

Research Article

A GIS-Based Approach for Delineating Market Areas for Park and Ride Facilities

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Abstract

Park-and-ride services are an integral component of many public transit systems in the United States. A necessary step when analyzing and planning for such services is to delineate catchment areas for park-and-ride facilities. Previous approaches for delineating catchment/market areas are either problematic or have unrealistic data requirements. This paper develops a Geographic Information System (GIS)-based approach for delineating market areas. The detailed approach simultaneously accounts for park-and-ride facility accessibility and user travel direction. It is shown that the developed approach performs better than existing approaches. Further, this paper provides a detailed and formal description of these approaches, which should facilitate interpretation and implementation in a GIS environment.

1 Introduction

Traffic congestion has been and is expected to continue to be a major concern for urban areas of the United States (Levinson et al. 1997). A primary reason for traffic congestion is no doubt continued reliance on the private automobile (Newman and Kenworthy 1999). Increased use of public transit is a potentially effective way to overcome automobile dependency and would likely contribute to a more sustainable existence of urban areas (Newman and Kenworthy 1999). Public transit, however, is not well suited for low-density areas because there is usually not enough travel demand to support fixed route transit service (Sargious and Janarthanan 1983). An effective alternative is the use of park-and-ride services to extend public transportation to low-density areas. That is, park-and-ride users could start their trip in a low-density area using an automobile and then switch to transit at a park-and-ride facility later in the same trip (Kerchowskas and Sen 1977). There are potential benefits to users, operators and the transportation system as well as to communities in the establishment of park-and-ride (Mather 1983). Thus,

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many transit agencies across the United States consider park-and-ride services an essential element of their transit systems (Turnbull 1995, MAG 2000, COTA 2001).

It is important that park-and-ride services be well planned in order to attract as many single occupancy vehicle users as possible to the transit service (Spillar 1997). In order to achieve this, an important step in the planning process is the ability to identify associated park-and-ride market area boundaries (Turnbull 1995). A market area, also known as a study, service, catchment or commutershed area, is the geographic area from which users of a park-and-ride facility are likely to come (Bowler et al. 1986, Bolger et al. 1992). Delineating such areas is important because they help explain the spatial and socioeconomic characteristics of potential users in the market area as well as their associated travel characteristics (Bowler et al. 1986). This information can then be used, for example, to predict potential demand for park-and-ride facilities and better plan system integration (Allen 1979).

Interestingly, there are a range of alternative approaches that exist for identifying park-and-ride catchment/market areas. They can be broadly divided into three categories: (1) methods that assume a geometric shape for the market area; (2) methods based on travel cost comparison between travel modes; and (3) methods identifying current or past users.

Turnbull (1995) suggests that a market area can be assumed to have a geometric shape, such as a circle or parabola. A problem with assuming a certain shape, however, is that it fails to consider the different levels of accessibility that users may have in a given area. To illustrate, even though users A and B in Figure 1 may appear to be equally close to the park-and-ride facility, they are not likely to have an equivalent degree of accessibility to it. The reason for this, in this case, is that the street network topology is such that user A would be required to travel a greater distance than user B. Similar

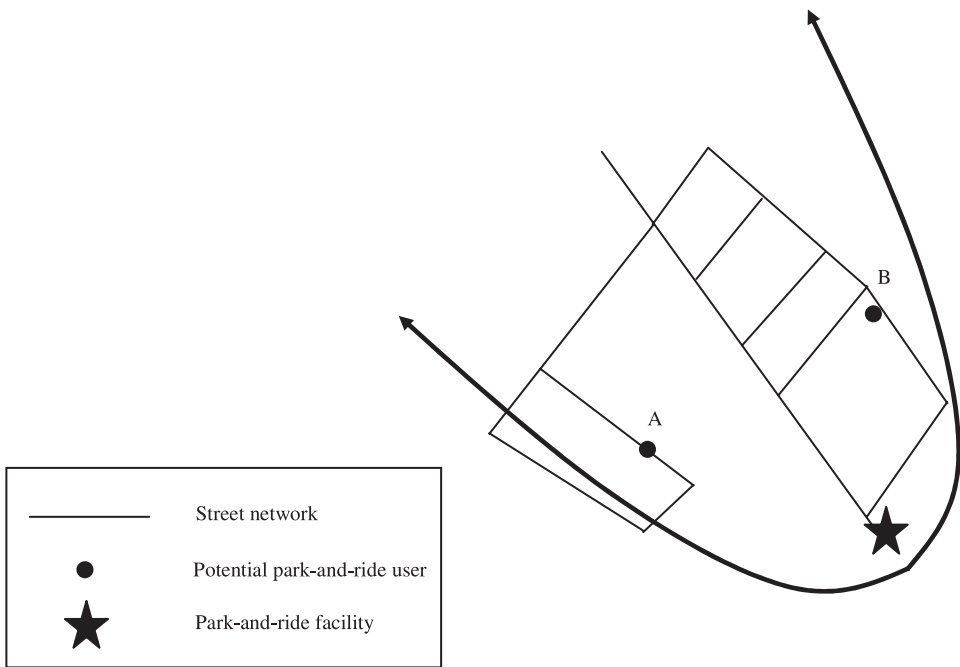


Figure 1 User accessibility within a parabolic market area

circumstances could also arise due to terrain undulation or spatial barriers, but the street network is certainly critical in urban areas.

Sargious and Janarthanan (1983) delineate the boundary of a market area based on travel cost. Such costs include time valuation, travel time, and use fees. That is, potential users of a park-and-ride facility would be included in a market area if they find it advantageous, in terms of travel cost, to drive to that facility and then use transit, as opposed to using their automobile, for the duration of their trip. A problem with this approach, however, is that it is not amenable to explicitly accounting for user travel direction. That is, potential riders desire a facility in their direction of travel and view backtracking as a negative. Travel cost approaches do not account for this consideration.

When data on locations of park-and-ride users are available, delimiting a market area can be accomplished relatively easily. Allen (1979) conducted a license plate survey to help identify the shapes and sizes of market areas for different types of park-and-ride lots. The available data were then used to develop estimates on user travel time/distance to the various types of lots. Such estimates are suggested as being useful for identifying market areas for similar types of park-and-ride facilities in locations where data are not available. Lutin et al. (1981) used survey data to calibrate a market area model. They suggest that logarithmic/exponential functions can describe the relationship between the park-and-ride ridership and the distance or time traveled to the park-and-ride lot. Clearly, if data are available on the locations of park-and-ride users for a region, such data should be used. However, due to concerns about user privacy, data on the exact location of individual users are becoming increasingly difficult to obtain as agencies like Department of Motor Vehicles are reluctant to provide such information, either for public consumption or research purposes. If this is the case, the utilized market area delineation approach cannot rely on user locations as input.

