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Section 5310 Transportation State Management Plans: A Baseline Review

*Alexandra Enders and Tom Seekins
University of Montana*

Abstract

The Federal Transit Administration's Elderly and Persons with Disabilities Program (§5310), in place since 1975, has been particularly important for states trying to fill gaps in accessible transportation services where existing transportation is "unavailable, insufficient, or inappropriate." This article provides a baseline review and analysis of §5310 State Management Plans. It shows the similarities and differences in the approaches states have taken in the kinds of policies they enact, what they emphasize, and how transportation services are organized, planned, designed, and carried out to meet the special needs of elderly individuals and people with disabilities.

Introduction

The 1970 amendments to the 1964 Urban Mass Transportation Act (P.L. 91-453) established a national policy for integrating people with disabilities when it was declared to be:

... national policy that elderly and handicapped persons have the same right as other persons to utilize mass transportation facilities and services; that special efforts shall be made in the planning and design of mass transportation facilities and services so that the availability to elderly and handicapped persons of mass transportation which they can effectively utilize will be assured; and

that all Federal programs offering assistance in the field of mass transportation (including the programs under this Act) should contain provisions implementing this policy.

The Federal Transit Administration's (FTA) Elderly and Persons with Disabilities Program was developed in response to this legislation. Section 5310 of the Federal Transit Act (49 U.S.C. §5310) has two major parts. The first, §5310(a)(1), directs the FTA to support public transportation services planned, designed, and carried out to meet the special needs of elderly individuals and individuals with disabilities within its other capital assistance grant programs. The second part, §5310(a)(2), provides funds states can use to fill gaps when transportation services covered by the first part are "unavailable, insufficient, or inappropriate."

The goal of the second part, managed by the states, is "to improve mobility for the elderly and persons with disabilities throughout the country" (USDOT 1998). Since the first federal grants in 1975, this program has helped local human services organizations acquire vehicles for community transportation services. While this capital assistance program originally was designed to fund vehicle purchases, it allows flexibility to meet local circumstances. Each state, as the grantee, must describe how it will implement the program in a State Management Plan (SMP), addressing specific items that are periodically updated (USDOT 1998, USDOT 2007).

The first federal §5310 grants to states were awarded 15 years prior to the 1990 Americans with Disabilities Act. This relatively small but important program has evolved over the years. Its funding has grown, almost doubling in the past decade to \$135,823,746 in FY 2009.

While statewide long-range transportation plans have been systematically evaluated (Noerager & Lyons 2002), little has been reported about the comparative structure, content, or status of state §5310 policies that set the parameters for local implementation. Kidder (1989) demonstrated the cost-effectiveness of coordinating §5310 sub-recipients to increase transportation in small towns and rural areas. Subsequently, coordination became an area of emphasis in national policy (e.g., Executive Order No. 13,330 [2004]). However, Seekins, Enders, and Sticka (2007) found that less than half of §5310 sub-recipients participated in any kind of coordination and less than five percent participated in consolidated programs.

The purpose of this study was to assess the status of the SMPs and to establish a baseline against which changes in national transportation policy might be assessed. Specifically, we aimed to learn more about the approaches states took to

meet the needs of elderly individuals and people with disabilities; identify current practices, approaches, and innovations; and provide a resource for state policymakers, administrators, and advocates to learn from and build on each other's work.

Methods

§5310 SMP policies in place before the passage of SAFETEA-LU (Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users, P.L. 109-59, August 2005) were reviewed. Document analysis methods (e.g., Bailey 1978; Watson 2005) were used to review only the approved written documents describing each state's approach to implementing the §5310 grant program. While this approach may not capture all the details of actual program implementation, it is a non-reactive method that consistently describes the status of the formal, approved approach.

We framed this analysis within a post-ADA context, with the implicit assumption (put forth in the 1970 statement of national policy) that in the 21st century, a desired outcome of the §5310 program is an integrated public transportation system accessible for everyone, including people with disabilities and elderly.

Data Source

State management plans and related documents were collected from all 50 states and the District of Columbia. Initially, we contacted each state §5310 coordinator by mail to announce the project. Mail, email, and phone calls followed to request a copy of the state's current SMP, and the application packets, scoring sheet, and review criteria used to select grant subrecipients, along with any other relevant supporting documents.

The SMPs reviewed were the states' most recent operating document prior to the passage of SAFETEA-LU. The documents dated from 1998 to June 2005. SMPs ranged from less than one page long (part of a larger combined program document) to 117 pages. A total of 28 covered only the §5310 program; 11 covered both §5310 and §5311 programs; 6 included other FTA programs; four also included related state programs; and 2 were fragments from larger unreferenced documents.

Measurement and Assessment

FTA Guidance Circular C 9070.1E (in place from October 1998 through April 2007 and in effect throughout the baseline review period) was used to develop a basic

review template. FTA required that an SMP provide information about 12 elements. These formed the core variables in this baseline assessment, including 1) program goals and objectives, 2) roles and responsibilities, 3) eligible grantees, 4) local share and local funding requirements, 5) project selection criteria and method of distributing funds, 6) annual program of projects development and approval process, 7) coordination, 8) private sector participation, 9) civil rights, 10) Section 504 and ADA reporting, 11) other provisions, and 12) state program management.

The data recording form had two sections. The first, State Policies, included the 12 data elements listed above. The second, Policy Review, included state definitions of disability and the youngest age to be considered elderly; state policies about vehicle useful life, vehicle procurement, ownership and matching funds; and numbers of subrecipients and federal dollar tracking.

The assessment included checking for evidence of public involvement, state-determined options and exclusions, and mechanisms to support rural-urban equity in resource distribution. We identified noteworthy practices and included notes about each state model.

Procedures

Each SMP was read in its entirety and observations were noted. In the early stages of review, it became apparent that, despite common language, states actually were investing \$5310 resources on different transportation “pathways.” These pathways involved movement either to integrate transportation systems, as suggested by Kidder (1989), or to maintain separate specialized services. A pathway was described for each state. As the review proceeded, new categories of observation emerged. When a new category was added, previously scored SMPs were reviewed to seek evidence of these new items.

Limitations of the Study

This study was based on formal state management plans and related documents and included no additional interviews or follow-up questions. It is likely that the written documents did not capture all aspects of a state’s implementation. Some SMPs are quite sparse and do not include even the information available on the state’s DOT website. It should be noted that only one researcher reviewed all of the SMPs. Despite these limitations, this is the first comprehensive assessment of state policy governing the \$5310 program, to the authors’ knowledge. No previous study

offered guidance in developing the categories of measurement for assessment. As such, this study offers a baseline on which future studies may be based.

Results

This analysis addresses many aspects of the policies and procedures governing state program implementation, including service eligibility, how subrecipient need is established, programmatic intent and orientation, vehicle accessibility requirements, and geographic equity. The analysis also reports on coordination, including assuring coordination barriers do not exist, and insurance liability and responsibility, as well as vehicle utilization criteria. Analysis of SMP elements more relevant to internal administrative protocols are not included here but can be found in a more detailed report with additional analyses available at http://rtc.ruralinstitute.umn.edu/transportation_publications.asp.

Service Eligibility

States used a variety of disability definitions to determine rider eligibility. Not one used the exact definition in the Federal Transportation Act (FTA) (49 U.S.C. 5302[a] [5])¹ or the 2000 Census² definition that determines how §5310 funds are apportioned among the states. This lack of consistency makes it difficult to measure how well the program is meeting national goals. Only 30 SMPs included a definition of *disability*. A total of 13 were similar to the FTA definition, 10 used or were similar to the ADA definition, and 3 used their own definitions. Nevada included multiple definitions, and Iowa's transit system was open to everyone but mentioned that regional systems could use their own definitions.

Thirty SMPs also defined *elderly*. Twenty-two used 60 years of age; four used 65 years of age, and two used 55 years. Wisconsin applicants could adopt a higher age limit not to exceed 65 years of age. Mississippi gave two numbers, 55 and 60 years of age. And, again, Iowa's transit is open to everyone, so no age limit was given.

Two states included additional eligibility criteria for riders: Georgia allowed local determination, and Idaho based ride priority on the purpose of the trip.

How Subrecipient Need is Established

The intent of the §5310(a)(2) program is to provide transportation services that meet the special needs of elderly persons and persons with disabilities when other public transportation is unavailable, insufficient, or inappropriate. Accordingly, statements that defined when existing transportation services were *unavailable*,

insufficient, or *inappropriate* were sought. Upon finding that only one state (California) had specific criteria defining these three critical dimensions, the criteria were relaxed to include a statement such as “Identify shortcomings of existing services and how your project will overcome them” as acceptable. Only 14 SMPs included any criteria for these three key terms, and only one, California, had detailed operational descriptions and tied each term to scoring criteria.

Seven of these 14 SMPs included both 1) instructions for how the subrecipient was to document need and 2) criteria for the terms unavailable, insufficient, or inappropriate. An additional 13 SMPs, for a total of 20, included directions for how subrecipients should document transportation need. These directions ranged from asking applicants to describe the urgency of the agency’s need to documenting transportation need within their communities, i.e., not just in terms of the organization’s need. For example, in Louisiana, a “... grant will not be approved unless you can demonstrate that the existing services in your geographic service area are insufficient, inappropriate, or unavailable.” It is interesting to note that with most (n=37) SMPs without criteria for describing *unavailable*, *insufficient*, or *inappropriate* transportation, the concept of need sometimes seemed to stray from the original intent. Even though an agency may be able to demonstrate that its clients urgently need a service, it does not necessarily follow that existing community transportation services are *unavailable*, *insufficient*, or *inappropriate*.

Sign-Off Mechanisms

SMPs in some states required applicants to contact all the urban and rural transportation providers and private non-profit and private for-profit operators in their service areas to verify that the proposed service could not be provided by existing systems and to include these responses with their applications. Examples include:

- Idaho: Applicants must provide “a Letter of No-Conflict from urban and/or regional public transportation provider; and if a senior center, also from Aging and Adult Services.”
- Indiana: “The Provider Notification Letter requests assurance from public and private transit operators in the service area that the services they provide are not designed to meet the needs of elderly persons and people with disabilities as proposed in your section 5310 application.”
- Michigan: “Obtain individual sign-offs from each public and private transit and paratransit operator in your service area, stating that the services they are providing or are prepared to provide are not designed to meet the

special needs of elderly persons and persons with disabilities within your service area....”

Programmatic Intent and Orientation

Surprisingly, the review found considerable ambiguity about the relationship between the states’ programs and national transportation goals. While half of the states appeared to be heading purposefully toward integrated transportation systems, others were using their §5310 funds to maintain separate specialized human services transportation programs. The pathway taken appeared to depend on whether a state interpreted the §5310 program as a mechanism to strengthen and coordinate human services transportation or as a resource to improve a community’s overall transportation systems in the process of meeting the needs of the elderly and people with disabilities.

