link has both ending nodes in the zone, assign the raster cell to the closest ending node. Otherwise assign the raster cell to the one ending node in the zone.
f. Add the raster cell’s area to the node’s subzone area.

The computer program developed for this research also has the ability to eliminate nodes and links from consideration when allocating raster cells. For example, freeway links and interchange nodes do not have immediate access to land and should not be the origins or destinations of any trips. The computer program also has the ability to weight the area of nodes according to indicators of trip-end density, but this ability was not used in any of the tests presented here. An interesting implication of this algorithm is that the ends of each trip always occur within their respective TAZs.

During each all-or-nothing traffic assignment, trips are assigned between intersections rather than between centroids. Centroid-to-centroid trips are factored into intersection-to-intersection trips in proportion to the weighted area of the origin intersection times the weighted area of the destination intersection. Otherwise the assignment method is the same as more traditional traffic assignments.

The implications of this method for automatic subzoning for network coding are small and manageable. Links, nodes and TAZ boundaries must be drawn carefully to scale so that their geographic relationships can be correctly ascertained. Every TAZ must contain at least one valid intersection. Each external station must also be given a TAZ, although this TAZ can consist of only a single raster cell located exactly on top of the intersection node to receive the external stations trips. Although the subzoning method could conceivably use shape-point information for links, all links were assumed to be straight for this research. Centroid connectors, if present on the network, were ignored.
DESCRIPTIONS OF THE TEST NETWORKS

Two different test networks were used: Fredericton, New Brunswick and Racine, Wisconsin. These cities were large enough to provide a reasonable test for the traffic assignment method but small enough to be manageable. They were chosen because their networks were drawn with a great deal of precision relative to their TAZs and were developed to standards of the profession by people not associated with this research.

Fredericton Network

Fredericton has a population of about 79,000 people. The network with TAZ polygons is shown in Figure 2. The base case network contains 56 centroids, 12 external stations, 70 centroid connectors, 570 street links and 439 intersection nodes. Of these intersections, 47 were explicitly coded as signalized, one intersection was coded as an all-way stop, and 99 intersections were coded as some-way stops. Many of the links contained multiple shape points. The network was created for highway traffic forecasting purposes. The Fredericton network, as received, had already been calibrated to obtain good traffic volumes in the base case. To the extent possible, the calibration was removed, as it is likely that some of the calibration was performed to overcome deficiencies in the traffic assignment step. Thus, traffic forecasts in the tests presented here are worse than those obtained by the planners in Fredericton. Fredericton had been using parameters for most of the model steps derived from NCHRP Report #187. (4) These parameters were retained.

As received from Fredericton, the network did not contain TAZ boundaries. These were added by tracing a background graphic of the TAZs and roads. The background graphic was in vector form. The tracing had a precision of about two meters or one raster cell. Some of these TAZ were quite large, ranging in size between 0.06 and 19.5 square kilometers. The TAZs were irregular in shape, some of them having polygons with over 50 vertices. Adding the polygons to the network took approximately 20 person-hours. The urban area was subdivided into a little more than 50 million raster cells.

Fifty million raster cells are probably too many by a factor of 16 or more. The evaluation of this many raster cells for each simulation was time consuming, but this raster cell size was left as is because (1) the additional computation would not hurt the results, (2) a high degree of precision should be maintained for all tests and (3) raster cells would be smaller in dimension than the length of any link in the network.
Figure 2. Network and Zone Structure of Fredericton

For comparison purposes, a second “detailed” network was prepared. This network contained every street in Fredericton. Local streets and collectors were added by tracing the same background graphic as noted earlier. Speeds on the new streets were set to 15 km/h to assure that major street traffic would not cut through residential areas. The detailed network contained 1753 intersection nodes and 2142 street links. Spatial precision of the new nodes was also about two meters or one raster cell, although no attempt was made to match mild curves in these roads by adding shape points to links. The detailed network had about 4 times the number of possible origins and destinations as the base network.

