Analysis of Transit Service Areas Using Geographic Information Systems

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The transit route location and analysis problem requires the estimation of a population within the service area of a route. A route's service area is defined using walking distance or travel time. A procedure for performing service area analysis on transit routes using a geographic information system (GIS) is compared with the more common technique of buffering, and implementation strategies for three GIS packages—namely, ARC/INFO, TransCAD, and SPANS—are discussed. A case study is performed for Logan, Utah, where a new fixed-route transit system currently is being planned. The case study compares the technique proposed here with that from two other approaches. Effects of the socioeconomic data source on the accuracy of these approaches are discussed.

User-oriented transit service is designed to meet particular needs of a selected group of travelers. Transit routes are located to provide convenient linkages between a user's origin and destination in such a way that out-of-vehicle time, such as access and transfer time, is minimized. The planning of transit routes requires understanding demographics, land use, and travel patterns of an area. The dynamic nature of these systems necessitates regular review and analysis to ensure that the transit system continues to meet the needs of the population it serves.

Geographic information systems (GISs) provide a flexible framework for planning and analyzing transit routes and stops. Socioeconomic, demographic, housing, land use, and traffic data may be modeled in a GIS to identify efficient and effective corridors in which to locate routes. However, very little research has been done on transit applications using GIS, except for studies currently under way at the Massachusetts Institute of Technology (*1*).

Part of the route location and analysis problem requires estimating the total population in the service area of a route. A route's service area is defined using walking distance or travel time and indicates the route's accessibility to the public. Here we consider only the problem of estimating persons within walking distance of a route. The problem of identifying service areas for park-and-ride or automobile or bus users is assumed analogous to walk or bus trips. Once the service area for a transit route is identified, population information for this area is used as input to travel demand models for estimating ridership.

This paper describes a procedure for performing service area analysis on transit routes using GIS. Aerial photographs are used to verify the suitability of this method. This procedure is compared with the more common technique of buffering, and implementation strategies for three GIS packages, namely ARC/INFO (Workstation Version 5.0), TransCAD (Version 2.0), and SPANS (Version 4.0), are discussed. A case study is performed for Logan, Utah, where a new fixed-route transit system is being planned. The service area estimation technique proposed here is demonstrated using census data. Other data sources, such as postal delivery route and aerial photographs combined with census data, are considered with regard to the potential for reducing error in the estimation process. Results of this technique are compared with results generated using the standard buffer methodology.

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PROBLEM DESCRIPTION

If pedestrian travel is assumed to take place on an isotropic plane, lines of equal walking time, or isochrons, may be constructed around a transit route to define its service area. The population within these lines represents potential transit users.

The scale of analysis for service areas ranges from entire transit systems to individual routes to bus stops. For instance, a transit system may be analyzed by constructing isochrons around each route to evaluate system coverage and duplication of service. In a GIS framework, the entity of interest in this analysis is a series of connected line segments that form the transit network. Microanalysis may be performed for each individual stop along a route. An investigation of this nature is made to ensure that bus stops are sufficiently placed along a route to provide adequate accessibility to the public. However, stops should be spaced far enough apart to minimize redundancy in coverage as well as prevent increased travel time, which results from stops too close together. The entity of interest in this analysis is a point that represents the bus stop location.

In general, the problem to be solved is to count occurrences of a data attribute within some proximity of an entity. Manual techniques using transit routes overlaid on aerial photographs are standard practice (*2*). In defining transit service areas, an attribute may be population or households and the entity may be a transit route or bus stop. Solutions to this general problem typically are achieved using GIS buffering operations. Buffers represent lines of equal distance around either point or line entities. Areas or polygons defined by the buffer line may be overlaid onto other polygon layers in a data base, such as census blocks, and the value of the attribute is determined on the basis of the amount of intersection between the areas of the polygons.

Service area delineation problems are more complicated for transit applications. Assuming that average walking speed is reasonable for determining access time to a transit route, service areas may be defined using distance. Walking, or pedestrian activity, typically occurs along a street network. Consequently, euclidean, or straight-line, measurement of distance in a buffering operation is not appropriate in this analysis. The common practice in transit planning is to use 0.25 mi as the upper limit on walking distance to a transit route (*2,3*). However, non-euclidean distance metrics may be more appropriate for locating buffer lines. For instance, consider an urban area with a predominant grid layout of streets. The Manhattan metric,

$$d = |x_1 - x_2| + |y_1 - y_2| \tag{1}$$

(where d is distance, and (x_i,y_i) is the cartesian location of ith point) more accurately describes walking distance than the measure of euclidean distance:

$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{2}$$

However, the accurate analysis of transit service areas requires models that can determine distance along paths in the road network, as opposed to buffering algorithms that use calculation of euclidean or other metric equations for distance. The procedure described here for estimating population in a service area uses specialized network analysis procedures in conjunction with standard buffering of entities.