The above review details the range of existing approaches typically used for delineating market areas for park-and-ride facilities. These approaches are either problematic or have unrealistic data requirements. Further, there is no objective method to guide the decision as to what market area approach to use, or on how to evaluate and compare such approaches.

Geographic information systems (GIS) are known for their capabilities in creating, analyzing, manipulating, storing and representing spatial data (Hanson 1995). These capabilities have been used for delineating retail store trade areas (O'Kelly 1999), although their use in the analysis of park-and-ride facilities has been limited (the only case we are aware of is the work of Horner and Grubestic 2001). This paper develops a GIS-based approach to support park-and-ride market area assessment that simultaneously considers accessibility and user travel direction. In addition, this paper provides a detailed description and formal specification of the market area delineation approaches, and shows how such clarity is useful for GIS implementation. The next section examines two existing methods for market area delineation. Following this, a new approach for delineating market areas is developed. Next, the different market area delineation approaches are evaluated. Finally, discussion and conclusions are given.

2 Delineating Market Areas

The two commonly used modeling approaches for delineating market area boundaries in park-and-ride studies are detailed in this section. The first is an assumed parabolic

shape (a special case of category 1 above) and the second is structured using travel costs (category 2 above).

2.1 Parabolic Shaped Boundary

Several studies have assumed parabolic shapes for representing market areas for park-and-ride facilities, which could be attributed to the fact that such shapes represent a user's tendency to drive to a park-and-ride facility if it is in their direction of travel (Keck and Liou 1976, Christiansen et al. 1981). A theoretical justification for hyperbolic market areas, not unlike parabolic, can be found in Hanjoul et al. (1989) among others. Of course, by definition the parabolic approach necessarily assumes one major travel destination. The major steps involved in parabolic market area delineation are:

1. Define the parabola surrounding the park-and-ride facility oriented toward the major activity center.
2. Determine the maximum extent of travel to the facility.
3. Identify potential users in the market area.

Specifics associated with each step of the parabolic market area delineation process are now given. In step 1, a parabola is defined for a given park-and-ride facility representing much of the boundary associated with its market area. The general form of a parabola is:

$$Ax^2 + Bxy + Cy^2 + Dx + Ey + F = 0 \quad (1)$$

If the parabola is oriented around the y-axis, equation (1) can be simplified as follows, assuming that the parabola has its vertex at (h, k) and the directrix is $y = k - p$:

$$(x - h)^2 = 4p(y - k) \quad (2)$$

If the orientation is around the x-axis, equation (1) simplifies to:

$$(y - k)^2 = 4p(x - h) \quad (3)$$

If the vertex is placed at the origin (i.e. $(h, k) = (0, 0)$), equation (2) becomes:

$$y = \frac{x^2}{4p} \quad (4)$$

In this case p represents the distance from the focus to the vertex. The interpretation of p is that it represents the acceptable backtrack distance, which is the distance that users are willing to backtrack to reach a facility. Similar to equation (4), if the vertex of the parabola represented by equation (3) is placed at the origin, equation (3) becomes:

$$x = \frac{y^2}{4p} \quad (5)$$

Under idealized conditions, equation (4) or (5) could be used to represent the market area for a park-and-ride facility, assuming that associated parameters are known or can be determined.

With the basic parabola defined in step 1 (shown in Figure 2a using equation 4), step 2 involves further refining the market area boundary to reflect the maximum distance a user is willing to travel to use a park-and-ride facility. This is typically imposed through the use of a maximum travel distance, d_{max} , to enclose the parabola. This is