SMPs were grouped along three different pathways. Figure 1 shows the three pathways from a ridership perspective. Each pathway reflects assumptions about what gaps the program is trying to fill.

The first pathway focuses on the assumption that public transportation may be *inappropriate* for the elderly or people with disabilities who are clients of human service agencies. Instead, special, segregated services are needed. This pathway leads primarily to rides for the agency’s clients or for individuals with similar ages or similar diagnoses. Further down this pathway, rides may be coordinated for people similar to agency clients, but client categories are not combined (i.e., seniors and people with developmental disabilities do not ride together). Or, taking a different branch on this path, several agencies may decide to coordinate rides for all their clients. In either case, while the services are indeed “planned, designed, and carried out to meet the special transportation needs of the elderly and persons with disabilities,” they remain segregated from any public transportation systems. Arizona provides an example of this approach.

The second pathway reflects the assumption that existing public transportation is *insufficient* and emphasizes broader coordination to increase efficiency. States on this path organized human service agencies to meet the transportation needs of their clients, while moving toward a system that would be sufficient for all. This pathway expanded eligibility beyond an agency’s clients to people who are similarly transportation disadvantaged. Goals in these SMPs lead to integrated systems for the general public, “planned, designed, and carried out to meet the special trans-

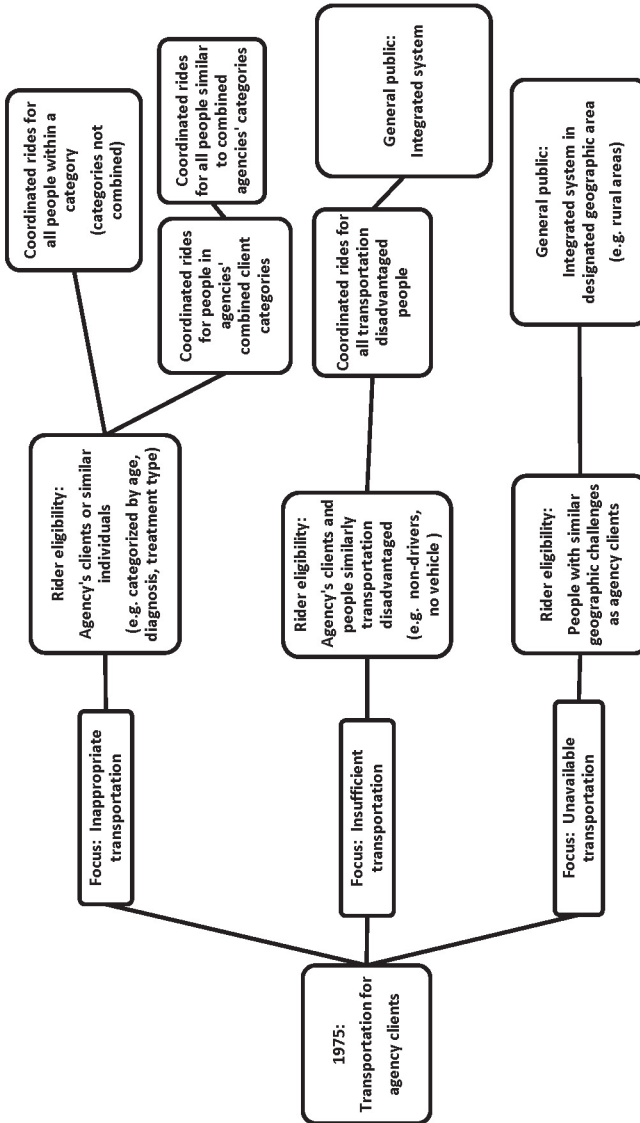


Figure 1. Alternate pathways used by State \$5310 programs.

portation needs of the elderly and persons with disabilities.” The SMPs from Alaska and Michigan provide examples.

The third pathway emphasized the assumption that transportation is *unavailable* and organized all available resources to create a system for public transportation. These states typically focused on the lack of transportation in rural areas and used §5310 resources to provide a foundation for integrated public transportation services. This pathway can lead to integrated, sometimes regional, systems for the general public in designated geographic areas, which are “planned, designed, and carried out to meet the special transportation needs of the elderly and persons with disabilities.” Iowa and North Carolina provide examples of this approach, which Kidder (1989) had demonstrated more than 20 years ago.

A total of 16 states appeared to be on the first pathway; 25 appeared to be on the second or third pathways, heading toward some type of integrated public transportation system. Of these 25 states, 10 seemed to be on the second path, heading toward fully-integrated transportation systems; 13 seem to be headed toward integrated general public/rural and small urban systems; and 2 states appeared to target rural systems exclusively.

Vermont seemed to be on all three pathways at once. Rhode Island had a state-wide system and used §5310 funds for paratransit services within its general public transportation system. SMPs from the eight remaining states were unclear or did not provide enough information to discern the pathway.

The tension between specialized transportation and general public systems was apparent in the two SMPs (Nevada and Kentucky) that required assurance from subrecipients that they would not restrict their riders from using public systems when available. Other SMPs explicitly stated that §5310 funds could not be used to support services competing with other providers. Vermont had a state law (24 V.S.A., Chapter 126, 5090 Human Service Transit) requiring agency programs to buy client transportation through public transit systems wherever cost effective and appropriate to client need.

The intent to develop coordinated, integrated public transportation systems and to use §5310 funds to fill in existing gaps is clearly stated in a number of SMPs. For instance, Mississippi’s SMP cites the adjunct role of the program:

While the MDOT acknowledges that the §5310 Program focus is on elderly and disabled persons, it is the MDOT’s policy that §5310 services are to be

considered as an adjunct to existing and/or planned public transportation system. Rather than establishing exclusive service for closely qualified clientele, these services are intended to provide a full range of mobility to anyone in the categories of elderly and handicapped.

Vehicle Accessibility Requirements

Many elderly individuals and people with disabilities use mobility devices such as wheelchairs. While vehicle accessibility to accommodate these riders is a requirement for §5310 capital assistance, waivers are permitted. Seven states (almost 14%) did not appear to allow any vehicle accessibility purchase waivers. California, Delaware, Illinois, Maine, Minnesota, Pennsylvania, and Rhode Island state that §5310 funds could be used only for the purchase of accessible vehicles, without exception.

The other 44 SMPs had exceptions related to the system or service viewed as a whole. States took a variety of approaches to the *equivalent service* criterion for wheelchair access. Some (e.g., Tennessee, Montana) required that subrecipients must have and maintain an accessible vehicle within its organization. Others permitted shared use or allowed purchase of accessible service instead of buying accessible vehicles. Exceptions tended to be made for recipients that had other accessible vehicles, but some exceptions were broader, e.g., if other accessible vehicles were available in their service area. Most did not allow the subrecipient an exception because it was stated that current riders did not need an accessible vehicle, unless the agency already had an accessible vehicle. Generally, a lift-equipped vehicle had to be replaced with a lift-equipped vehicle unless there was already another in the fleet.

Thresholds for triggering a waiver varied. For example, in Louisiana "... you will not be allowed to select a vehicle without a wheelchair lift unless 50% of your present fleet is handicapped accessible, less than 5 years old and has less than 100,000 miles," while Washington, D.C. required equivalent service only when a subrecipient requested a non-accessible vehicle with capacity greater than 16, including the driver.

Twenty-two SMPs included criteria for certifying accessibility waivers. Another eight appeared to have a waiver procedure but did not provide details. The other 14 SMPs were unclear.

Geographic Equity

The §5310 grant program is somewhat unique in that its funds are available to any geographic area in a state, regardless of population density. While state plans are not required to address this issue, SMPs were reviewed to determine if a goal of geographic equity was included and if mechanisms were described to support rural-urban equity. Accessibility gaps in transportation services have narrowed considerably since 1970, especially post-ADA in larger metropolitan areas. In non-urbanized rural areas, especially in areas where there are still no transportation services at all, the transportation picture may still look like it did in 1970 - nothing is still nothing.

The §5310 program has been important in filling the gaps in accessible transportation services for seniors and people with disabilities. Historically, Kidder (1989) demonstrated how the §5310 resources could be used to build basic public transit systems in rural areas through coordination among human service transportation programs. States continue to use the flexibility built into the §5310 program for this purpose. Some (n=13) states appeared to invest their §5310 funds primarily in general public/rural and small urban transportation systems. North Carolina went one step further and allocated all its §5310 funds to the §5311 non-urbanized program, while still addressing the programmatic intent of §5310. Arizona's SMP appeared to focus on rural areas and precluded awards to programs eligible for §5307 funding.

Coordination

Coordination became a §5310 program emphasis as early as 1975 (Applies Resource Integration 1980; Hauser, Rooks, Johnston & MacGillivray 1975; Knapp, Worthington & Burkhardt 1980; Ohio Department of Transportation 1991) in order to promote efficient resource use and recognition of the role the program could play in developing rural transportation services (e.g., Kidder 1989). Nationally, coordination has evolved from an option, to a point of encouragement, to an emphasis, and, more recently, as a requirement (Executive Order No.13,330 2004; SAFETEA-LU 2005; Federal Interagency Coordinating Council on Access and Mobility 2006). Despite this, Seekins et al. (2007) found that fewer than half of §5310 subrecipients participated in any kind of coordination and that less than five percent participated in consolidated programs.³

Thirty-seven SMPs described state-level mechanisms, legislation, review boards, and policies encouraging or mandating coordination at local level. These ranged in content from simply including boilerplate language from FTA guidance to detailed descriptions for implementation mechanisms with citations to relevant state stat-

ute. Table 1 presents selected examples of coordinating mechanisms described in the SMPs.

Table 1. Coordinating Mechanisms

State	SMP Statements Encouraging or Mandating Coordination
Arizona	Encourages the use of a local “umbrella agency” by applicants – i.e., a coordinated application of two or more agencies.
Connecticut	Application appendix describes various coordination models, providing guidance about what is possible with coordination.
Florida	Florida Commission on Transportation Disadvantaged; 11 local clearinghouses; Regional Planning Councils; Community Transportation Coordinator in each county (Chapter 427 Florida Statute 427.015[1] to ensure that coordinated transportation services are provided to the transportation disadvantaged in a designated service area.
Indiana	Requires applicants to establish or participate in an existing Transportation Advisory Committee.
Iowa	Subrecipients are the 16 Regional Transit Systems designated by the state to be responsible for coordinating publicly-funded passenger transportation services, including services to the elderly and people with disabilities.
Kentucky	Only one agency in an area will be funded and is designated the §5310 recipient. The designated recipient assumes responsibility for coordinating requests from any group for service in their area.
Maine	Biennial Operation Plan (BOP) in each of eight regions must provide “maximum feasible coordination of funds among all state agencies that sponsor transportation in the region.” Agencies cannot receive funds without being included in BOP, and all providers receiving funds must coordinate.
New York	Rural Public Transportation Coordination Assistance Program established in state law.
South Dakota	Coordinated Transportation Initiative, a joint effort of the state departments of Human Services, Social Services, and Transportation, seeks to create a single entity in each community. SMP describes how the process operates.
Utah	Coordination of §5310 and §5311 providers is mandatory in applicable areas; includes signing off area providers.