Figure 1 graphically depicts the difference in results between euclidean and network distance measurements. Points A and B are quite close to the transit route when measured in straight-line euclidean distance. However, persons walking to the route must cover considerably more ground. Persons living at Point B may not consider themselves within the route's service area because of the long walk. In fact, as shown in Figure 2, the entire street block on which Point B is located is outside the 5-min walk (assuming a 3.5–mph pace) area for this route.

Figure 2 also demonstrates the difficulty of developing a buffer area or polygon enclosing the population within a certain distance. One procedure may be to identify each street segment within a specified distance and buffer it. Next, all

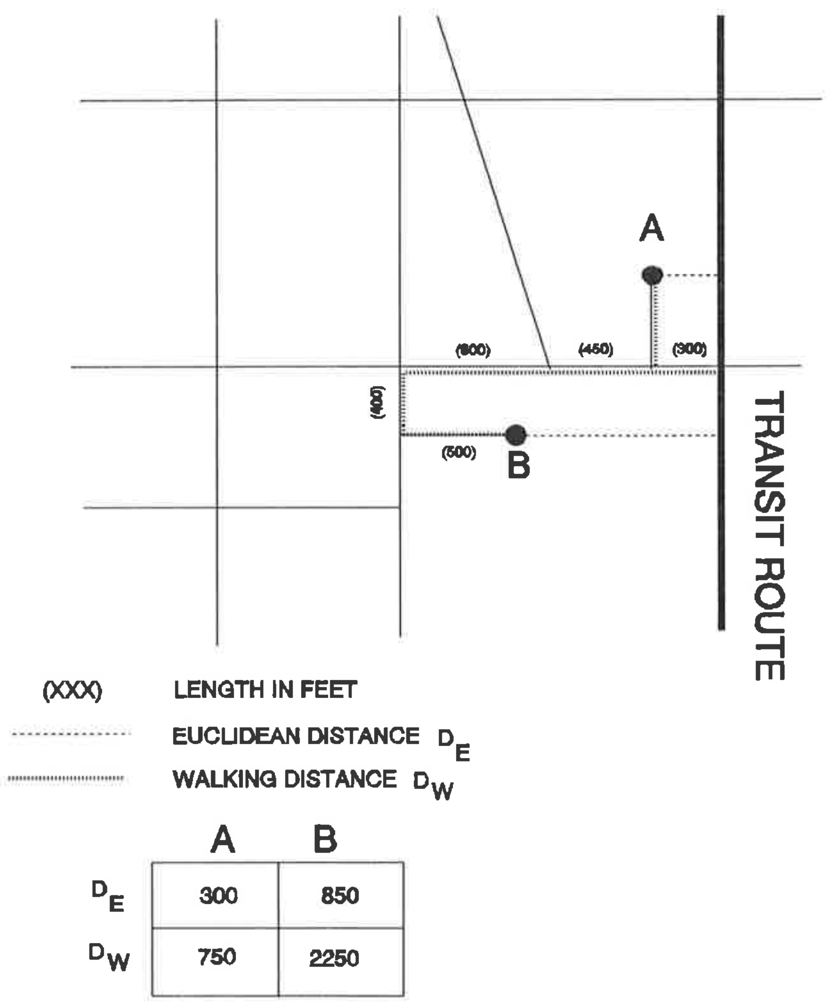

FIGURE 1 Network distance versus straight-line distance.