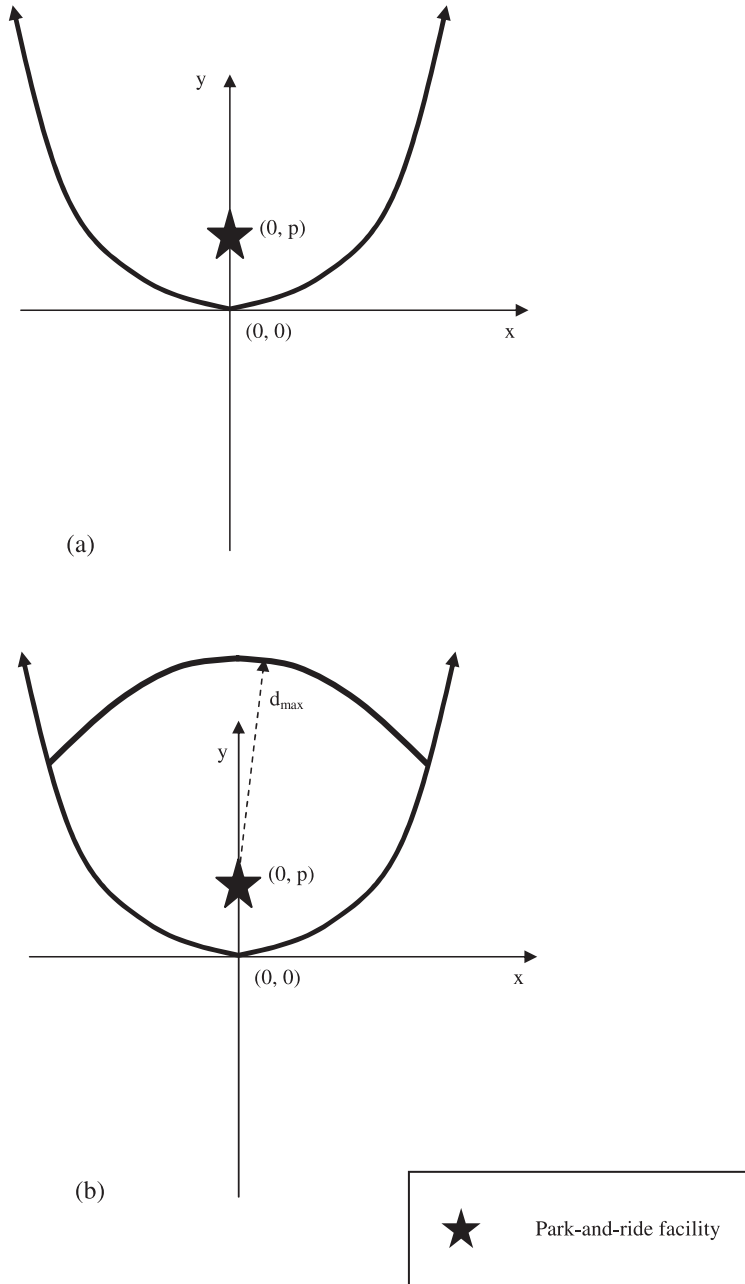


Figure 2 Parabolic market area delineation

illustrated in Figure 2b. Given the boundary of the market area defined in steps 1 and 2, it is possible to identify potential users residing within this enclosed area. Mathematically, a user at (x, y) is in the market area if $Ax^2 + Bxy + Cy^2 + Dx + Ey + F \leq 0$ and $d[(x, y), (x_f, y_f)] \leq d_{max}$, where (x_f, y_f) is the coordinates of the park-and-ride facility.

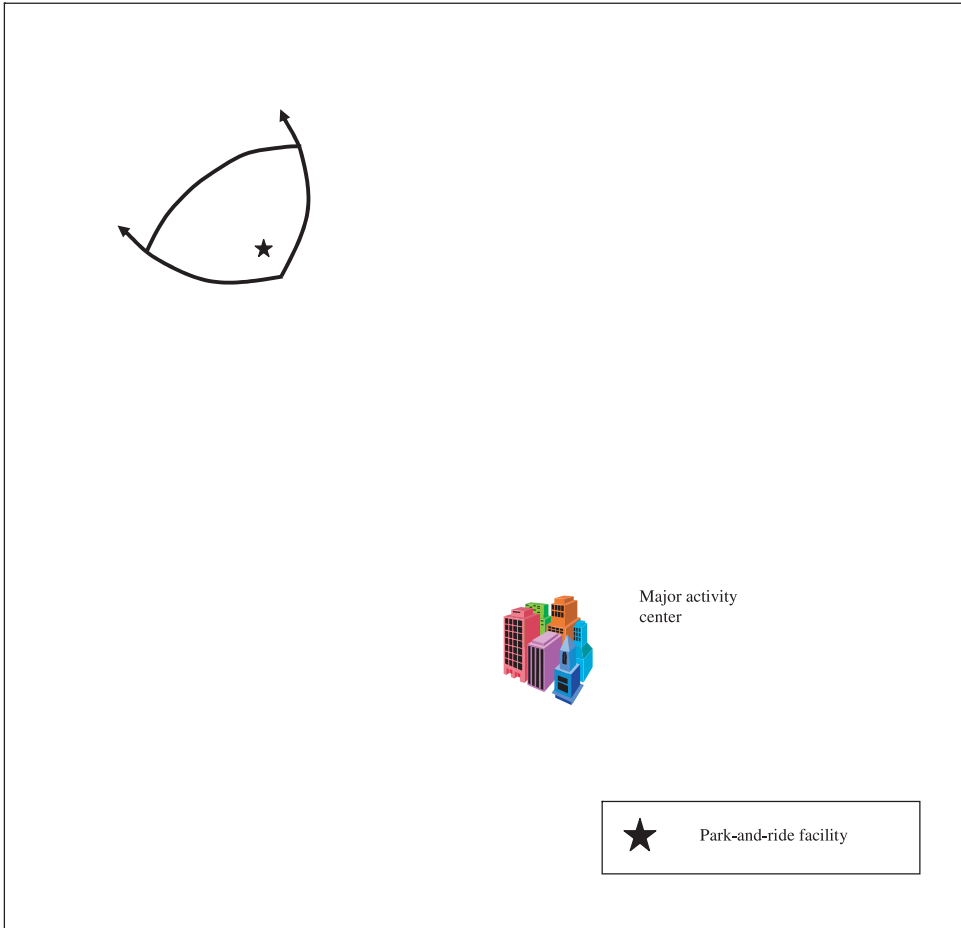


Figure 3 Parabolic market area orientation

A minor complicating feature of the associated parabola in practice is that the park-and-ride facility is not likely to be horizontal or vertical relative to the major activity center. What is required in this case is that the market area boundary be rotated about the park-and-ride facility so that it is appropriately oriented toward the major activity center. Such a reorientation is shown in Figure 3. The mathematics associated with such a rotation may be found in Larson and Hostetler (1986), among other such introductory calculus texts.

2.2 Market area delineation based on travel costs

An alternative market area delineation approach is based on travel cost structure (Sargious and Janarthananm 1983). Travel costs typically include time valuation, travel time, and use fees. The major steps for delineating a market area for a given park-and-ride facility using travel cost are:

1. Compute automobile travel cost for each potential park-and-ride facility user from their residence to their assumed destination (major activity center or centers).
2. Compute travel cost for the user using park-and-ride.
3. Compare travel costs to delineate the market area.

Step 1 involves the estimation of travel cost using an automobile between the user residence and the activity center(s). Let c_{im} represent the computed automobile travel cost between a user i and activity center m . Travel cost associated with the use of park-and-ride is determined in step 2. Let \hat{c}_i represent automobile travel cost between the location of a user i and a park-and-ride facility, and let the transit travel cost between facility and activity center m be represented by \tilde{c}_m . The total cost for using park-and-ride can be expressed as $\hat{c}_i + \tilde{c}_m$. Step 3 involves the delineation of the market area by comparing the alternative travel costs. Using the above notation, a user is included in a park-and-ride market area if $c_{im} \geq \lambda(\hat{c}_i + \tilde{c}_m)$. Typically $\lambda = 1$, but this parameter could be adjusted to account for slightly higher travel costs using transit ($\lambda > 1$) or more stringent requirements for transit ($\lambda < 1$).

3 Incorporating accessibility and travel direction

The previous section detailed the two primary approaches that have been used to delineate park-and-ride market areas. As noted previously, the parabolic market area approach assumes that users at equal distances from a park-and-ride facility have the same degree of accessibility to the facility. As a result, it is not sensitive to spatial structure. Further, it assumes only one major travel destination. The travel costs market area approach, on the other hand, does not consider travel direction explicitly as it cannot explicitly determine directional attributes in costing, but does allow one to address multiple travel destinations. Given these limitations, a new approach is developed which takes into account both accessibility and travel direction.