One possible outcome of coordination is that a local system of public transportation could develop where previously none had existed. For example, Michigan's SMP provided a mechanism for using funds to help change specialized services to a more broadly-integrated regional public transportation service model. The SMP states:

Counties that only have specialized services are eligible to apply for regional funds for service that meets the above definition. Up to 20 percent of the proposed new service can be used to provide local service in addition to the existing specialized service transportation. In those cases, if the regional program is successful, at the completion of the three-year demonstration period, the specialized services program would have to be folded into the countywide service being provided. This service would be eligible for formula funds and would have to be advertised, open door service available to the general public. Details of this possible eventual merger should be addressed in the regional coordination study.

Table 2 provides examples of different approaches states used to encourage sub-recipients to increase coordination.

Table 2. Coordinating Incentives

State	SMP Statements Providing Incentives for Coordination
Alaska	Vehicle must work in a coordinated system, even if the recipient is not currently part of the system, but might be within vehicle’s useful life.
Colorado	Emphasizes that “evaluation of coordination is, to a large extent, an evaluation of an entire community’s coordination success, not just that of the applicant.”
Delaware	Funds only those agencies willing to participate in a coordinated system.
Illinois	Applicants who score “zero” on coordination are ineligible for funding no matter how high their total score may be.
Kansas	All applicants must go through Coordinated Transit Districts, the backbone of the program.
Maine	Under Biennial Operation Plan (BOP) regulation, all providers receiving funds must coordinate. Providers cannot receive funds without being included in BOP.
Michigan	Act 51, Public Acts 1951 requires coordination of specialized transportation services. Applicants must serve as coordinating agency in a county or multi-county region; coordination plan update must be submitted with application. In urbanized areas, agencies new since 1994 required to lease vehicles to the transit agency.
Minnesota	Applicants demonstrating coordinated efforts are given priority.
New Hampshire	DOT can take vehicle away or require coordination if hours of service are less than 30-40 per week. If agency cannot generate these numbers, they have to find an eligible agency to coordinate with.
New York	Shared vehicle use mandated. Clearly states that “cooperation among organizations does not constitute co-ordination.” Application must include certification that coordination barriers do not exist.
Ohio	\$400,000 set aside for projects that exemplify multi-agency coordination.

Table 2. Coordinating Incentives (cont'd.)

State	SMP Statements Providing Incentives for Coordination
Oregon	"If the source of match causes the use of the project to be limited to a specific group of clients or purpose, identify the limitation. If the constraint limits or prohibits coordination with other transportation providers, the project may not be funded."
South Dakota	"Communities with coordinated transportation system are not guaranteed additional state or federal dollars for transit purpose but they will receive a higher priority for funding from state agencies when dollars for transit vehicles procurements and operating grants are being allocated."
Tennessee	Assigns higher ratings to applicants who coordinate general public and specialized transportation.
Texas	Coordination required within each district. "If a TxDOT district office does not need the entire allocation, the commission or the executive director will distribute the balance to the remaining TxDOT district offices in accordance with the distribution formula or to individual projects identifying an exemplary commitment to a coordinated transportation network."

Three states had policies that actually could discourage coordination and/or participation in collaborative systems. For example, South Carolina’s SMP discouraged vehicle use agreements between agencies, and Arizona’s SMP said it encouraged coordination but included a disclaimer saying coordination could “... detract from the recipients (presumed) primary §5310 mission” and that §5310 assistance should be a “distinctly separate function” within the organization.

Assuring Coordination Barriers Do Not Exist

Oregon’s SMP included attention to barriers that could be imposed by the applicants matching funds: "If the source of match causes the use of the project to be limited to a specific group of clients or purpose, identify the limitation. If the constraint limits or prohibits coordination with other transportation providers, the project may not be funded."

Seekins et al. (2007) found that insurance was a major barrier to coordination and reported several reasons §5310 subrecipients gave for lack of coordination, including that their insurance did not permit it, and the organization’s board of directors did not allow it. Therefore, language in the SMPs and application packets was sought that addresses this issue. New York’s application package included a “Certification That Coordination Barriers Do Not Exist,” wherein applicants must

certify that they are not restricted in coordinating transportation services because of any internal policies or regulations.

Insurance Liability and Responsibility

Insurance coverage for liability includes passenger and driver liability issues. No SMP was found that addressed the broader issue of generic liability responsibility, nor was any SMP guidance found about how liability responsibility is to be shared in coordinated models.

Vehicle Utilization Criteria

When considering participation in a coordinated system, there is an implicit question that usually goes unasked and unanswered, but is important to consider: Why would an agency want to allow its vehicles to be used by others when additional use will increase the vehicle’s mileage and wear and hasten the need for replacement? Table 3 lists examples of states that included vehicle utilization criteria that encourage more use.

Table 3. Utilization Criteria and Passenger Service Hour Expectations

State	SMP Statements Encouraging More Vehicle Use
California	Rejects applications with expected use lower than 20 hours per week.
Massachusetts	Priority for services operating 8-hours-a-day, 40 hours-a-week service. (SMP, p.5)
New Hampshire	“The DOT does not want to acquire vehicles that will not be utilized extensively. Do not apply unless your agency has sufficient funds to operate a vehicle at least 30-40 hours per week or a working agreement with other eligible agencies to ensure such a level of use.” (Application guidelines, p. 4)
New York	Vehicle expected to provide minimum passenger-one-way trips every 6 months: 1,000 trips for a 7-passenger vehicle; 1,500 trips for an 8-11 passenger vehicle; 2,000 trips for a 12+passengers vehicle. Application focused on buses, with a 12+ passenger bus being the smallest vehicle listed.
Ohio	Minimum expected utilization of at least 6 hours a day, 10,000 miles per year.
Tennessee	Reviewers look for at least 25 hours actual passenger service per week. (SMP, p.12)
Washington	Vehicles expected to attain a minimum of 100 passenger-service-miles per week per vehicle; or 100 one-way-passenger-trips per week per vehicle.” (SMP, p.21)
West Virginia	Vehicle must have at least 80,000 miles on it at time of application to be considered for replacement. (SMP, p.4)

Discussion

The relatively small §5310 program has been carried out in surprisingly complex ways at the state level. This review documents the formal status of the program across the states, as presented in approved SMPs, and establishes a baseline against which changes in national policy can be assessed. A great deal of variation was found among state SMPs both in how policy was interpreted and how programs were implemented. These variations impact who is eligible to ride, the accessibility of procured vehicles, and not only the extent to which services are coordinated, but also what transportation should be coordinated.

The primary finding of this review is that the central criteria for establishing the local need—unavailable, insufficient, or inappropriate—are, for the most part, not clearly defined in state plans despite the stated intent of the §5310 program to make transportation service available to elderly individuals and persons with disability where it is otherwise unavailable, insufficient, or inappropriate. Only 14 states defined these dimensions in any way, and of those, only California provided operational criteria. Most states used an “agency need” based criteria that did not incorporate specific criteria for judging unavailable, insufficient, or inappropriate. As such, it becomes difficult to determine whether the existing allocation of program resources meets legislative intent or national transportation goals.

The problem is one of perspective. A program (e.g., a senior center or a program serving developmentally-disabled adults) in a community with established fixed-route services may be found ineligible for §5310 funds because transportation is, in fact, *available*. Alternatively, one could qualify because the available transportation is found to be *insufficient* (e.g., it does not run often enough to get clients to work). In this post-ADA era, how could the argument be made that available public transportation was *inappropriate* because of the presence of a disability? Such an argument would seem to be predicated on the idea that regular public transportation is inappropriate for agency clients, or with more subtlety, that perhaps agency clients are deemed inappropriate for public transportation.

One concern that emerged from the review involved the use of a “sign-off mechanism.” Some states required that an applicant, to be eligible to receive §5310 funds, secure written declarations by other transportation providers in the service area that they are unable or unwilling to provide transportation to the elderly and persons with disabilities. Such provisions may have started prior to the passage of the ADA in 1990. While this has never been challenged in court, such a provision may place those providing sign-off letters at risk for complaints filed under the Ameri-

can's with Disabilities Act, as well as the Older Americans Act. Both laws prohibit discrimination against these groups of individuals.

Maintaining a segregated system because other transportation entities may not want to add service that is "planned, designed, and implemented to include the elderly and people with disabilities" is, at best, a pre-ADA construct. Lacking strong incentives and expectations for coordination and systems integration, this special-needs approach is counterproductive in the long run, because it inhibits integrating public transportation systems.

The second main finding of this review is that there was a surprising variety found in what was expected for coordination. There was considerable ambiguity about whether coordination was to take place among all public transportation providers in an area, or just among the human service agencies that provide transportation. The confusion may be understandable. Policy guidance statements (2006) from Federal Interagency Coordinating Council on Access and Mobility clearly emphasize coordinating all public transportation providers in order to create a public transportation system that serves everyone. On the other hand, the federal coordinating initiative, United We Ride, is subtitled "Coordinating Human Services Transportation." What is clear is that differences in interpretation lead to different outcomes. For example, Iowa used §5310 resources as the backbone of community public transit systems to create a public transportation system that serves everyone, not just human service agency clients. North Carolina fully integrates the §5310 program into its rural transportation system. Other states, e.g., Arizona and New Mexico, developed networks of coordinated transportation among its human service agencies for their clients.

This diversity is reflected in the pathways concept that emerged from this review. SMPs reflect three pathways, including 1) maintaining agency-based segregated systems, 2) building coordinated transportation for clients of human services agencies, and 3) creating fully-integrated community public transportation programs. Ambiguous language and the pathways concept makes it easy to predict that there would be significant challenge in communicating about, managing, administering, and transforming this important program. One of the meta-issues identified is that federal administrators, state coordinators, local transportation providers, and transportation advocates actually may not mean the same thing, even when using exactly the same words.

Guidance is needed about the meaning and intent of the phrase "planned, designed, and carried out to meet the special needs of the elderly and people

with disabilities.” Both the legislation and administrative guidance are imprecise. Does it mean designed exclusively for the target group or designed to include the target group? The language, added pre-ADA in 1970, turns on the phrase *special needs*. Does *special* mean over and above, or does it mean routine accessibility – for example, lifts on buses?

In this post-ADA environment, it was surprising to find ourselves raising the issue about whether or not special transportation services should be included when developing public transportation systems. Is the intent of §5310 to make human service transportation as comparable as possible to public transportation, or is it to make public transportation systems work for people with special mobility needs? If the latter is the case, the questions then become: What needs to happen to bring more people with special mobility needs into the public transportation system? How can the public system be improved without creating a special (*albeit* coordinated) system that is separate and self-perpetuating? SAFETEA-LU's increased focus on coordinated transportation and funding for both new and existing grant programs makes it even more important for SMPs to identify and use selection criteria and outcomes measures that work, and to be unambiguous about their program objectives.