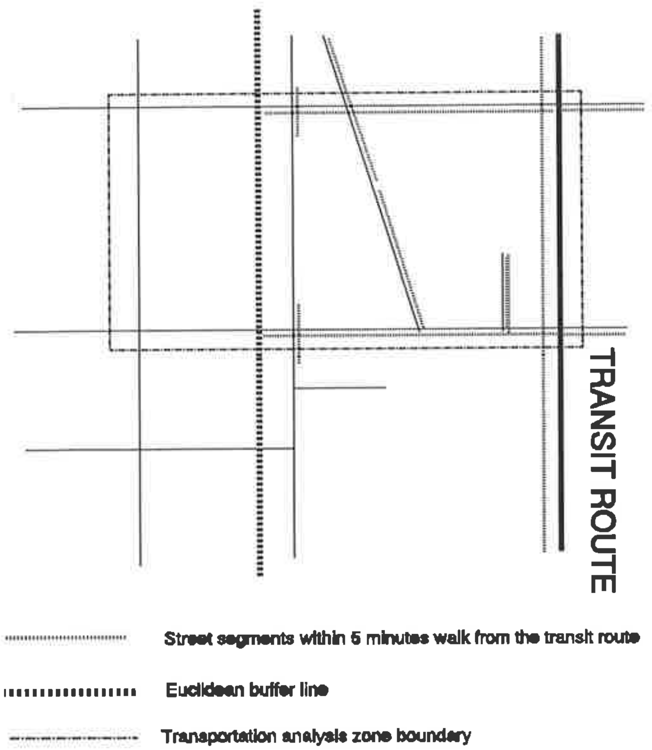

FIGURE 2 Streets in service area of transit route.

buffer areas may be joined to form one service area polygon, similar to the euclidian buffer polygon. These polygons may be overlaid onto the socioeconomic variable polygons to estimate population. But this is a tedious procedure, and there are no appropriate rules for defining the width of the buffer area for any particular segment. If population estimates are based on intersecting areas, the buffer width controls the estimated values.

To summarize, although the problem of delineating transit service areas is similar to the problem of creating buffers around entities in a GIS, an analysis based on euclidean buffer areas is inappropriate since the number of streets and people may be overestimated. Further, methods that attempt to buffer street segments, determined to be within a certain walk distance from a route, introduce error in population estimates.

REVISED APPROACH TO SERVICE AREA ANALYSIS

Problems with previously described methods may be overcome by eliminating the buffer process for individual segments and redefining the procedure for estimating population within service areas. The common approach for estimating populations within a service area uses euclidean buffering and polygon overlay techniques. Most often, polygon coverages of an area are formed by transportation analysis zone (TAZ) or census block, block groups, or tract boundaries. Attributes for these polygons include population, housing, and possibly, employment data. Polygons associated with socioeconomic data are referred to as analysis zones. A single value for each of the attributes is associated with each analysis zone. Consequently, a uniform distribution of the attribute within the area is assumed. In many instances, a polygon generated from the buffer of a route or stop intersects several polygons, either fully or partially. The following equation, called the area ratio method, is typically used to estimate population in the buffer area:

$$p_{w_i} = \frac{a_{b_i}}{a_{z_i}} * p_i \tag{3}$$

where

p_{w_i} = population in service polygon i within walking distance of the transit route,
a_{b_i} = area of service polygon formed from intersection of buffer polygon with analysis zone polygon i,
a_{z_i} = area of analysis zone polygon i, and
p_i = population of analysis zone polygon i.

This equation is appropriate only when the underlying street network is an evenly spaced fine mesh grid. A more appropriate measure—namely, the network ratio method—for allocating population uses network distances, as follows:

$$p_{w_i} = \frac{m_{w_i}}{m_{z_i}} \times p_i \tag{4}$$

where m_{w_i} is the total street miles within walking distance from the transit route of streets in analysis zone polygon i and m_{z_i} is the total street miles of streets in analysis zone polygon i.

An assumption of this model is that the number of houses on a street is proportional to the street length. Furthermore, this model assumes that houses are uniformly distributed on streets in a zone. In residential areas this assumption is relatively good. In mixed residential zones or zones with retail, industrial, and recreational activities, this assumption is weak but no weaker than those of the previous model.

These two models were applied on three neighborhoods in Logan. Six aerial photographs, two for each neighborhood, at a scale of 1 in. = 100 ft were used. These photographs represent the most accurate data base available on which to test the models. The small-scale photos enabled us to count the number of houses without field verification. Commercial buildings are not counted in these tests, and it is not possible to distinguish between single- and multiple-family dwellings.