For each park-and-ride facility, delineating the market area incorporating accessibility and travel direction considerations involves the following major steps:

1. Compute automobile travel time for each potential user from their residence to the park-and-ride facility.
2. Determine whether the facility is in the potential user's travel direction.
3. Assess whether the user is in the market area.

Figure 4 illustrates the above steps in a flowchart. Step 1 involves computing travel time using an automobile from a potential user's residence to the park-and-ride facility (or vice versa). Step 2 involves determining whether or not the park-and-ride facility is in the potential user's travel direction. One approach for assessing this is to assume that two vectors can be used to reflect basic travel direction, as suggested in Figure 5. It is conceivable that a more complex notion of travel direction could be derived using the underlying transportation network and associated travel route. However, the idea here is to determine the basic direction of travel, so this simplification is more than reasonable.

With vectors \mathbf{a} and \mathbf{b} , the angle α , where $0 \leq \alpha \leq 180^\circ$, can be calculated as follows:

$$\alpha = \cos^{-1} \left(\frac{(-\mathbf{a}) \cdot \mathbf{b}}{\|\mathbf{a}\| \|\mathbf{b}\|} \right) \tag{6}$$

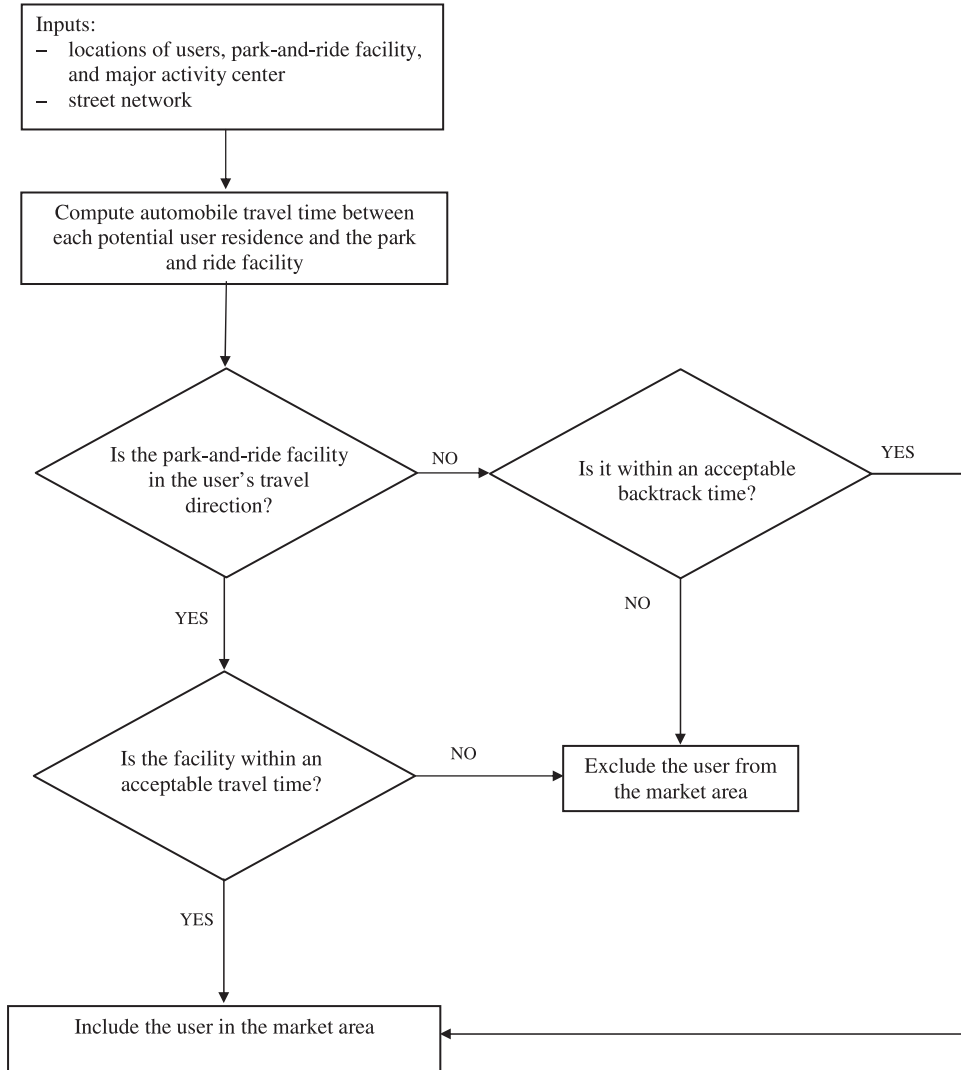


Figure 4 Delineating a market area using accessibility and travel direction

An acceptable angle, Φ , must be specified in advance. If $\alpha \geq \Phi$, the facility is in the user's travel direction, whereas $\alpha < \Phi$ indicates that the facility is *not* in the user's travel direction. Certainly, it would be possible to devise an evaluative approach that gives increasing importance to α as it approaches 180° , as this more accurately reflects the degree to which a park-and-ride facility is in a user's travel direction. However, a cut-off value approach using Φ is reasonable because direction is only one component of the choice to use park-and-ride services. In addition, little is known about choice behavior associated with user willingness to deviate from their travel direction in order to use park-and-ride services.