In addition to these main findings, variations in policies involving acquiring accessible vehicles, and defining disability and elderly were identified. It is particularly surprising that only seven states require, without exception, vehicles purchased with §5310 funds to be accessible, since the target of the program is elderly individuals and people with disabilities. While accessibility waivers may maximize program service efficiency, they may hinder program effectiveness. Waivers also may be inconsistent with the expectations of other transportation programs and providers and may serve to reduce the overall supply of accessible vehicles in a community.

The lack of consistency about what constitutes a disability, and even about how old an elderly person is, makes it difficult to measure how well the program meets national transportation goals. While demographic categorization may sound like a minor point, these variations make it difficult to understand the gaps in transportation services: Who is or is not being included, and where are the unmet or underserved needs? This brings us back again to the central question of how to assess whether existing transportation is *unavailable*, *insufficient*, or *inappropriate*, and this time adds the uncertainty of to whom? It impacts how subrecipients identify the populations they serve; how ridership data is categorized and collected; how

to realign programs to serve areas where transportation services are unavailable, insufficient, or inappropriate; and how outcomes are measured.

For reasons ranging from managing resources to measuring performance, it would be desirable to include the FTA grant programs in the National Transit Database (NTD). However, one of the issues in any attempt to include §5310 data in the NTD is that states do not count or categorize rider numbers in the same way. There is a lack of interstate and even intra-state uniformity. What has been measured locally may or may not match what has been programmatically targeted at the federal or state levels.

The core management functions expected from states are expanding, but state budgetary and administrative constraints mean that staffing levels are not increasing, even though more federal funding is available. The Transportation Research Board (2007a, 2007b) reports the need to streamline grant administration and facilitate consolidated grant agreements, noting:

Some states are moving toward one grant agreement for each transit operator which include all state and federal program requirements and clauses. These often have a consolidated application and associated grant agreements. However, given the differences in federal programs, these consolidated applications and grant programs are difficult to develop. Some states suggest that all state transit programs be consolidated on the federal level in the next reauthorization rather than continuing with a variety of siloed federal programs.

This state management plan review suggests that, programmatically, the consolidated management and application approach is noteworthy and appears to lead to better systems integration. Supporting and maintaining separate segregated transportation services is both inefficient and ineffective when there is any possibility of developing integrated public transportation systems that are planned, designed, and implemented to meet the needs of the broadest range of riders, including people with disabilities and older individuals. If a public transit system can incorporate more integrated accessible service elements, it should be given the first option to do so.

Conclusion

The road from the 1970 national policy stating that “elderly and handicapped persons have the same right as other persons to utilize mass transportation facilities

and services" has taken many twists and turns. Along the way, federal investment in public transportation has increased.

The §5310 (a)(2) program is meant to address the gaps in transportation services. As emphasis shifts to integrated transportation systems serving the general public, including older adults and people with disabilities, program evaluation must include how well such systems actually get people where they want to go, when they need to get there. As transportation systems and services evolve, it becomes increasingly important, at all levels of government, to be clear about where they are intended to end up. As changes are made, it is critical that they be targeted to outcomes measured not only in numbers of rides and vehicles, but also in shared values. Agreement must be reached not only on what to coordinate, but why. As discussed in the pathways concept, without a shared vision of policy and practice and a clear idea of which way to go, it is unlikely systems and services will reach the intended destination: efficient and effective integrated transportation for all.

Federal involvement and investment in local public transportation has evolved continuously over the past 50 years. As public policy changes and funding fluctuates, programs distributing public subsidies should be continually reassessed to address the gaps and needs in areas where transportation is unavailable, insufficient, or inappropriate. This review sets a baseline for assessing progress in closing transportation gaps.

Recommendations

Nine recommendations derived from this baseline review are offered.

1. *Congress should review the framework, background, and premise of the §5310 program to clarify that this grant program is meant to support public transportation systems, not just serve human service programs. Achieving consensus about the purpose and values of transportation system capacity building, and a shared understanding about the direction the programs are headed, would be extremely helpful for state-level collaboration. Guidance should be clear and unambiguous, removing the uncertainty about goals, reducing administrative complexity, and building compliance incentives for productive approaches to improve integrated transportation systems for all.*
2. *Congress should clarify that the intent of transportation coordination is among all providers, including human service providers, in an integrated public system. While state flexibility should be maintained, federal clarity is needed so state*

implementation does not inadvertently undermine national goals. A core issue is whether two systems (human services and public transit) are coordinating services with each other, or whether one transportation system is coordinating all its varied elements, including publically-supported human services transportation. Collaborative federal-state working groups need to identify existing barriers and challenges, as well as what needs to happen to bring more people with special mobility needs into the coordinated public transportation system, and to identify what it would take to improve the universal design of the public system, without creating a special (albeit coordinated) system that is separate, segregated and self-perpetuating.

3. *States should place §5310 goals into the context of their overall agency transit goals. SMPs should be required to describe how they are addressing both parts §5310(a)(1) and §5310(a)(2) and how they are strategically and tactically linking the public transportation system with the safety-net services that address existing gaps.* Program goals and objectives in states that have combined management plans generally draw from the overall perspective of the state DOT's transit department, and usually reflect more integrated, broader mobility goals than those found in any one of the department's program elements. This makes it easier for everyone to understand the larger mission and values of the state's transportation agency.
4. *National, state, and local expectations should be established for "conversion planning." FTA and other federal agencies should work with states and advocates to develop mechanisms that permit and actively facilitate the evolution of the §5310 program. Reward mechanisms should be developed for those states and local communities who increase the accessibility, integration, and accountability of their transportation systems.* This program requires continual change and reassessment. Any state conducting business-as-usual probably is not keeping up with the evolving transportation environment. The §5310 (a)(2) program can be used as a safety net where public transit systems exist, but conversion planning should be in progress. Some states place a priority on replacing vehicles for agencies who primarily serve only their own clients; this should be recognized as perpetuating a segregated system.

Further analysis is needed to identify targeted strategies to speed the transformation from segregated human service transportation to integrated systems. When needs are still unmet, it may be difficult to decide how to

change. This review and the grassroots community study done by Seekins and others in 2007 make it clear that even when states take integrated transportation coordination very seriously, they may have an embedded base of agencies that need to change from a client-agency-based orientation to an integrated transportation model.

For example, more information is needed about the effect of Mississippi's policy to require a 50 percent match when an applicant intends to use a vehicle to serve only agency clients. Has Colorado's policy "... to assign lower scores and priority to those applicants who directly or indirectly limit or direct all or a significant part of their service to a particular clientele (e.g., elderly persons, developmentally-disabled persons, residents, or customers of a particular facility, etc.), unless that service is operated separately from that for which funding is sought," facilitated better more integrated transportation systems?

It is essential to identify the policy barriers to conversion and to figure out how best to address them. For instance, when §5317 funds expand a system beyond basic ADA requirements, §5310 funds that previously filled those gaps might be reallocated to areas where transportation is still unavailable, insufficient, or inappropriate. But, as currently configured, this would be difficult to do ("Maintenance of Effort: Recipients or subrecipients may not terminate ADA paratransit enhancements or other services funded as of August 10, 2005, in an effort to reintroduce the services as 'new' and then receive New Freedom funds for those services" [FTA circular C9045.1, p. III-8]).

5. *Each federal and state funding cycle should include a requirement to analyze and identify federal and state regulations and local practices that create barriers to developing more inclusive, integrated public transportation systems. A model practices center should be established to assist states. Consistent, continuous funding can lead to inflexible regulation and interpretation, which can stifle evolution and efficiency in developing systems. To help keep segregation from continuing, federal statutes and guidance, state management and implementation, and local practices should be reviewed regularly and assessed for effectiveness in preventing segregated transportation programs. States should be asked to identify exemplary practices they have used to improve integration of public transportation systems and to discuss them with their federal sponsors.*

A mechanism should be developed to provide state feedback to the federal agencies about elements in federal statute, regulation, or guidance that interfere with the state's ability to plan, design, and carry out integrated transportation services that "meet the special needs of elderly individuals and individuals with disabilities." While part of this function might be addressed in the triennial program reviews carried out by federal FTA regional office staff, it may be more effective if supported by expanding existing technical assistance programs (e.g., Project Action or the National Coordination Resource Center) or contracted through an external organization. A model practices center should be established to assist states analyze barriers; collect, review, and disseminate best practices; provide technical assistance about how best practices can operate in diverse environments; and foster collaboration and sharing among states.

6. *To prevent perpetuating siloed, dead-end programs that lack flexibility, Congress and federal agencies should reevaluate statutes and guidance, especially policies that encourage a funding stream to continue indefinitely in its initial form.* Federal statutes and guidance and state management and implementation should be designed to prevent institutionalizing segregated programs. Funding streams intended to address gaps (e.g., §5310, §5316, §5317) should be systematically reassessed as the thinking evolves about special needs, special services, and universally-designed generic systems. Allowing one element of the overall system to remain static can prevent flexibility in deploying resources when the mix changes. For example, allowing §5317 to create a new separate funding stream, without flexibility for integration into an evolving integrated public transportation scenario, is likely to have unintended negative consequences for system innovation and integration. Given the language in current FTA §5317 guidance (C9045.1, p. III-8), the potential for this is highly likely: "Eligible projects funded with New Freedom funds may continue to be eligible for New Freedom funding indefinitely as long as the project(s) continue to be part of the coordinated plan."

This situation is similar to the problems in federal support for rural housing. When cities and suburbs outgrew areas that originally were rural, federal resources targeting rural areas were still available in what had now become urban areas.

7. *Federal and state agencies should develop transportation program evaluation goals that reflect program objectives.* As the emphasis moves toward

integrated transportation systems, evaluation needs to include how well a transportation system supports the community participation of riders, not just how well riders can get to senior centers or other human service programs. Evaluation should look at who is unable to get transportation services—the gaps in the system—and should provide feedback on where to invest in projects that can leverage and coordinate integrated transportation.

8. *SMPs should include discussion of how the tension between human service transportation and the rest of the transportation system is recognized, addressed, and managed.* That there is tension between special human services transportation and public transportation systems is apparent, when at least two SMPs required assurance from subrecipients that they would not restrict their riders from using public transit. That is only one challenge, but it is an important one. Others include a lack of agreement about objectives and outcomes. What should be coordinated? Who can ride? Which riders are excluded? Why? Who defines need? What takes priority: service-agency need or community-rider need? Segregated services or integrated services? Is active conversion planning under way? The most significant contributor to these tensions may be unspoken issue of costs and utilization.

A state may take these conflicts for granted as a part of business-as-usual and not realize that other states may be handling these issues differently. There was no mention of how states addressed and managed these tensions in any of the SMPs. In states where little tension exists, it would be easy to address this point. In states where these conflicts are creating major barriers, it makes no sense not to address and describe how the issues are managed.