The first neighborhood to which these models were applied is in downtown Logan. The street network is predominantly an evenly spaced grid in this older part of the city. The land use is primarily commercial along Main Street, where the bus route is located, and residential on adjacent and parallel streets. The second neighborhood chosen is primarily residential housing circa 1950; it is in the northeast section of the city next to the university. The street network is predominantly grid; however, blocks are more rectangular than square and an occasional cul-de-sac or dead-end street exists. The third neighborhood selected is the newest and has the highest housing costs of the three, containing residential development from the 1980s and 1990s. It is located directly south of the second neighborhood, and its street network has no apparent pattern.

For each photograph, the street with the transit route is identified, and an arbitrary rectangular analysis zone approximately 2,100 ft × 2,000 ft is drawn such that one edge lies along the transit route and the opposite edge is parallel to the route. The euclidean buffer line, parallel to the transit route, is drawn at approximately 1,600 ft. This distance is slightly longer than the 1,540 ft used to determine streets within walking distance along the network to include those houses directly across the street from houses within a 1,540-ft euclidean buffer. The number of houses in the analysis zone and buffer zone was determined from the photos. The area of the analysis zone and buffer zone was calculated. Total street miles in the analysis zone and within the 1,540-ft network distance were calculated. The area ratio model and network ratio model were used to estimate the number of houses within the service area defined by both the euclidean buffer and the network walking distance method.

Results are presented in Table 1. The network ratio method is shown to be more accurate for determining the number of households in primarily residential, modified grid street network areas. It is unclear whether the larger error in the downtown, regular grid neighborhood can be attributed to the network structure or the nonuniform spacing of houses along streets caused by the mixed residential-commercial land use.

To perform network ratio service area analysis, the following tools are needed in a GIS:

1. A procedure to total street miles within each analysis zone polygon,
2. A procedure to identify all street segments, or parts of streets, within a specified distance from a point or line entity,

TABLE 1 Results from Aerial Photographs

NEIGHBORHOOD	1A	1B	2A	2B	3A	3B
TOTAL HOUSES IN ANALYSIS ZONE	253	248	184	126	91	153
AREA IN ANALYSIS ZONE	42 $\times 10^5$	42 $\times 10^5$	42 $\times 10^5$	42 $\times 10^5$	359 $\times 10^4$	389 $\times 10^4$
AREA IN BUFFER ZONE	308 $\times 10^4$	308 $\times 10^4$	308 $\times 10^4$	308 $\times 10^4$	274 $\times 10^4$	296 $\times 10^4$
HOUSES IN SERVICE AREA (AREA RATIO METHOD)	186	182	135	92	69	117
HOUSES IN SERVICE AREA (AERIAL PHOTOGRAPHS)	216	212	135	122	85	150
ERROR RATE (%)	13.8	14.2	0	24.6	18.8	22.0
TOTAL STREET MILES IN ANALYSIS ZONE	2.42	2.57	2.25	2.08	1.28	2.26
TOTAL STREET LENGTH IN WALKING DISTANCE FROM TRANSIT ROUTE	1.45	1.54	2.25	1.78	1.21	1.62
HOUSES IN SERVICE AREA (NETWORK RATIO METHOD)	152	149	184	108	86	110
HOUSES IN SERVICE AREA (AERIAL PHOTOGRAPHS)	195	195	184	117	86	124
ERROR RATE (%)	22.1	23.6	0	14.5	0	11.3

3. A procedure to total street miles for those streets identified in Task 2 above for each analysis zone polygon, and
4. The capability of creating new data attributes from the mathematical manipulation of others.

EXISTING GIS SOFTWARE CAPABILITIES

Most GIS software packages available on the market satisfy Tools 1 and 4. Those that do not can usually interface with user-designed software and off-the-shelf data base management packages.

ARC/INFO's network software, combined with its data base management tools, is fully capable of performing service area analysis. A detailed description of the steps required to accomplish data import and data base construction follows.

TIGER data can be imported into ARC/INFO using procedures outlined in the user manuals. Separating the various themes (i.e., roads, census tracts, block groups, etc.) into individual coverages involves relating arcs within the data base to the TIGER tabular data set. Roads are identified and separated using codes in TIGER files that indicate the facility type of an arc. These arcs are extracted from the data base and placed into a separate road layer. Census tracts and block groups are extracted in a similar manner and placed into corresponding layers.

Road networks are created by splitting road line segments into 5-m increments. This provides a 5-m resolution to use in identifying service areas. The ALLOCATE utility in the network portion of ARC/INFO is used to identify possible transit stops. For example, let each stop service a 1,540-ft distance (impedance) (490.44 m) in all directions. The GROW subroutine identifies road segments no farther than the specified distance and, consequently, the area serviced by each stop.