Racine Network

The Racine network was needed to verify that the Fredericton network was sufficiently typical in its behavior. The network with TAZ polygons is shown in Figure 2. Racine an isolated community of roughly 81,000 people that is contained within the region served by the Southeastern Wisconsin Regional Planning Commission (SEWRPC). SEWRPC’s traffic network was judged too large for this research, so a subarea network of Racine was adopted for this study. This network was originally created to assist transit ridership forecasting and had not been calibrated at the street level for highway traffic forecasting. TAZs and major arterial streets were consistent with SEWRPC’s network. TAZ boundaries had been added to the network when it was originally drawn.
For the purposes of this research many new centroid connectors were added, most attaching to the arterial network at midblock. When completed, the network contained 83 centroids, 175 centroid connectors, 373 intersection nodes and 493 street links. The network had 6 external stations. Sixty-seven of the intersections were signalized explicitly on the network.

The network was originally drawn to a precision of about 10 feet, but raster cells were selected to be about 20 feet on a side. Unlike Fredericton, TAZs in Racine were highly regular in shape, most being squares one-half mile on a side. Raster cells aligned nicely with most TAZ boundaries. Maintaining precision of coding between TAZs and network links was quite simple, as the TAZs boundaries tended to be major arterials. All TAZs together contained slightly less than 2 million raster cells.

Demographic data for the Racine network was developed from the 1990 Census Transportation Planning Package. All relevant parameters for trip generation and automobile occupancy were taken from NCHRP Report #365. (5)

Obtaining Reference Trip Tables

One vehicle trip table was obtained for Racine and another one was created for Fredericton. Each base network was run through a traditional equilibrium assignment (i.e., using centroid connectors) for 100 iterations of the method of successive averages (MSA). (6) This method included feedback to trip distribution. Mode split was ignored. The two trip tables were then used in all subsequent tests.

OTHER TRAFFIC ASSIGNMENT ISSUES

Assignment Method

All tests loaded traffic with fixed-demand equilibrium assignment using MSA. MSA was required because of explicit traffic controls in the network. (7) Vine building was used to create
paths so that left turn restrictions could be correctly included. None of the networks had turn penalties.

**Delay Calculation**

As required by MSA, delays from congestion were estimated after each average of traffic assignments. Delays at signalized intersections were calculated with the operational analysis procedures from Chapter 9 of the 1997 HCM. Delays at some-way stops were calculated with procedures from Chapter 10 of the 1997 HCM. Delays at the lone all-way stop in Fredericton were calculated with an M/G/1 queuing model of a very similar design to the iterative procedure from the 1997 HCM.

Delays along uncontrolled road segments were calculated with the BPR travel-time/volume formula, with parameters adjusted to level of service (LOS) E definition of capacity as recommended in NCHRP Report #365. The volume to capacity ratio on two-lane roads included 40% of the traffic in the opposite direction to emulate the recommendations from Chapter 8 of the 1997 HCM.

The 24-hour assignments involved calculating an average 24-hour delay. This was accomplished by factoring the assigned volumes into individual hours, calculating the delay for each hour and taking the volume-weighted delay across all hours.

**Discussion**

When an area-spread assignment is run without centroid connectors, any information from them would be lost. In both Fredericton and Racine, the centroid connectors only provided the impedance corresponding to travel along the centroid connector at an intrazonal speed. Zonal access charges (e.g., parking) were not used in either network. The absence of the centroid connector’s impedance in the area-spread assignments did not unreasonably affect the tests is this paper because the trip table was determined with the centroid connectors included. However, a complete application of an area spread assignment would require that the zone-to-zone impedance be modified appropriately before the vehicle trip table is calculated. The absence of centroid connectors would also have implications for calculating MOEs such as vehicle miles (kilometers) traveled (VKT or VMT) or air pollution emissions.

Fredericton has several zones near the exterior of the network that are quite large and lightly developed. The assumption that trips are evenly distributed across these particular zones is probably weak. One of the reasons for including the Racine network in this research is to determine whether similar results are obtained in a network where the zones are of more uniform size.

The 24-hour assignments loaded all traffic at once. While this technique is similar to that used in many small urban areas, it is less accurate than had each hour been individually loaded. A considerable amount of link-level calibration would have been required to achieve good results when all trips were loaded at once.
COMPUTATIONAL TESTS

Comparisons of traditional and area-spread assignments are made more complicated because none of the networks were calibrated to match existing traffic counts. Comparisons to counts can still be made, but they will not necessarily reveal much about the validity of the techniques. Instead, the results from the “detailed” network in Fredericton were used as a basis of comparing the two techniques. Thus, there were three possible assignments: traditional; area-spread; and area-spread detailed. Table 1 shows summary statistics for each of the three assignment methods when run for the 5-6 pm hour in Fredericton for 100 MSA averages.