9. *Federal and state transportation agencies should say explicitly that they expect grant subrecipients to act as part of an overall transportation system.* An expectation in policy and resource distribution from both federal and state transportation agencies that subrecipients will function as part of an integrated system is likely to encourage transportation providers to act like they are part of the public transportation system. In states where this currently is not the case, operational examples ranging from planning to data collection and reporting should be provided. The behavior of public transportation providers also may need to be modeled to encourage them to include human service agencies in their culture. Incentives should be

made available. A model practices center may be useful in helping states share approaches that work.

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Endnotes

- ¹ Individual With a Disability means an individual who, because of illness, injury, age, congenital malfunction, or other incapacity or temporary or permanent disability (including an individual who is a wheelchair user or has semi-ambulatory capability), cannot use effectively, without special facilities, planning, or design, public transportation service or a public transportation facility. 49 U.S.C. 5302(a) (5).
- ² Census 2000 disability criteria: Individuals were classified as having a disability if any of the following three conditions were true: 1) they were five years old and over and reported a long-lasting sensory, physical, mental or self-care disability; 2) they were 16 years old and over and reported difficulty going outside the home because of a physical, mental, or emotional condition lasting six months or more; or 3) they were 16 to 64 years old and reported difficulty working at a job or business because of a physical, mental, or emotional condition lasting six months or more.
- ³ Local coordination is a particularly complex issue. The term coordination has been used to reflect a range of practices (e.g., Burkhardt et al. 2004), including

1) coordinated systems in which independent agencies coordinate service areas and target groups, or pool purchases; 2) brokerages in which agencies coordinate schedules or “broker” rides across agency clientele; and 3) consolidated systems in which several agencies pool all of their transit resources into a separate transportation agency that serves the entire community.

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University Traveler Value of Potential Real-Time Transit Information

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Abstract

Intelligent transportation systems (ITS) have become common in public transit systems, particularly providing real-time transit information. For new implementations, it remains difficult to predict and quantify system and user benefits of technology implementation. Although previous studies have quantified the operational benefits of real-time transit traveler information systems, a gap in knowledge exists around passenger benefits of such systems. The objective of this research was to create a refined method for evaluating transit rider benefits from real-time traveler information and predict changes in traveler behavior. The study was conducted on a rural university campus, isolating the impacts of the system from the multiple influences that often affect transportation in larger metropolitan areas. This study uniquely integrated transit system performance, pedestrian travel times, and traffic simulation to determine travel times and predict mode split. Findings indicated that reducing passenger waiting anxiety was the most significant measure of traveler benefit from such a system. While the benefits found were specific to the study site, the methodology can be used for other transit systems evaluating real-time transit technology investments in rural or urban environments.

Introduction

Intelligent transportation systems (ITS) are used to improve transportation quality and efficiency through the integrated use of communications and technologies, but anticipating the effect of technology investment in the multimodal and multifaceted transportation system is daunting. Within the scope of ITS, advanced public transportation systems (APTS) focus on public transit, and the Federal Transit Administration has invested significant research funding in this area since the mid-1990s. Past research has endeavored to capture the effects of traveler information on transit operations, traveler wait time, and willingness to ride. In many cases, the research involved examining a change in one variable, such as attractiveness of transit, without examining corresponding changes in the transportation system, such as more transit riders leaving space on the road for more vehicles. An examination of the impact of APTS on the full transportation system is needed to provide a true predictive tool for the impacts of ITS investment.

The objective of this research was to create a refined method for evaluating transit rider benefits from real-time transit information (RTTI) and predict changes in traveler behavior. This study was conducted to quantify the benefit that a proposed automatic vehicle location (AVL) and transit traveler information system could provide to transit riders. The real-time traveler information system was anticipated to provide pretrip information via the Internet and enroute information on displays at key transit stops. The new method incorporates the simulation of traffic and the stochastic estimation of pedestrian travel times as modes competing with the transit system performance. The results of this method can provide decision makers with information about the potential value of advanced public transportation systems to passengers in smaller communities and university campuses.

Previous Research into the Impacts of ITS

Designers of RTTI systems have aimed to streamline management of operations and provide benefits for riders. This section describes the current state of knowledge on the impacts of real-time transit traveler information.

System Benefits

Previous studies on RTTI significantly focused on improving operational efficiency through vehicle allocation (Crawford 2010) and other management means (Pangilinan et al. 2008; Khattak and Hickman 1998; Law et al. 1998; Nace and McKay 1997; Kontaratos et al. 1996), but not particularly on the user benefit of such systems.

The following subsections indicate research findings on the impacts to individual travelers.

Ridership Generation

As a primary system benefit for public transit, ridership generation has received much research attention. The factors found to increase the use of a new service, such as a new route or stop, have included younger riders, frequent riders, riders without a car, and the presence of riders closer to the new service than to existing (Chatterjee and Ma 2007). The ridership influence from RTTI appeared in the results of a 2002 intercept survey of 928 tourists and local residents riding the Island Explorer system serving Acadia National Park and surrounding communities on Mount Desert Island in Maine. In this study, 85 percent of bus riders surveyed said real-time information relieved uncertainty about when the bus would get to the stop, and 80 percent of bus riders surveyed said real-time information helped them decide to use the bus. The statement "I would plan to use this information if visiting in the next 12 months" met with agreement from 92 percent of the users (Zimmerman et al. 2004). This latter study indicated both a system benefit of generating ridership and a user benefit of time savings.

Mode Shift

The behavioral factors surrounding a traveler's tendency to shift modes away from personal vehicles also has been frequently studied. Throughout the world, programs have begun to encourage car drivers to explore new modes of transportation such as transit, walking, or biking (Jones 2003; Cairns et al. 2004; Brog 1998; Department of Transport 2000; Ampt and Rooney 1999; Rose and Ampt 2001; Taniguchi et al. 2002; Taniguchi et al. 2003). These encouragements typically increased awareness of travel alternatives through marketing and are generally termed travel feedback programs. These programs have induced reductions in car use between 7 and 19 percent in Australia, the European Union (Jones 2003), and Japan (Fujii and Taniguchi 2006). Most recently, Taniguchi and Fujii found that little difference exists between the benefits of diverse types of travel feedback programs and that travel feedback programs were the most effective method of changing travel behavior because they impacted either the behavioral intentions or the implementation intentions of travelers (Taniguchi and Fujii 2007). These findings suggest that although travel behaviors are difficult to change, particularly with travelers who habitually use automobiles, a travel feedback program has the most potential to encourage less personal car use, compared to other methods. Specifically, provid-

ing RTTI can provide a part of a traveler feedback program, thereby playing a role in discouraging personal vehicle usage and encouraging transit ridership.

Traveler Information and User Benefits

The following subsections indicate research findings on the impacts to individual travelers.

In-Vehicle Travel Time

Various research areas have related to the value of in-vehicle transit travel time. Some have evaluated the impact of traveler multitasking on the value of their travel time—for example, talking on the phone while riding on the bus. The researchers of one study hypothesized that because travelers viewed long waits and travel times negatively and because multitasking can make these times seem shorter or at least more pleasurable and useful, then multitasking can make the perceived cost of travel and wait times lower. Through a stated-preference survey of over 200 Dutch travelers in the Eindhoven region, researchers found that riders who enjoy multitasking perceive the time cost of their travel 32 percent lower than those who prefer to sit and wait for or on transit vehicles (Ettema and Verschurne 2007).

Intelligent transportation systems have a small role, at best, in encouraging multitasking to reduce the perceived cost of in-vehicle travel time. On-board announcements of upcoming stops can help alert multitasking people who would otherwise feel the need to focus on watching out the window for landmarks. Even so, a stronger benefit to real-time information lies in the potential to reduce the cost/utility of time that travelers spend waiting for a transit vehicle to arrive.

Out-of-Vehicle Wait Time

Several studies have focused on real-time information for transit riders. One such study used numerical methods and focused on the importance of capturing the wait time of those passengers that miss a bus due to its early arrival compared to the schedule. The findings suggested that as the standard deviation of bus arrival increases, information systems should predict that buses will arrive earlier than expected, thus reducing the number of passengers who “just miss” a bus (Chien et al. 2006).

Other studies have focused on measuring the reduction of perceived wait time when RTTI is provided, finding a wide range of results. Wardman (2003) used a face-to-face survey, finding that between 21 and 65 percent of riders perceived a shorter wait time with RTTI. Kronborg et al. (2002) found that although travelers using RTTI still overestimated their wait time (9-13%), those without arrival infor-

mation perceived wait time even longer (overestimating 24-30%). Further studies in London and the Netherlands found that providing RTTI reduced the perception of wait time by 26 percent (Schweiger 2003) and 20 percent (Dziekan and Kottenhoff 2007), respectively. While these studies identify a range of overestimation for urban transit riders, none focuses on the unique population of a college campus.

Mishalani et al. (2006) recently examined the difference between perceived and actual bus rider wait times at stops on and around the Ohio State University campus, finding that for bus headways between 3 and 15 minutes, riders perceived their wait time approximately 15 percent longer than it actually was (Mishalani et al. 2006), providing a foundation for the study described in this article.

Another study has investigated the perception of transit riders towards the value of real-time information. The findings of this work suggested that while the expected ridership increases are modest, passengers put enormous value on "... knowing when the next bus will arrive ...[,] knowing how long the delay is ...[,] and] improving on-time performance" (Peng et al. 2002). While no quantifications of these values were undertaken in this study, subsequent work has evaluated the impact of AVL on schedule performance, discovering that on-time performance can be improved by such systems (Pangilinan et al. 2008).

These last studies lend themselves back to the works discussed earlier. As individual travel experience improves, ridership improves. User benefit and system benefit are closely linked. Also, the previously-mentioned Island Explorer survey findings pose that traveler information might directly improve the user experience by helping riders save time.

Summation of the Literature Review

As presented, the most decisive findings of advanced public transportation systems have focused on operational efficiency benefits of real-time transit information, not on user benefits. User benefits have been described qualitatively (multitasking as a preferred activity) or quantified through rider surveys, yet surveys have shown that perceptions of wait time inaccurately reflect actual wait times.

When decision makers are considering investing in intelligent transportation systems, they need an objective way to evaluate costs and benefits. This study sought to quantify user benefits of real-time transit information.

Methodology

As identified in the introduction, the objective of this research was to create a refined method for evaluating transit rider benefits from real-time traveler information and predict changes in traveler behavior. This method uniquely integrates transit system performance, pedestrian travel times, and traffic simulation to determine travel times and predict mode split. Figure 1 depicts the method developed. The next subsections detail the implementation of this procedure.