To identify service areas based on a simple euclidean buffer, the BUFFER routine is applied to each stop for a maximum distance of 490.44 m. The buffer polygon is used to CLIP any road segments located within the boundary. Each euclidean buffer totally encloses all roads identified by the ALLOCATE utility.

Census block groups are clipped using the same buffer area. Area estimates for each block group are calculated within the buffer zones and compared to the total area of each block group. Only those block groups that fall within the buffer area are examined.

Road networks and block groups within the buffer area are combined using the IDENTITY subroutine in ARC/INFO to identify roads associated with each block group. This provides an estimate of total road length within each block group falling within the buffer area.

Necessary steps for determining transit service area populations using ARC/INFO may be summarized for each of the procedures previously outlined.

1. Procedure to total the street miles within each analysis zone polygon.
   a. Clip roads with euclidian buffer zone. Clip census block groups with same buffer zone.
   b. Use *Identity* to join roads to census block groups using the block groups as the identity coverage and the line option to preserve arc topology within each road segment.

c. Within *Info*, reselect for each census tract, block group combination located within the buffer area. Use *Report* with the *Total* option to tally all road segment lengths associated with that block group.

2. Procedure to identify all street segments, or parts of streets, within a specified distance.

a. Use the *Densifyarc* subroutine with the *ARC* option to split each road segment at a specified interval (we used 5 m).

b. Enter the *ALLOCATE* network utility and position *CENTERS* at selected points along the network. Set the *IMPEDANCE* for each center based on a predetermined walking distance (we used 1,540 ft).

c. Use the *GROW* routine to identify those road segments located within the specified impedance (distance).

d. *WRITE* arc data to the network coverage arc attribute table (AAT). This will identify which road segment belongs to a particular center.

3. Procedure to total the street miles for those streets identified in Step 2 for each analysis zone polygon.

a. In *INFO* select road coverage AAT. *Reselect* all roads that have been assigned to a center.

b. For each segment assigned to a center, *Reselect* for an individual census tract block.

c. Run *Report* with the *Total* option for the length of each road to sum all road segments associated with a center and one census tract block.

d. Repeat Steps *a* through *c* until all census tract blocks have been summed.

4. Creating new data attributes from the mathematical manipulation of others.

a. Manipulate numeric fields using the *Calc* command in *Info*. Preparation for the mathematical manipulation includes the addition of pertinent data (i.e., total number of households per block group, and total number of individuals per block group) and the addition of an *Item* to hold the output.

b. Use the *Additem* command in *Arc* to add the items needed to perform the calculation.

c. Once in *Info*, use the *Reselect* command to select only those records that fit a particular description (i.e., arcs belonging to a particular block group or center).

d. Use the *Calc* command, which uses standard algebraic notation, to calculate the output value for each selected record.

Analysis of service areas is somewhat complicated using ARC/INFO, but the sophistication of the software enables users to perform a wide variety of applications.

SPANS is capable of euclidean buffering only. Network procedures in SPANS are not well developed. Users may create specialized procedures to integrate with SPANS. However, because most transportation planners are familiar with vector models, a conversion to a vector structure from quadtrees is helpful first.

MODEL IMPLEMENTATION

The rest of this paper focuses on implementing transit service area analysis using TransCAD. TransCAD has a euclidean buffering procedure (*Query buffer zone* command) that buffers a single line entity. Several problems exist with this procedure for use in analyzing transit networks. First, the end of a line segment is not buffered, and the buffer line is drawn through the endpoint (node) instead of creating a semicircle with a set radius from the endpoint [see Figure 3 (*top*)]. Second, the algorithm handles only nearly straight line entities. For example, if the transit route runs south, then turns west for a few blocks, then turns north, the buffer is drawn as shown in Figure 3 (*bottom*). Third, the tallied results displayed in a pop-up window, as well as the buffer polygon boundaries, cannot be saved to the data base. To use the results for each transit route, a user has to print the contents of the window and enter them in the data base later. Finally, each transit route has to be represented as a single entity in the data base to buffer the whole route. Otherwise, each street segment in the route must be buffered separately and the results totaled manually. If the route is not straight, some areas are counted many times and population is overestimated.