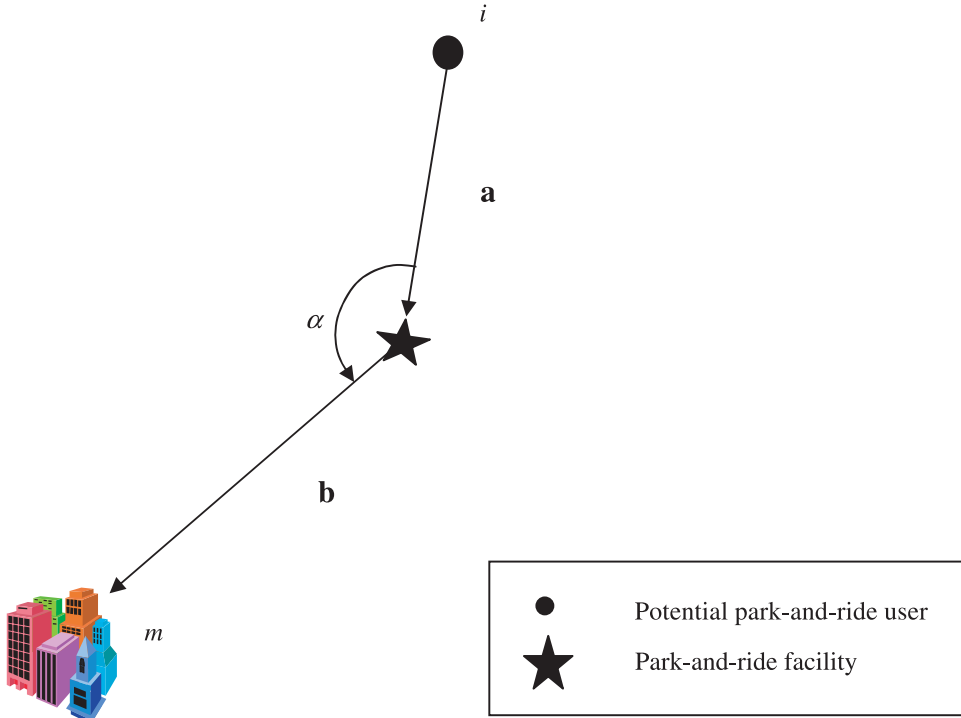


Figure 5 Assessing potential user travel direction

Finally, step 3 involves examining the potential park-and-ride facility users for inclusion in the market area. Such users are included in the market area if one of the following conditions is met:

1. $\alpha \geq \Phi$ and $t[(x, y), (x_f, y_f)] \leq t_{max}$

where $t[(x, y), (x_f, y_f)]$ is the travel time from a user's residence to a park-and-ride facility using an automobile, and t_{max} is the maximum travel time that users are willing to drive to reach the park-and-ride facility.

2. $\alpha < \Phi$ and $t[(x, y), (x_f, y_f)] \leq t_{back}$

where t_{back} is the tolerable backtrack travel time.

Condition (1) represents the situation where the park-and-ride facility is in the user's travel direction *and* also within an acceptable travel time. Condition (2) represents the case when the park-and-ride facility is *not* in the user's travel direction, but is within an acceptable backtrack travel time. It should be noted that this approach can easily accommodate a travel cost or time consideration as well to further restrict the delineated market area, similar to the travel cost approach.

One important feature of this approach is the ability to determine directional relationships between geographic entities. That is, given the locations of a potential user, a park-and-ride facility and the major activity center, it is possible to assess whether the

facility is in the user's travel direction. This is essential for determining whether such a user is a potential park-and-ride user for a particular facility.

4 Comparative evaluation of market area delineation approaches

The market area delineation approaches detailed in the previous sections are now comparatively assessed. This analysis will be carried out using an application in an urban area where park-and-ride services are an integral component of the public transportation system.

4.1 Application details

The park-and-ride system in Columbus, Ohio is utilized in the evaluation of the detailed market area delineation approaches. Columbus is one of the few growing cities in the Midwest (MORPC 1998). The Central Ohio Transit Authority (COTA) provides mass transit services for the greater Columbus metropolitan region, with a transit service area of around 552 square miles inhabited by 1,082,450 people (MORPC 2001). COTA maintains 24 park-and-ride facilities containing 2,330 spaces (COTA 2001). Medium and long-term plans are to add 14 suburban transit centers, which will include park-and-ride lots (COTA 1999). Figure 6 shows the locations of existing park-and-ride facilities in Columbus. The utilization of these facilities ranges from six percent to full utilization, though they are generally under-utilized as shown in Table 1 (COTA 2001).

Each approach was implemented using Avenue scripts in ArcView GIS 3.2 on a personal computer. Several scripts were developed to automate repetitive use of GIS functions as well as to facilitate implementing new functionality that is not readily available in GIS. Existing GIS functionality that was used included routing, spatial query and distance measurement. Thus, GIS is clearly more than a visualization tool, though it is no doubt fundamental in depicting market area boundaries.

There are several noteworthy application details. Census data at the block level was used to represent potential park-and-ride users, with each block centroid representing the number of potential users. Downtown Columbus was considered the major activity center in this region as most, if not all, park-and-ride trips are currently destined to downtown. Parameter values were selected partly by experimentation and partly based on accepted standards. For the parabolic market area approach, d_{\max} was based on an assumption that typical users would not likely drive more than 5 miles to reach the facility, as suggested by COTA (1993). The maximum backtrack distance, p , was assumed to be 1 mile, as suggested by Bowler et al. (1986). Of course, any range of parameter values can be assessed in the developed approaches. For the travel cost approach, travel time was used as a proxy given that costing information was not available for use in this study. Street network-based travel time was determined for both park-and-ride and automobile travel, similar to what was done in Horner and Grubestic (2001). In this study $\lambda = 2$, indicating that some leeway is given to park-and-ride users in distinguishing between travel modes. The two alternatives were then compared to delineate the market area, as described previously. The travel time over the street network was estimated using travel speeds as a function of roadway facility type (e.g. freeway), number of lanes, and area type (downtown, urban area, suburban area, etc.) (USDOT 2000). For example, a freeway segment with four lanes in an urban area was