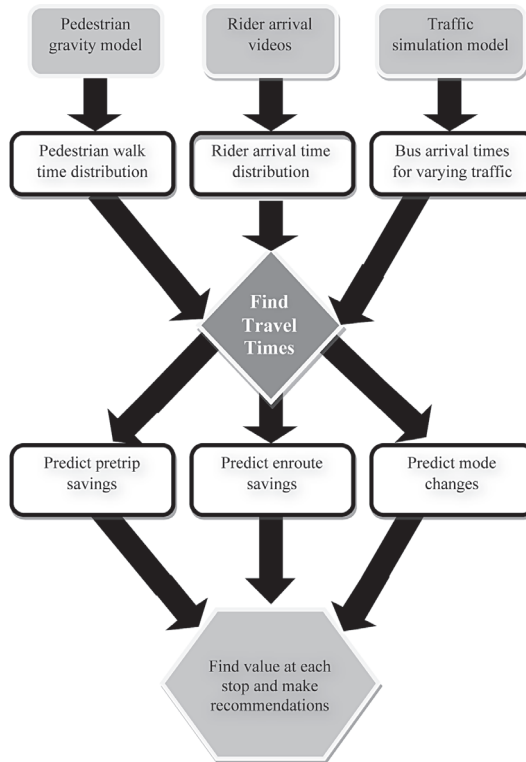


Figure 1. Process for quantifying the effects of real-time transit Information.

Clemson Area Transit (CAT) served as the test system for this study. Located in rural South Carolina (Figure 2), this bus system has operated as the only public transit serving Clemson University and the cities of Clemson, Seneca, Central, and Pendleton. CAT served a 2009 year-round residential population of 13,002 in Clemson and university enrollment of 19,111 (Table 1). CAT ridership for 2009 was reported at 1.4 million (Howard 2010).

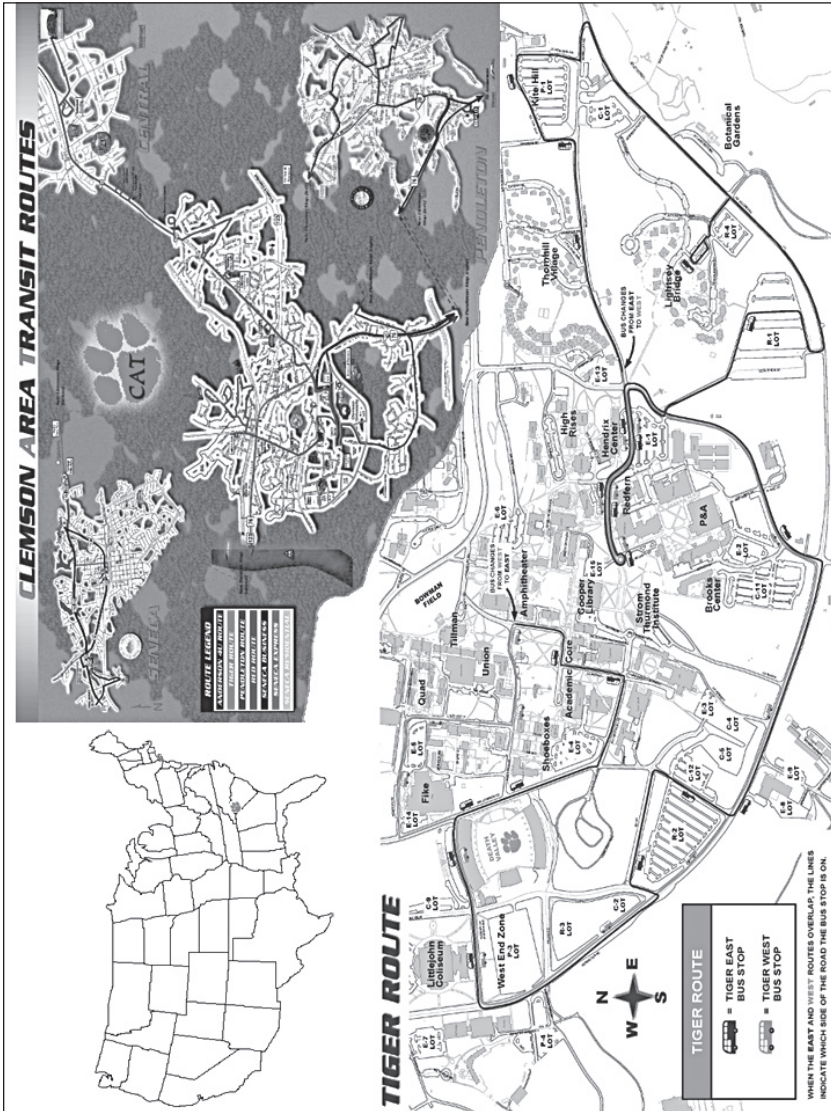


Figure 2. Clemson Area Transit location and routes.

Table 1. 2009 Estimated Local Populations and Student Enrollments Served

	2009 Estimate
City of Clemson	13,002
City of Seneca	7,832
Town of Central	4,079
Town of Pendleton	3,153
Clemson University	19,111
Tri-County Technical College	6,758

Sources: U.S. Census Bureau, *Clemson University Fact Book*, Tri-County Technical College "At a Glance."

The rural and small-town environment in which CAT operates provides an ideal scenario for isolating transportation impacts because many factors are controlled. Travel alternatives such as taxis and overlapping transit routes are relatively non-existent. Roads are uncongested, which eliminates routine delay as a contributing factor to outcomes. Also, CAT is a well-performing system; it has been recognized as a national leader for generating the highest ridership of a fare-free municipal transit system (Miller 2001).

CAT has not yet deployed ITS technology, so the system provides a base case for research at a time when service facilitation through technology makes sense. System management is investigating feasible ways to implement a prototype AVL system on buses and methods for disseminating this information. Management has expressed interest in communicating this information to passengers via displays at key stops and on the Internet. At the start of this research project, finding the value of a transit real-time information system by measuring user benefit was of great importance to CAT and Clemson University.

Find Travel Times

Travel times included walking time to the transit stop, wait time at the stop, travel time on the bus, and walking time to the final destination. The following sections detail how these times were estimated.

Gravity Model Development for Pedestrian Walk Times

To determine the location to which each transit passenger would likely walk on campus, a gravity model was built. Initially, an AutoCAD file of the entire campus was used, and a coordinate system was set around each stop in the study area.

The locations of nearby campus buildings, such as dorms, labs, and classrooms, were identified in the AutoCAD file. Next, the number of students residing in each dorm was determined, and the number of credit hours offered was calculated for key campus classroom buildings. Last, data from a 2005 on-campus travel pattern survey (Adams et al. 2005) was used to estimate that 60 percent of all bus travelers were going to class and 10 percent were going to their residence. The remaining 30 percent were traveling to other destinations such as shopping or eating. Using this information, researchers divided the transit riders between the class and residence destinations surrounding each campus bus stop. Because Eom et al. (2010) found that student registration is directly comparable to campus building activity level, the gravity for classroom buildings was determined using the number of contact hours in each building. Contact hours were calculated by multiplying the number of students per class by the number of credit hours for each class and summing the products for all of a building's classes. For example, if a particular building had only one three-credit class, with 10 students, the building's gravity would be represented by 30 contact hours (3 credits x 10 students). The researchers logically neglected buildings that were closer to other bus stops along each route, assuming travelers would find the fastest combination of transit and walking trips to reach their destination. The average gravity for classrooms was determined using Equation 1, where x denotes the east-west distance (ft) from the bus stop, y denotes the north south distance (ft) from the bus stops, and C_h represents contact hours. Similarly, for determining the gravity of residence locations nearby campus bus stops, Equation 2 was used where x and y are defined above, and R denotes the number of residents living at each location, for example, the Clemson House dormitory.

$$G_{class}(x, y) = \left(\frac{\sum x * C_h}{\sum C_h}, \frac{\sum y * C_h}{\sum C_h} \right) \quad (1)$$

$$G_{residence}(x, y) = \left(\frac{\sum x * R}{\sum R}, \frac{\sum y * R}{\sum R} \right) \quad (2)$$

To finish developing the pedestrian gravity model, the results from equations 1 and 2 were again weighted using the aforementioned ridership data; therefore, the gravity from class buildings was more significant than those from residence buildings. The gravity model was used to determine a representative walking distance and location that transit riders would access from each stop. These equations assume that pedestrians are familiar with the area, choose rather linear routes, and have no significant (larger than a building) obstacles to/from their bus stop and building.

After identifying these locations, representative walking times were collected for key bus stops and between certain bus stops. These walk times were used to create a normal distribution of walk times for each bus stop.

Transit Rider Arrivals and Wait Times

Passenger arrival rates have been studied frequently, and there is consensus that for headways greater than 10-12 minutes, the arrival distribution is not random (Csikos and Currie 2008). Although others have approximated arrivals with respect to headways (Luethi et al. 2007), there exist multiple models from around the world. The availability of video data at the study sites allowed the authors to observe transit rider arrivals in the study network from 10 AM to 2 PM (peak campus occupation), and calculate their wait time. During the observation, the bus arrival headway was consistent, and the authors assumed negligible impacts to the arrival distribution measured. Passenger arrivals did not follow the smooth bell shape of a normal distribution; instead, they more closely followed an exponential distribution, as shown in Figure 3. In addition to the normal and exponential distributions, the authors also examined the Weibull, Poisson, and lognormal distributions for goodness of fit, finding the exponential slightly better than the Weibull distribution, as shown in Table 2. This similarity is no coincidence because the Weibull distribution is merely a special case of the more-general exponential distribution.

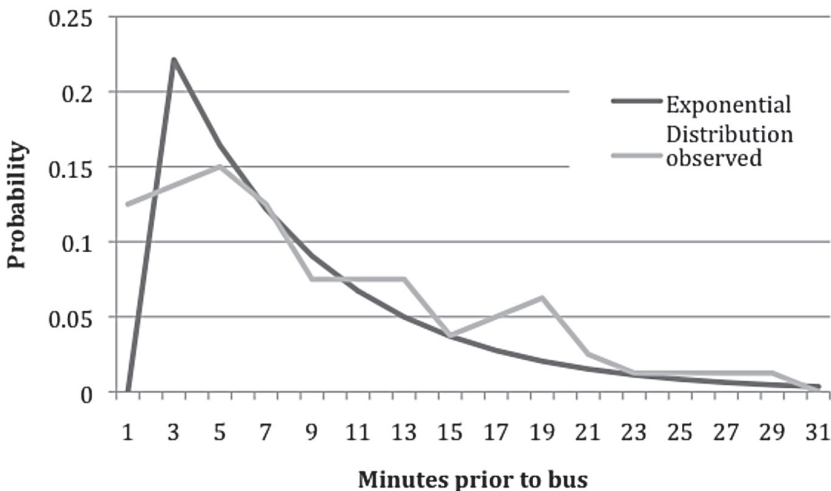


Figure 3. Passenger arrival probability distribution for Red Route bus stops (Fries et al. 2009).