TransCAD contains tools to accomplish previously mentioned Steps 1, 3, and 4. Further, this system facilitates developing user-programmed procedures using any programming language desired. Consequently, a simple tree-search algorithm was created to identify all links within a specified walking distance of each node along a transit route. The output of the procedure is a value between zero and one for each link in the network. This value indicates the proportion of a link within walking distance from the route (e.g., 0 indicates that none of the street segment has access to the route; 1 indicates that the whole street segment is within walking distance, and 0.5 indicates that half of the street segment has access to the transit route).

This new procedure for selecting links within a specified walking distance of a point enables TransCAD to be used

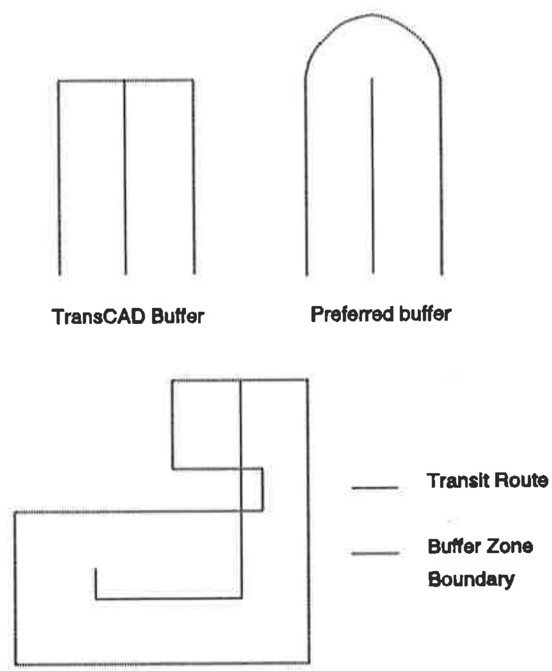

FIGURE 3 Example of buffering problems in TransCAD.

effectively in analyzing transit service areas. The necessary steps in performing this analysis are listed as follows in the order of the procedures defined above. Words and phrases in italic are from the TransCAD software.

1. Procedure to total the street miles within each analysis zone polygon:
   a. In the *Map Display: current layer* = links (street segments). *Select* (by *pointing*) links on a bus route.
   b. *Current layer* = analysis zones (i.e., block groups, TAZs). *Select (intersecting) by vicinity* (0.25-mi tolerance) of the *selected* links.
   c. In the *Data Editor: display selected only*. In a blank data column (real values) use *edit column aggregate* to *sum* the length of links in each analysis zone.
2. Procedure to identify all street segments, or parts of streets, within a specified distance:
   a. In the *Map Display: current layer* = links (street segments). *Select (intersecting) by vicinity* (0-mi tolerance) of the *selected* analysis zones.
   b. Choose the *procedure* to *make* a *network* from the selected set of links.
   c. Invoke the new *procedure* (transit service area analysis) to identify links from the network that are within walking distance from the transit route. Note, users must provide the walking distance in feet or walking time in minutes and average pace. Also, users must point to each intersection along the transit route for which the set of links in the service area is desired. A blank data column (real values) must be specified for output.
3. Procedure to total the street miles for those streets identified in Step 2 for each analysis zone polygon:
   a. *Current layer* = analysis zones (i.e., block groups, TAZs).
   b. In the *Data Editor: display selected only*. In a blank data column (real values) use *edit column aggregate* to compute (*weighted sum*) the length of links in each analysis zone weighted by the value returned in Step 2 indicating the proportion of each link within walking distance.
4. Creating new data attributes from the mathematical manipulation of others: In the *Data Editor: display selected only*. In a blank data column (integer values) use *edit column formula* to enter Equation 4. Note p_i may represent any variable attribute in a data base. For instance, the number of elderly people in the service area, the number of renters, or the number of children may be determined if these variables are part of the data base.

CASE STUDY

The process described here for delineating transit service areas and estimating the population within these areas is demonstrated for Logan, Utah. This city (population, 33,000) is in the process of developing a fixed-route transit system. Reasons cited for developing a transit system include

1. Increasing mobility for university students and households with one car,
2. Providing cost-effective transportation for the increasing elderly population,
3. Reducing traffic volumes, particularly on Main Street, and
4. Increasing accessibility to downtown businesses that suffer from limited parking availability.

The purpose of this case study is solely to demonstrate the potential of GIS for transit analysis. Results presented here are not derived from a comprehensive planning study and are not intended to recommend any particular route. In essence, enough data for demonstration purposes were available, so we used them to show how our model may be applied.