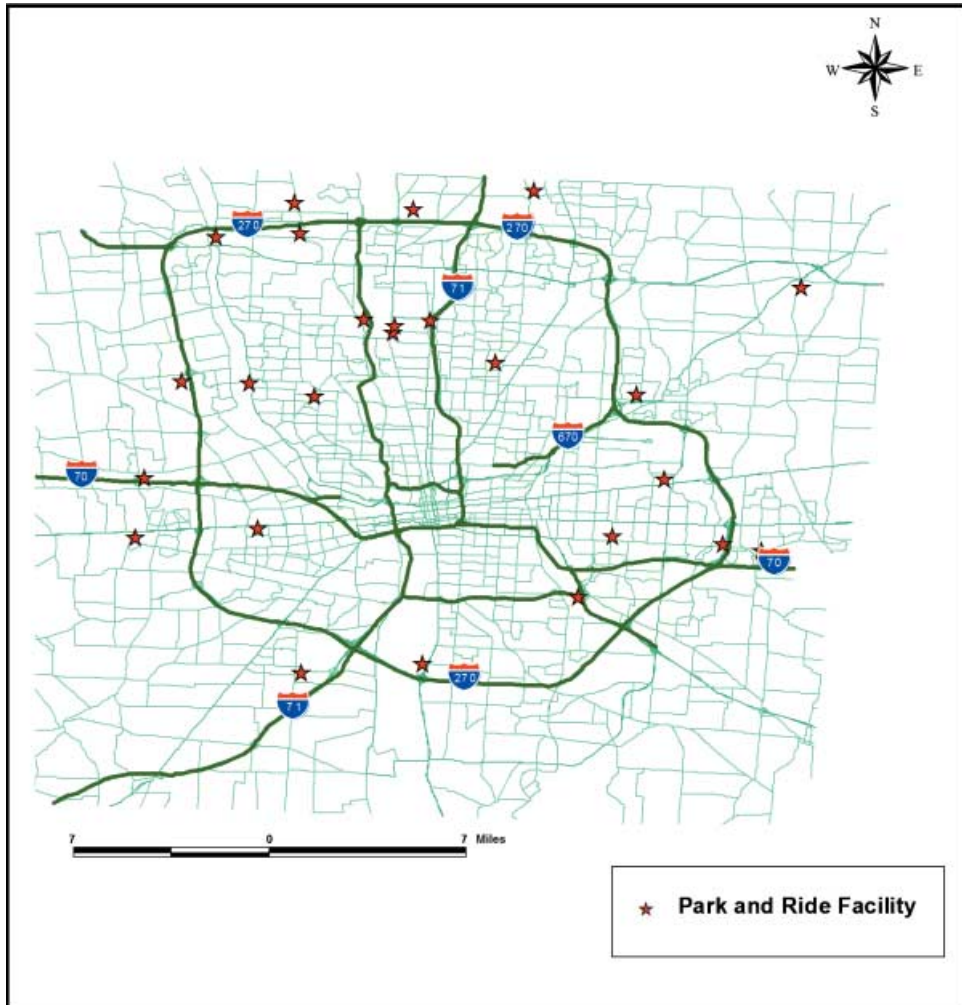


Figure 6 Park-and-ride facilities in Columbus, Ohio

assigned a speed of 45 miles per hour. The implementation of the accessibility and travel direction approach required the specification of associated parameters as well. The maximum travel time, t_{\max} , was assumed to be five minutes and the maximum backtrack travel time, t_{back} , was assumed to be one minute, consistent with the other approaches. The maximum allowable travel direction deviation, Φ , was set at 90° .

4.2 Implementation using GIS

In the previous sections, several market area delineation approaches (existing and new) were detailed. Unlike previous studies, this paper provided a formal and detailed description of each approach, facilitating implementation in a GIS environment. One reason why GIS implementation is facilitated is that delineating market areas involves the use of detailed spatial data. As such, standard GIS functionality is oriented to manage and

Table 1 Utilization of park-and-ride facilities in Columbus, Ohio (April 2001)

Park-and-ride facility location	Available spaces	Spaces used	Utilization rate
Berwick Plaza	60	38	63.3%
Broad/S. Hampton	68	68	100.0%
Crosswoods	169	25	14.8%
Dublin	82	56	68.3%
Great Southern	84	33	39.3%
Griggs Dam	28	13	46.4%
Grove City	150	69	46.0%
High/Jeffrey	32	16	50.0%
High/Royal Forest	40	36	90.0%
Hilliard	100	22	22.0%
Hilliard-Rome Rd	80	13	16.3%
Indianola/Morse	105	26	24.8%
Kingsdale	35	19	54.3%
Livingston/Barnett	101	51	50.5%
New Albany	50	19	38.0%
Northern Lights	60	61	101.7%
Olentangy/Bethel	150	9	6.0%
Pickerington	150	133	88.7%
Reynoldsburg	214	77	36.0%
Royal Plaza (Gahanna)	60	26	43.3%
St. Andrew	14	14	100.0%
St. Peter's	20	15	75.0%
Westerville	230	57	24.8%
Westwoods	100	44	44.0%
Whitehall	148	37	25.0%
Cleveland and Mecca	12	0	0%
Main and Weyant	12	3	25%

Source: Central Ohio Transit Authority (COTA) (2001)

manipulate data as well as visualize and summarize areal information. Below we detail how GIS was instrumental in implementing aspects of each market area approach.

In defining a parabolic market area, GIS is used to specify the polygon associated with the parabola around a park-and-ride facility. The parameters for doing this are given in equation (1) and by the maximum travel distance, thereby enclosing the parabola. Once this polygon is created, it is possible to use spatial query operators to determine potential users within the market area. Carrying out any of these operations outside of GIS would require the development of computational geometry procedures in addition to database management processing.

Similarly, for the travel cost market area approach, GIS facilitates analysis through the management of the transportation network and subsequent capabilities to work with routes and determine shortest paths from a park-and-ride facility to areas in the region. Again, once market area boundaries are established from a travel cost evaluation

of the network, it is necessary to generate the polygon defining the market area. With this, it is then possible to conduct spatial queries and provide area summaries.

Finally, the new market area approach based on accessibility and travel direction also relies extensively on the use of GIS. Two important aspects of implementation were determining travel time between a user and a park-and-ride facility and determining whether a facility is in a potential user's travel direction. The former was relatively easy to implement in GIS using network and shortest path functionality. Determining whether a facility is in a user's travel direction, however, requires new GIS functionality to be developed. Specifically, the location of potential users, park-and-ride facilities and major activity centers was needed to evaluate relative spatial proximity. One aspect was distance between these locations. Another involved assessing whether a facility was in an associated travel direction. This was operationalized by creating travel vectors from a potential user to the park-and-ride facility and from a potential user to its intended travel destination. These vectors enable directional assessment. Again, this is all facilitated by existing GIS functionality.