Table 2. Distributions’ Goodness of Fit to Passenger Arrival

Distribution	Goodness of Fit (r^2)
Normal	0.572
Poisson	0.383
Lognormal	-0.823
Weibull	0.779
Exponential	0.780

Researchers also examined the activities of those awaiting bus arrival. Findings suggest that 54 percent of waiting travelers multitask. To allow the applicability of previous research (Ettema and Verschurne 2007), multitasking was considered as participating in any task while waiting for the bus. Because multitasking can decrease the time-cost of waiting for a bus, this factor was used to determine an appropriate time value.

Three different bus routes were examined in this analysis (Red, Blue, Pendleton), and the scheduled headways are displayed in Table 3. Passenger arrival data were collected for Red route (30-minute headways) passengers, and the passengers arriving at stops for the Pendleton route (60-minute headways) were assumed to follow the same distribution of arrival because both routes have long enough headways to cause travelers to plan their arrival at the transit stop. Thus, it was assumed that riders of both routes would arrive approximately 5 minutes before the bus and rarely arrive more than 10 minutes prior. Because of the Blue route’s short headways (5.7 minutes), riders would not likely refer to schedules and were assumed to arrive randomly (McLeod 2007).

Table 3. Scheduled and Observed Bus Headways

Bus Route	Scheduled Headways (mins)	Observed Avg. Headway (mins)	Standard Deviation (mins)	Error (E) for 95% Confidence (mins)
Red	30	29.7	2.1	0.7
Blue	6	5.7	1.6	0.4
Pendleton	60	59.8	3.1	1.8

Bus Arrival Distributions

Bus arrival distributions were collected from video data similar to passenger wait times and, in some cases, during the same viewing. To increase the number of observations, bus headways also were used from videos containing no stops by

recording the frequency a certain bus passed by, assuming it would arrive at stops with roughly the same headway and variance. The aggregated data for these bus arrivals is shown in Table 3. Note that the average headway of each bus has been captured with 95% confidence and an error that was no more than three percent of the headway (maximum found for Pendleton route).

Travel Time Calculation

After finding the characteristics of walk times, rider wait times, and bus headways, the travel times were found. To account for the variable nature of transportation network demand and travel times, particularly for transit vehicles without dedicated rights-of-way, a traffic simulation model was used. The model was built using VISSIM and included approximated 13,000 links, over 700 parking lots, and 12 traffic signals around campus. Because multiple routes were available between each origin and destination, a dynamic assignment approach was taken to model the background traffic. Further, multiple classes of vehicles were defined to mimic the parking restriction differences between faculty and staff, students, visitors, local residents, and university vehicles. This model was extensively calibrated and validated as described in Fries et al. (2010). Calibration included checking volumes, adjusting link costs, verifying signal operations, and comparing travel times, then adjusting driver characteristics until travel times were within one percent of observed. The validation included verifying volumes were within one percent of observed, comparing travel speeds, and conducting face-validation, a visual comparison of the simulated traffic and the observed daily traffic.

CAT operates eight transit routes: Orange Route, Red Route (eastbound and westbound), Blue Route, Pendleton Route, Central Maverick Route, Seneca Express Route, Anderson Route, and Lightsey Bridge Route. These routes serviced 29 stops in the model and, while several routes may service the same stops, passenger loads were modeled uniquely for each line according to the 2007 Ridership Count Survey (Connectics 2007). Dwell times were not specified; instead, dwell times were determined based on the number of passengers observed to either board or alight at a stop.

The simulation model also was used to quantify the impact of varying traffic demands. Seven scenarios were simulated, each representing a different percent of the average traffic demand, including 50, 75, 100 (base scenario), 125, 150, 175, and 200 percent. During these simulations, the average travel times were recorded for buses and private vehicles (considered as all vehicles other than buses).

Summing the total travel time for transit riders, a random number generator selected 100 walk times to each bus stop based on a normal distribution from the collected data. Next, another random number generator selected 100 wait times from an exponential distribution developed from the observed wait time data. After that, 100 bus travel times were found from the simulation model using the base scenario (100% traffic demand). Last, 100 samples were taken randomly from a normal distribution of walk times from the destination stop. Adding each sample together provided 100 stochastic travel times for each pair of origins and destinations selected. For example, one traveler on the Red route took 5.1 minutes to walk to the bus stop, waited 2.1 minutes for the bus to arrive, spent 9.8 minutes on the bus, and walked an additional 2.4 minutes to reach his/her final destination, therefore spending 19.5 minutes traveling. Authors reviewed the data to ensure that the riders reducing their travel time by using pre-trip information did not benefit also from reduced utility for that same time (that he/she would have been at the bus stop), thereby preventing the model from counting the same benefited time twice.

Quantifying Impacts

The impacts sought in this research were in four categories: pre-trip time savings, en-route time value, mode change savings, and impact of varying traffic. The preceding paragraphs discuss how these impacts were determined.

One way that travelers can benefit from transit real-time information would be planning their arrival at stops. The methodology for this analysis referred to the Intelligent Transportation Systems Deployment Analysis Software (IDAS) to determine that in 2008, approximately nine percent of transit travelers in the U.S. will use pre-trip travel information to better-plan their trip (McTrans, Inc. 2003). Due to the prevalence of tech-savvy students on and around a college campus, this assumption is conservative. Because pre-trip information will benefit only those who would have arrived at the bus stop excessively early, compared to arrival of the bus, this approach assumed that those who were planning to arrive at the stop earlier-than-average (5.2 minutes prior to the Red bus) would instead arrive at that average time. Because not all travelers will have an opportunity to save time using pre-trip information, the time savings were averaged over all 100 travelers, where a value of zero was noted for those travelers who could not save any time using pre-trip information. Using this overall savings - for example, 0.5 minutes - and applying it to the nine percent of riders who might use such a service, the total time savings was estimated.

To quantify the time savings into dollars, IDAS was again referenced. Applying the recommended inflation rate of 3 percent to the 1995 values of transit traveler time and accounting for the observed multitasking, the 2008 time values were found as \$19.96/hour. This cost was determined from the IDAS estimation of \$24.14 (2008) and accounting for those multitasking (54% observed), valuing their time 32 percent less (Ettema and Verschurne 2007). While other works have explored the non-linear value of waiting time (Denuit and Genest 2001; Osuna 1985), many assumptions were required to fit a value curve to travel times at Clemson, and this analysis was considered beyond the scope of this study. The benefit for pre-trip traveler information is considered solely as time saved by passengers waiting at the bus stop less.

The proposed system was not being evaluated for operational improvements, again making the estimate conservative. Instead, the benefits were taken from the reduction of passenger anxiety/utility, reducing the uncertainty and thus the utility of the time, while awaiting a bus. Various studies have confirmed that travelers are uneasy waiting for buses and perceive time to be longer than it actually is (Dziekhan and Kottenhoff 2007; Schweiger 2003; Nijkamp et al. 1996). One study on a college campus was the most applicable to the study site, finding that awaiting passengers perceived their wait time 15 percent higher than it actually was (Mishalani et al. 2006). In quantifying the benefits, the perceived 15 percent extra wait time is considered the savings because of the reduced uncertainty of passengers and is valued at \$19.96/hour for CAT passengers, as previously discussed. For example, a particular passenger arrived at her stop 2.1 minutes prior to the bus, perceived her wait as 2.4 minutes, and could have reduced the utility of her wait type by 0.3 minutes if she knew when the bus was arriving.

Between certain on-campus origins and destinations, providing real-time bus arrival data could encourage would-be riders to walk instead, to save time. The walk time distributions to and from the centroid of each bus stop area were taken from the previous data collected and compared to the predicted travel time including waiting, riding on the bus, and walking from the bus stop. After finding the percentage of riders that had an opportunity to save time by walking, a sensitivity analysis was conducted to predict the savings under different passenger decision conditions. For example, the analysis sought the benefits if all passengers walked if they could save time doing so. Because various factors influence mode choice, developing a model such as a logit model was beyond the scope of this analysis.

Because traffic is ever-increasing in the Clemson area, and it is unclear when the proposed transit traveler information system will be implemented, an examination

of traffic variation was conducted. The procedure simply compared the change in private vehicle travel time with the change of transit travel time, attempting to identify the volume at which private vehicle travel time increases significantly more than transit vehicles due to parking space searches.

Findings

Enroute savings was the most significant benefit of the proposed system, particularly at locations with high ridership, such as the P1 parking lot. Mode change represented the least benefit from the proposed system. Table 4 and Figure 4 show the anticipated benefits if the proposed system were fully operational and if different numbers of passengers decide to change mode because of the bus arrival data. The column titled “Possible Riders Shifting” displays the number of riders per day that might save time if they decided to walk instead of waiting for the next bus. Because it is not likely that all riders will decide to change modes to save time, the table illustrates the value if different percentages of riders are willing to shift modes to save themselves travel time. These findings indicate little financial benefit for riders to shift modes, supporting previous work by Hickmann and Wilson (1995).

Table 4. Daily Mode Change Findings

Origin	Destination	Avg Time Savings (mins)	Possible Riders Shifting
Sikes Hall	Hendrix Center	3.73	8
Hendrix Center	Lot P1	0.10	70
Lot P1	Hendrix Center	0.06	6

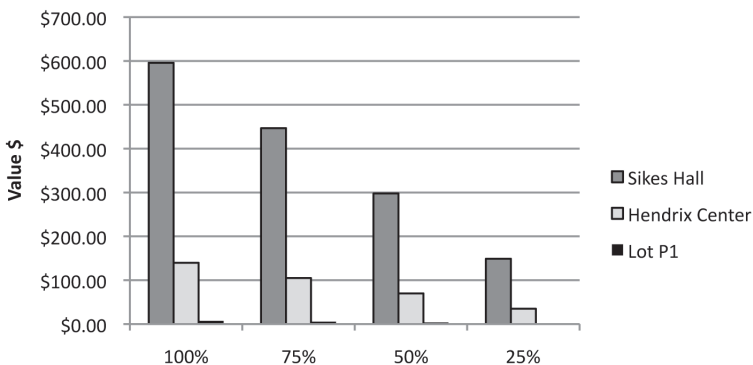


Figure 4. Daily mode shift value.

Table 5 shows the compiled results from all three of these benefits areas. Note that the mode change value was used at the 50-percent level and was not found for most sites because walking between the origin and destination was not reasonable. The annual values were determined accounting for only the Fall and Spring semesters of normal operation. Also, the total does not add benefits of anxiety reduction and mode shift because both reduce the same wait time (at the same value) and their addition would incorrectly count a portion of saved travel time.