Data Base

The TIGER files for Cache County serve as the spatial data component of the GIS data base. Particularly, road segments, identified by codes starting with an A, and census block group boundaries constituted line and area (polygon) layers in TransCAD.

Attribute data were collected at two resolutions. For the lower resolution, population and housing information reported at the block group level was found in the Census Bureau's Summary Tape File 1A (STF1A). Note, data reported at the block level are not yet available. A subset of these variables was read from the tape into a TransCAD data base using a menu-driven basic program. Selection of variables, which are listed in Table 2, for the data base was influenced by a previous discussion of important transit planning factors (*4*) as well as the city's goals for the transit system.

Maps of census block boundaries and data base variables were generated during the study to assist in locating the stu-

TABLE 2 Census Block Group Area, Road Miles, and Population Data

TRACT NO.	BLOCK GROUP	AREA (SQ. MILES)	ROADS (MILES)	POPULATION
4	2	6.11	9.22	201
5	3	.19	3.04	1415
7	1	.44	5.77	2081
7	2	.46	9.03	2494
7	3	1.50	11.06	2040
7	4	.19	4.14	619
8	1	.13	2.34	1196
8	4	.12	2.06	526
8	5	.14	2.74	1158
9	1	.27	4.37	1620
9	3	.21	3.70	896
10	1	.15	2.50	784
10	5	.22	2.68	1156
11	1	1.83	9.79	1430
11	2	.53	5.43	332

dent, lower-income, and elderly populations to be served by the transit system. During route planning, maps of major traffic flows also are prepared. Other maps generated using GIS show the locations of major traffic generators in the city.

Ideally, a disaggregated data base enumerating individual households provides the greatest accuracy in estimating service area populations. Collection of detailed information is costly, both in gathering the data and building the data base. Even if housing structures are digitized from aerial photographs, field work is required to determine whether the structure is a single- or multiple-family house or is being used for commercial purposes. However, once the number of houses within walking distance is determined, from counting digitized house centroids along an arc, this value can be multiplied by the average household size for the block group to generate a more accurate estimate of persons in the service area. Increased accuracy results from relaxing the assumption that houses are uniformly distributed on a street and that the number of houses is proportional to the street length.

Another source of readily available data is information on the number of residences and businesses on each carrier route kept by post offices. Use of these data entails assigning a postal carrier route number to each street in a data base. Groups of street segments may be formed on the basis of postal route number. For each group, residences are distributed to streets on the basis of street length. An underlying assumption of this process is that the number of residences on a street is proportional to street length.

The impact of data sources on service area analysis is under investigation. It is hoped that the trade-off between the level of accuracy obtained from a particular data source and the cost required to build the data base will be discovered.

Results

For test purposes, service areas for six potential transit stops are shown in Figure 4. These stops form three service areas: one in downtown Logan on Main Street, one in a residential area covering the Island area development and Cliffside, and one near the university. An interesting feature of the second service area is that the buffer lines include streets that are inaccessible to the transit stop because of a steep barrier cliff. Barriers must be taken into account in service area delineation. Also, much of the land incorporated into the larger census tracts on the east side of town, particularly in Service Area 3, is undeveloped or agriculture or mountainous land. Residences are clustered on the western edges of these tracts.

Tables 2 and 3 contain information about service area population estimates for the block groups adjacent to the transit stops shown in Figure 4. Results are presented for three scenarios, namely,

1. Using euclidean buffers and the area ratio method (Equation 3),
2. Using the new procedure for identifying links within walking distance, based on network distance, census block group data, and Equation 4, and
3. Using a modified procedure to estimate total street miles within the buffer area in each block group, census data, and Equation 4 modified for total buffer street miles instead of street miles within walking distance.