4.3 Market area assessment

4.3.1 Visual comparison

The market area results for each approach are given in Figures 7–9. Displayed dots are census block centroids for the various market areas, representing potential park-and-ride

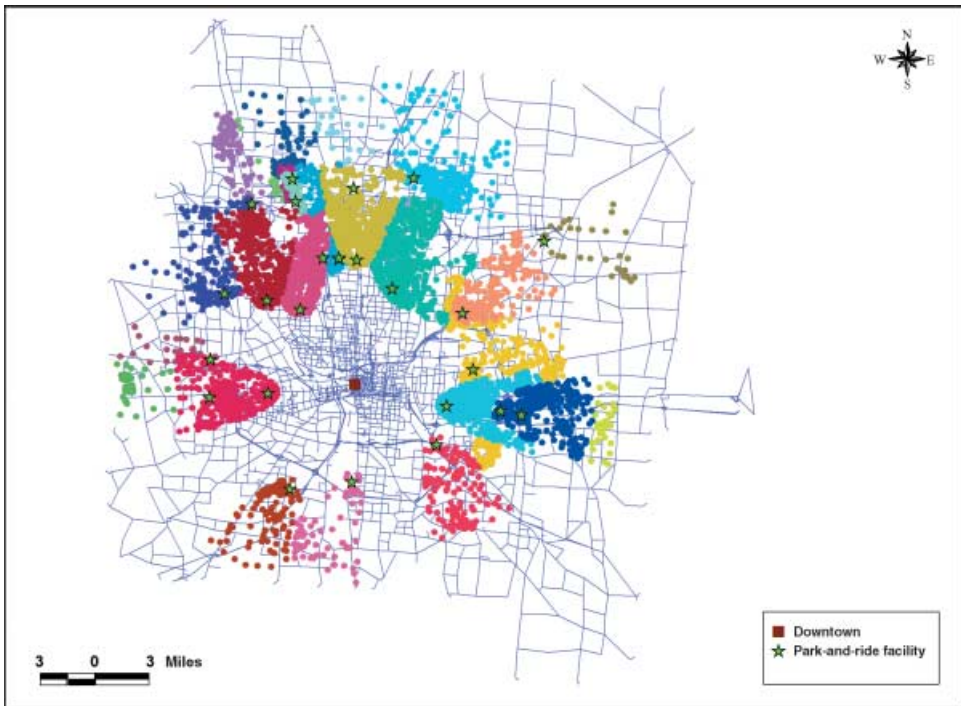


Figure 7 Market areas identified using the parabolic approach

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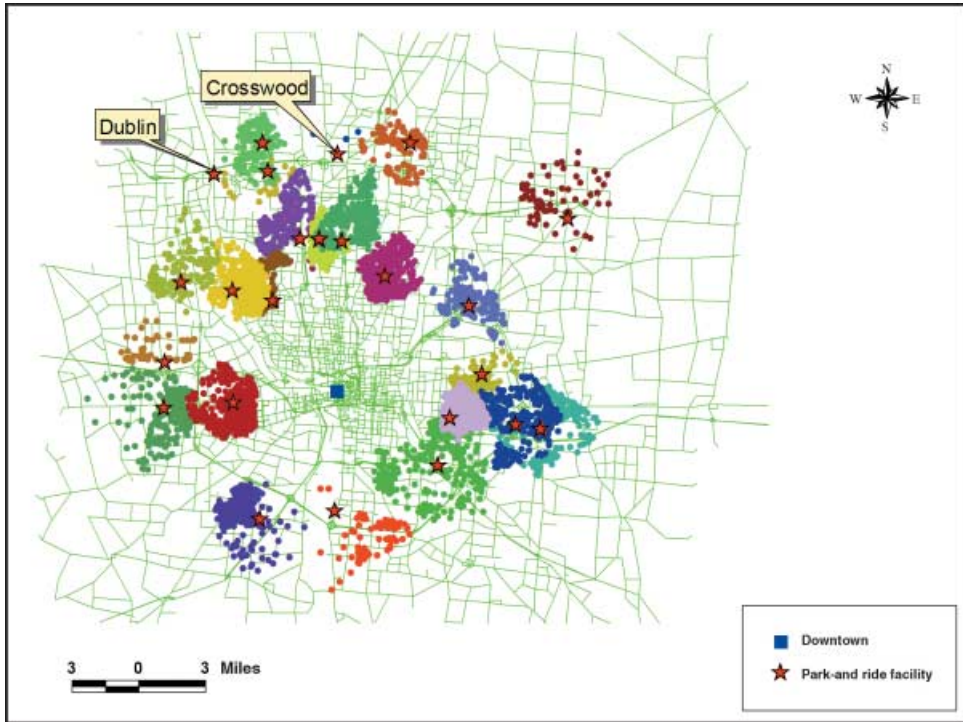


Figure 8 Market areas identified using the travel cost approach

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users. The various market area delineation approaches produced differently shaped catchment areas for many of the park-and-ride facilities. This is most obvious when visually comparing the parabolic shaped market areas (Figure 7) with the two other approaches (Figures 8 and 9). The reason for these differences is that the latter two approaches incorporate accessibility considerations and do not assume a particular geometric shape, unlike the parabolic approach.

The market areas that resulted from applying the accessibility and travel direction approach (Figure 9) are also different from those derived using the travel cost approach (Figure 8). The major difference in this case is that the travel cost approach appears to underestimate potential users of park-and-ride facilities. For example, the market areas associated with the Dublin and Crosswood park-and-ride facilities are virtually non-existent for the travel cost approach (Figure 8), because travel time using park-and-ride is greater than that using an automobile for almost all the potential users around the park-and-ride facility. In contrast, there is a recognizable market area for the same park-and-ride facilities when the accessibility and travel direction approach is applied (Figure 9) due to the fact that this approach explicitly considers travel direction. When the park-and-ride utilization rates in Table 1 are considered, it is clear that the Dublin facility is in fact used at a modest rate of 68 percent and to a lesser extent the Crosswood park-and-ride facility is as well (14 percent). However, both have essentially no