Table 1. Summary Statistics for Three Assignment Methods for PM Peak in Fredericton

<table>
<thead>
<tr>
<th>Method</th>
<th>Number of Arterial Link Directions</th>
<th>Arterial Link Directions with Zero Volumes</th>
<th>Average Arterial Link Volume</th>
<th>Percent Trips Not Assigned</th>
<th>VKT on all Streets</th>
<th>VKT on Centroid Connectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional Area</td>
<td>1006</td>
<td>93</td>
<td>406</td>
<td>2.84%</td>
<td>131177</td>
<td>9585</td>
</tr>
<tr>
<td>Area Spread Area</td>
<td>1006</td>
<td>4</td>
<td>423</td>
<td>0.78%</td>
<td>139678</td>
<td>0</td>
</tr>
<tr>
<td>Area Spread Detailed</td>
<td>1443</td>
<td>4</td>
<td>378</td>
<td>0.37%</td>
<td>142025</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 1 indicates that the differences between assignment methods are subtle. The traditional method had more than 9% of its link directions without any volumes, while the area spread assignment used almost every link direction. The area spread method failed to assign only 0.8% of the trips that were intra-subzone, but the traditional method failed to assign 2.8% of the trips that were intrazonal.

VKTs over the whole network were comparable. The total (both streets and centroid connectors) VKT from then traditional method came closest to the VKT from the detailed network, as expected. However, the difference between the two assignment methods was less than 1%. Average link volume from the area spread network was noticeably larger than from the traditional network. Note: the detailed network had more arterial links because of the many connection points needed for local streets; the total arterial mileage was the same.

The slight underestimate of VKT with the area spread assignment is likely due to two counterbalancing errors. First, the lack of traffic on local streets causes an underestimate of VKT. Second, an overestimate of VKT results from starting and ending trips at the closest node to the raster cell (via a link), not necessarily at the node that is on the shortest path.

Table 2 shows similar patterns for Racine. Area spread assignment used more links, had a greater percentage of trips assigned to the network, had a higher average assigned link volume and had a slightly lower total vehicle-miles-traveled (both streets and centroid connectors). The greater number of centroid connectors or the greater uniformity in zone shape in the Racine network did not seem to affect the comparison.
Table 2. Summary Statistics for Two Assignment Methods for PM Peak in Racine

<table>
<thead>
<tr>
<th>Method</th>
<th>Number of Arterial Link Directions</th>
<th>Arterial Link Directions with Zero Volumes</th>
<th>Average Arterial Link Volume</th>
<th>Percent Trips Not Assigned</th>
<th>VMT on all Streets</th>
<th>VMT on Centroid Connectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional</td>
<td>952</td>
<td>24</td>
<td>380</td>
<td>2.00%</td>
<td>80985</td>
<td>7759</td>
</tr>
<tr>
<td>Area Spread</td>
<td>952</td>
<td>4</td>
<td>400</td>
<td>0.50%</td>
<td>85703</td>
<td>0</td>
</tr>
</tbody>
</table>

Convergence Rates

Table 3 illustrates the degree of precision of the traffic assignments after a variety of MSA averages for Fredericton. Each assignment in this table is compared to an assignment with 100 averages. It is seen that the area spread method offers no advantages in root-mean square (RMS) error over the traditional method, despite the greater number of paths between zones in an area spread assignment.

Table 3. Assignment Precision as RMS Deviation (Vehicles) from a 100 Average Assignment

<table>
<thead>
<tr>
<th>Number of Averages</th>
<th>Traditional</th>
<th>Area Spread</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>454</td>
<td>471</td>
</tr>
<tr>
<td>5</td>
<td>316</td>
<td>325</td>
</tr>
<tr>
<td>10</td>
<td>48</td>
<td>44</td>
</tr>
</tbody>
</table>

Comparisons between Networks

Table 4 compares the results of each assignment method to each other assignment method after 100 MSA averages of the Fredericton networks. For Racine, the RMS difference between the two assignment methods was 102 vehicles.

Table 4. RMS Differences (Vehicles) on Arterial Links between Assignments

<table>
<thead>
<tr>
<th>Area Spread</th>
<th>Area Spread</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional</td>
<td>142</td>
</tr>
<tr>
<td>Area Spread</td>
<td>-</td>
</tr>
</tbody>
</table>

The Fredericton comparison is most interesting. It is seen that the difference between the two methods is huge, about one-third of the average link volume. Of the two assignment methods, area spread comes much closer to the results from the detailed network.