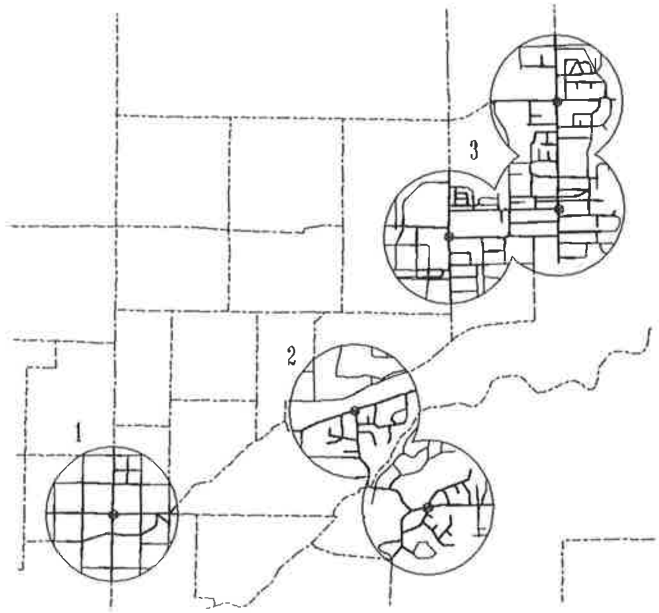

FIGURE 4 Map of example service areas (circles are euclidean buffers, dashed lines are block group boundaries, thick lines are streets within walking distance from the stop).

Table 2 contains information on the total area, total road miles, and total population for each group affected by the analysis. Table 3 shows the numeric data used to determine population in each service area for each of the methods described above. The final population estimates for each service area as summarized from Table 3 are as follows:

Service Area	*Total Population in Service Area (by Method)*		
	1	*2*	*3*
1	1,411	1,036	1,556
2	1,171	605	1,452
3	2,786	3,408	4,826

As shown, results vary based on the methodology and data used. Field verification is required to determine which approach yields the most accurate results. Notice, however, that the proposed service area analysis technique, that is, using walking distances, provides the most conservative estimates of population except for Tract 7, Block Group 3 of Service Area 3. Even in this instance, the result is believed to be more accurate than the buffer estimate. The area in the buffer polygon represents only a small portion of the total area of the block group, hence the low estimate. However, as stated previously, because of the mountains and undeveloped land, the population in this tract is not spread throughout but clustered in the area near the buffer. Because roads are not built in the undeveloped area, the ratio of roads within walking distance to total road mileage is more representative of the spatial organization of the population within the block group. Another noteworthy result occurs in Service Area 2. Streets, and consequently persons, are eliminated from consideration in Service Area 2 when walking distance is used in the analysis.

TABLE 3 Data Tabulated for Each Block Group in Each Service Area for All Methods

SERVICE AREA	TRACT NO.	BLOCK GROUP	BLOCK GROUP AREA WITHIN BUFFER	PERSONS IN SERVICE AREA	ROAD LENGTH IN ALLOCATED AREA	PERSONS IN SERVICE AREA	ROAD LENGTH IN BUFFER AREA	PERSONS IN SERVICE AREA
1	5	3	.0039	28	.04	10	.04	11
1	8	4	.0789	359	.85	205	1.30	316
1	8	5	.0032	27	.04	15	.06	26
1	9	1	.0009	5	.00	0	.00	0
1	9	3	.0619	266	.77	331	1.20	516
1	10	1	.1028	521	1.28	402	1.88	591
1	10	5	.0387	204	.51	74	.66	96
2	7	3	.1238	168	1.22	338	1.61	444
2	7	4	.0763	243	.00	0	1.15	589
2	8	1	.0135	126	.00	0	.24	36
2	9	1	.0002	1	.00	0	.00	0
2	9	1	.0660	404	.89	215	1.19	289
2	11	1	.2914	228	2.41	53	4.22	92
2	11	2	.0003	0	.00	0	.02	1
3	4	2	.0711	2	.55	254	.82	381
3	7	1	.1467	691	1.72	317	3.04	560
3	7	2	.3114	1691	5.15	1421	6.90	1906
3	7	3	.2965	402	3.93	1415	5.49	1979

People in Block Groups 7-4 and 8-1 cannot access these stops without descending a steep brush- and rock-covered cliff. No roads connect these areas, so walking paths cannot be built, and these people should not be considered in the analysis. As expected, the least variation in results occurs for Service Area 1, which most resembles a regularly spaced grid network.

CONCLUSIONS

A model that uses the tools in GIS is developed for delineating transit service areas and estimating population within these service areas. Network distance, as opposed to euclidean distance, is preferred for identifying streets with access to a transit system. The model was tested in Logan, Utah, using two different data sources. Although population estimates found using the procedure developed here seem reasonable, field verification is needed to justify the use of this approach over others. The use of network paths in service area definition has advantages over the common techniques because travel barriers are recognized and unevenly distributed populations are considered. Future areas for research include investigating the accuracy of estimates using a variety of data sources at different spatial resolutions.

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