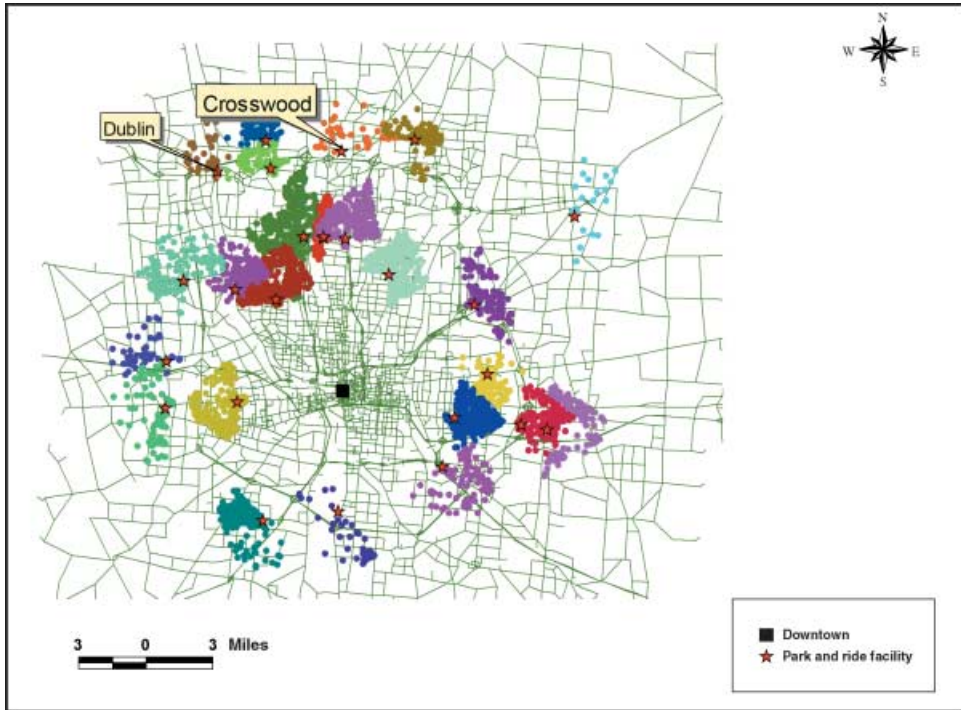


Figure 9 Market areas identified using the accessibility and travel direction approach
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user base when the travel cost approach is applied, in contrast to the accessibility and travel direction approach.

4.3.2 Assessment using regression analysis

The previous section provided a visual comparison among the market area delineation approaches, and presented evidence suggesting that the accessibility and travel direction approach performed better than the other two approaches. Nevertheless, this comparison is hardly substantiated in a rigorous way. Therefore, a need exists for further comparison of the various approaches. Something that makes sense in this case is a regression-oriented analysis. The reason for this is that supplementary information on the utilization rates of park-and-ride facilities exists (Table 1), so it is possible to evaluate the degree to which market area characteristics, both spatial and aspatial, explain observed utilization.

Multivariate regression was applied to each of the market area delineation approaches in order to assess their ability to explain the variation in utilization rates of park-and-ride lots in Columbus. The dependent variable, utilization of park-and-ride facilities, was regressed on the following independent variables associated with market areas: households with one vehicle or more; population density; percentage of trips destined to the major activity center; percentage of residential area; percentage of

population with access to transit; bus headway at a park-and-ride facility; degree of traffic congestion downstream of the park-and-ride facility; and distance between the park-and-ride facility and the major roadway. GIS was used to facilitate the quantification of these variables. For example, percentage of trips destined to the major activity center required the use of GIS to extract CTPP data at the TAZ level and interpret this at the block level. The degree of traffic congestion downstream of the park-and-ride facility, as another example, required the derivation of average daily traffic volume by street segments. This assessment and subsequent analysis were conducted using GIS.

The results of the regression analysis are summarized in Table 2 for each market area approach. Clearly the number of observations is low in this analysis. Nevertheless, subsequent analysis on residuals using Moran's I did not indicate a problem with spatial autocorrelation, which is expected given the variation in both location and neighborhood characteristics of park-and-ride lots. As suggested in Table 2, transformations of some of the variables were necessary to ensure that they were approximately normally distributed. Further, many independent variables were not found to be significant or were removed from consideration due to multicollinearity. The relationship between the dependent variable (utilization of park-and-ride facilities) and the independent variables is significant for each of the approaches, as indicated by the low p-values associated with the F-test shown in Table 2. In terms of the explanatory power of regression, the accessibility and travel direction approach resulted in the highest R^2 (0.47). This gives further support to the visual assessments given above.

5 Discussion and Conclusions

Park-and-ride services are considered an integral component of many public transportation systems in the United States. Improvement through planning efforts is essential if the goal is to remove as many vehicles as possible from congested roadways. An important step when planning for park-and-ride services is delineating ridership market areas. Market area delineation approaches that assume a certain shape do not fully consider accessibility issues. Approaches that use travel cost to delineate market areas do not explicitly consider travel direction. This paper has developed a GIS-based approach that incorporates accessibility and travel direction considerations in the delineation of the park-and-ride market areas.

In evaluating the various market area delineation approaches, it was shown that the approach developed in this paper performed better than existing ones. That is, a visual comparison among the resultant market areas showed that the accessibility and travel direction approach is more realistic than the other approaches. This was confirmed by a quantitative comparison using regression analysis. Of course limitations do exist in the performed analysis. One such limitation is that the sample size was relatively small (24 observations), which reduced the usefulness of some of the independent variables. Another limitation is that the various market area delineation approaches were compared in only one city, Columbus, Ohio. A comparison based on a number of urban areas would further confirm the anticipated advantages of the accessibility and travel direction approach over the others.

GIS are known for their capabilities in representing, creating, analyzing, and displaying spatial data (Hanson 1995). With few exceptions, the capabilities offered by GIS for delineating park-and-ride market areas have not been detailed in the literature.

Table 2 Regression results for the market area delineation approaches*

Variable	Parabolic	Travel cost	Accessibility and travel direction
Intercept	18.8615 (2.017) [0.056]	45.933 (3.187) [0.004]	19.132 (2.326) [0.030]
Distance between the park-and-ride facility and the major roadway**	-8.371 (-2.972) [0.007]	-9.914 (-3.583) [0.002]	-7.122 (-2.553) [0.018]
Degree of traffic congestion downstream of the park-and-ride facility***	NS	21.051 (1.557) [0.134]	NS
Percentage of trips destined to major activity center	0.891 (1.629) [0.118]	NS	1.040 (2.293) [0.032]
F-statistic	7.118 [0.004363]	7.293 [0.003935]	9.251 [0.001315]
R-squared	0.41	0.40	0.47

* t-values are shown in parentheses, and p-values are shown in brackets

** this variable was transformed as Ln(X)

*** this variable was transformed as $-(X^{-3})$

NS: not significant

This paper has shown that a clear description of market area delineation approaches combined with the use of GIS offers the capability for relatively easy implementation. Further, this paper has utilized GIS-based functionality for examining and visualizing park-and-ride market areas. Finally, this research has extended GIS capabilities to assist in the development of an approach that incorporates accessibility and travel direction considerations in the market area delineation. The capability to effectively and accurately delineate likely market areas help in explaining the spatial and socio-economic characteristics of users in the market area, which is a prerequisite for more detailed locational analysis in the planning of additional park-and-ride services. Planning for such services is essential if public transportation systems are to be more heavily utilized.

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