Comparisons to Traffic Volumes

Fredericton had traffic counts for 24 hours and for both direction of travel combined. Since the networks were deliberately not calibrated, good results were not expected. Table 5 lists how well each of the assignments did. There were 194 links with counts and 52 links with counts under 5000 vehicles. The mean absolute deviation from traffic was over 40% for all networks.
The area spread assignment did a little better in forecasting volumes on smaller-volume links. These results suggest that errors in matching these particular counts are probably less related to spatial inaccuracies in assignment than to errors in trip distribution, trip generation, traffic counts and link-level calibrations for these test networks.

<table>
<thead>
<tr>
<th>Assignment Method</th>
<th>All Links with Counts</th>
<th>All Links with Counts &lt; 5000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional</td>
<td>42.9</td>
<td>68.7</td>
</tr>
<tr>
<td>Area Spread</td>
<td>44.5</td>
<td>61.6</td>
</tr>
</tbody>
</table>

Computational Burden

As mentioned earlier, area spread assignment increases computation time at a rate slightly faster than the ratio of intersections to centroids, exclusive of the time necessary to create the subzones. Computation time also increases at a rate slightly faster than the number of links in the network. For example, the traditional assignment in Fredericton (with 6.5 intersections per centroid or external station) took 3 seconds for each MSA average on a 400Mhz Pentium II-class computer, while the area spread assignment took 23 seconds per average. The detailed assignment took about 8 minutes for each average.

The time necessary for subzoning is proportionally related to the number of raster cells and the number of links in the network. For Fredericton, it took approximately 20 minutes to accomplish the subzoning. For Racine, with a more reasonable raster cell size, the subzoning took only 26 seconds. Subzoning would require even more computation time if link shape were considered.

CONCLUSIONS

This paper demonstrates the practical feasibility of a method of traffic assignment that makes effective use of readily available information on the spatial relationships between nodes, links and zone boundaries.

Traditional network coding methods, using centroid connectors and ignoring local streets, cause errors in traffic assignments. In Fredericton, a small city with a coarse zone system, the error (RMS) associated with omitting local streets was estimated at about 90 vehicles per hour per direction of travel on a link. The combined error of omitting local streets and using centroid connectors was estimated at about 140 vehicles per hour. Errors of this size may or may not be significant to forecasts, depending upon the nature of the build alternatives, the policies to be tested and the quality of other steps in the model. Fredericton has a population-to-zone ratio that is similar to many large cities, so the absolute size of the error is likely to be typical of other places even if the relative size of the error were not.

Area spread assignment on an otherwise traditional network seems to do a better job at reproducing volumes created when all local streets are included in the forecast. However, this study was unable to determine whether area spread assignment did better at reproducing actual ground counts. Area spread assignment produces markedly different results from a traditional
traffic assignment. This difference by itself should be sufficient incentive to planners to take seriously spatial issues in network coding and traffic assignment.

A traffic assignment with all local streets should produce better results than an assignment without them. However, the presence of local streets adds greatly to computation times. It is unclear whether the potential improvement in forecasts is worth the data preparation effort and the computational burden.

Surprisingly, the estimate of VKT (or VMT) from a traditional network with centroid connectors was almost the same as the network with all local streets. VKT from the area spread assignment was underestimated, as expected, but the error was only about 2% in Fredericton. An error of this amount would be easily absorbed in the calibration process. Only a little of this 2% can explained by the number of trips not assigned to the network (intra-subzone trips) in the areas spread assignment, which is less than 1%.

Area spread assignment requires much more computation time, first because of the larger number of origins and destinations and second because of the need to create subzones around each intersection. Area spread assignment does not offer any advantages over conventional assignment in the number of iterations required to reach equilibrium. The time necessary to code TAZ boundaries on the network is reasonable.

Although area spread assignment did well on uncalibrated test networks, further tests are still needed on calibrated base-case networks with good peak-hour ground counts.

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REFERENCES
10. Alan J. Horowitz, "A Revised Queuing Model of Delay at All-Way Stop Controlled Intersections", Transportation Research Record, No. 1398, 1993, pp. 49-53.