Table 5. Transit Real-time Information System Benefits per Stop

Bus Stop	Route(s)	Value Per Day (Weekday)				Annual Value
		Anxiety Reduction	Pretrip Savings	Mode Shift Savings	Total	
Lot P1	Blue	\$2,592	-	\$5	\$2,592	\$414,745
E. Library Circle	Blue, Pendleton	\$2,158	\$41	-	\$2,197	\$351,508
Hendrix Center	Red, Blue	\$852	\$72	\$105	\$924	\$147,773
Sikes Hall	Red	\$387	\$103	\$447	\$489	\$78,319
Lemans	Red	\$424	\$86	-	\$510	\$81,626
University Village	Red	\$222	\$67	-	\$289	\$46,178
Tri-County Tech	Pendleton	\$94	\$27	-	\$122	\$19,447
Tigertown Village	Pendleton	\$31	\$12	-	\$43	\$6,879

The true value of such a system is likely much higher than found by this conservative estimate. For one, operational improvements of the bus system, though well-documented elsewhere, were not the focus of this analysis and were not included in the benefits. Second, the percent using the pre-trip data is conservative. Students at a university campus present a unique population to transportation system designers. Because students are increasingly tech-savvy, the proportion of students who would use such a service could be significantly higher than the national average, as specified by IDAS. Further, the availability of computers and networking on campus provides a fertile environment for the growth of pre-trip traveler information. In this study, pre-trip travel was valued for only those stops where users would walk to from their origin (i.e., home or class), not from commuter lots where another mode would have influenced departure time. In these cases, the core value of the real-time information, for example, at lot P1, would be making the wait time more pleasurable and, therefore, less costly. It

also should be noted that the small urban area in which Clemson University is located does not encounter as much travel time variability as the areas around larger cities.

This analysis did not include the impact of information error such as predicting an incorrect bus arrival time. Other transit traveler information systems, such as Next Bus in and around Washington, D.C., have provided prediction accuracy of over 90 percent (WMATA 2007), and prediction accuracy was found to increase as the transit vehicle nears a stop (Lin and Bertini 2002); therefore, information error was not considered as a significant factor impacting the utility of waiting riders.

Another interesting finding of this study was the impact of changing traffic volumes on the travel times of buses versus personal vehicles. As Figure 5 shows, private vehicle travel times change as significantly as transit vehicle travel times as future traffic volumes grow. While transit travel times increase with heavier road volumes, the total network travel delay is more significantly impacted by private vehicles than transit vehicles due to their numbers. As heavier road volumes can delay transit vehicles, real-time transit information can quell the anxiety of awaiting passengers, and increased personal vehicle travel times has the potential to shift more travelers towards riding transit.

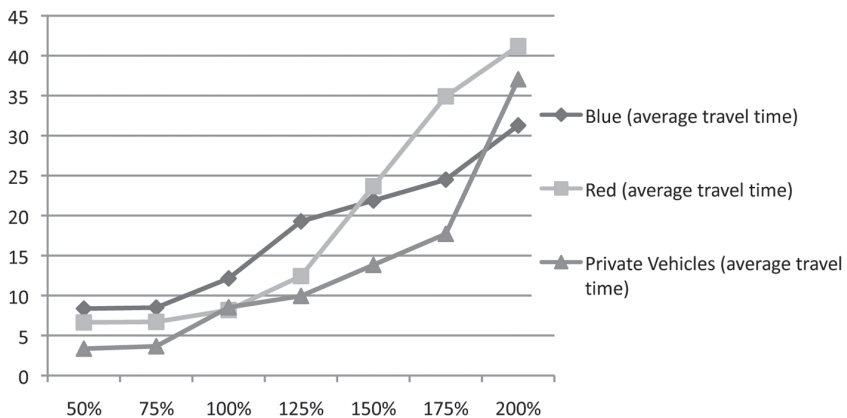


Figure 5. Travel time changes compared to ADT changes (Fries et al. 2009).

Conclusion

The most significant benefit of real-time transit information was reducing the utility of rider wait time at a stop. Specifically, reducing the anxiety level of waiting passengers was found to be the largest category of benefits to riders. Transit information provided

over the Internet can save riders waiting time at a transit stop, and the information provided to riders at a bus stop reduces the utility of that wait time. These two tools complement each other, first, possibly by saving travelers time at the stop, and next by making the true time at the stop more useful and less inopportune. Because both of these tools benefit individual riders, larger ridership creates more significant benefits; thus, ridership was the most significant factor influencing the studied benefits.

This study also investigated if real-time transit traveler information would encourage mode shift away from transit and towards walking across campus. Multiple factors influence mode change, in addition to pre-trip information and information provided at bus stops. These include weather, fitness of the rider, disabilities, familiarity with the area, trip chaining, and cargo to carry. Due to these considerations, the mode change savings found were not considered significant between walking and riding the bus; therefore, researchers do not anticipate this tool will significantly decrease the mode share of college campus transit but could encourage students to walk when buses are late.

Other agencies can use the methods presented in this study to examine similar applications on urban transit systems. Operators of college campus transit systems can use the findings of this study to help justify appropriate expenditures on real-time transit traveler information.

Future research should identify what proportion of commuters would shift towards bus and away from personal vehicles because of real-time transit information because the shift between private vehicles and transit has the potential to impact the transportation systems on multiple levels. Additionally, incorporating a non-linear value of travel time and developing a Logit model for mode-split at Clemson can provide further detail to these findings.

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Influences on Public Transport Utilization: The Case of Auckland

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Abstract

Regression analysis is applied to cross-sectional data for 318 census area units served by the public transportation system in Auckland, New Zealand. The goal is to ascertain the determinants of public transport patronage for the purpose of commuting to work in the region. The analysis addresses both the modifiable areal units problem and spatial autocorrelation. Elasticity estimates are derived for a number of hypothesized drivers of patronage. The paper shows that adjusting for spatial autocorrelation improves the fit of the regression model to the data, a finding that should be of interest to public transportation planners and analysts working with cross-sectional data of a geographic nature.

Overview

This paper applies regression analysis to cross-sectional data, derived largely from the 2006 New Zealand census, for 318 census area units served by the public transportation (PT) system in Auckland, New Zealand.¹ The goal is to ascertain the determinants of PT ridership for the purpose of commuting to work in the region. The paper addresses both the modifiable areal units problem (MAUP) and spatial autocorrelation. The analysis indicates that PT utilization responds positively to an increase in the total number of commuters within a census area unit, an increase in population density, and an increase in service frequency. It responds negatively

to an increase in automobile ownership rates, an increase in the distance from where commuters live to the nearest commuter rail or ferry station, an increase in distance to the central business district, and an increase in household income. However, only the total commuters, car ownership, station distance, and service frequency variables have statistically significant parameter estimates.

This paper and the time-series analysis by Wang (2009) are among the first to analyze in such detail the drivers of PT use in Auckland. This paper also complements the existing literature in the field by using data on how commuters actually traveled to work, rather than stated preference data, which may not accurately reflect what commuters would actually do in a hypothetical situation posed in a survey. Much of the existing research on this topic uses the latter type of data. It is also one of the first such studies to correct for spatial autocorrelation, which strengthens the regression model.

The merit of the cross-sectional approach used here is that it capitalizes on the variation in economic and demographic data between area units to estimate the impact of each of these variables on PT ridership by commuters from these area units. By the same token, however, it is incapable of measuring the impact of variables that do not vary by area unit, e.g., fuel prices and transit fares, on PT utilization.²

Public Transportation in Auckland

Auckland has been New Zealand's fastest growing region in the recent past, having grown 12.4 percent from 2001 to 2006, which accounts for 54 percent of national growth during this period (ARTA 2007). By 2021, Auckland's population is expected to have grown by 440,000 people and accommodate 37 percent of the national population, as compared to 32 percent of the population in 2006 (ARTA 2007). Rising congestion, increased petrol prices, and heightened concern about air pollution and other externalities, along with a realization that roadway expansion is a costly and often ineffective congestion reduction strategy, have increased public support for improved transport options, including better public transit service (Jakob 2006; Mees and Dodson 2006).

The PT system in Auckland consists of three modes: public bus, commuter rail, and ferry service. The total number of (unlinked) trips taken on the PT system during the fiscal year ending in June 2007 was 52.4 million, with buses, trains and ferries accounting for 82 percent, 10 percent and 8 percent, respectively, of trips

taken (ARTA 2007). Since 1989 bus, ferry and commuter rail services have been privatized, which has made centralized coordination for the purpose of promoting PT usage problematic (Mees and Dodson 2006). The introduction of inexpensive Japanese car imports has catapulted car ownership rates in New Zealand to the third highest in the world, with 82 percent of the adult population reporting owning a car, compared to 89 percent in the U.S. and 86 percent in Saudi Arabia (Nielsen Company 2007). This contributed to a decline in public transport use from a 15 percent to a 6.2 percent mode share from the late 1980s to 1996, although the share subsequently increased slightly to 6.5 percent by 2006 (ARTA 2007).

Since the end of the 1990s, some measure of re-regulation and coordination has been introduced. Now public bus transportation in Auckland is run by six separate private companies but coordinated by the Auckland Regional Transport Authority (ARTA), which is the implementing body for the transportation strategy of the Auckland Regional Council (ARC)³. ARTA also coordinates the commuter rail and ferry operations.

Since its inception in 2005, ARTA has focused largely on increasing PT use in order to reduce peak car travel and congestion in the region. That is, it has a largely commuter focus. Bus services are mostly radial to the central business district (CBD), although Auckland has a relatively dispersed workforce, and only 15 percent of employment in Auckland is within the CBD, as opposed to 19 percent in Christchurch and 22 percent in Wellington (O'Fallon, Sullivan, and Hensher 2004). The overall mode share figures published in a recent ARC Mode Split Research Study show great regional variation; for example, 48 percent of morning peak travelers into the CBD used PT in 2009, as compared to only 9 percent venturing to Manukau in south Auckland (*Auckland Transport Blog* 2010).

Population growth and increasing levels of affluence in Auckland reinforce the need for high-quality public transportation options. As reported by Litman (2010a), the growth in a metropolitan area's population shifts the composition of potential mass transit users away from transit-dependent users, who are generally low income or persons with disabilities, to discretionary riders, who tend to be more affluent than the captive riders. Moreover, demand for public transport services from higher income, discretionary riders is particularly sensitive to travel time, vehicle comfort, and other dimensions of service quality (Litman 2010a). In fact, in making his case for the superiority of commuter rail over other public transport options, Kenworthy (2008) emphasizes that the superior service quality of rail is what accounts for its ability to attract patronage in relatively affluent

cities more effectively than other transit options. Wang (2009) confirms that also Auckland rail attracts more affluent patrons. Interestingly, and contrary to common misperception, Kenworthy (2008) also reports cities become more public transport-dependent and less auto-dependent as they grow wealthier. The findings of Kenworthy and Litman certainly reinforce the aforementioned claims made by Jakob, Mees and Dodson.

Data

The unit of analysis is the New Zealand census area unit, and the point in time for the cross-sectional analysis, is March 6, 2006, the date of the last New Zealand census. There are 398 census area units within the ARC, of which sufficient data could be collected on 318. The sources of data are Statistics New Zealand, Land Transport New Zealand, ARTA, and the University of Auckland. ArcGIS was used in the compilation of data having a spatial dimension.

Dependent Variable

PT Users – PT users represents the number of people within the census area unit who ticked “public bus,” “train,” or “other” on the census questionnaire item that asks respondents how they traveled to work on census day.⁴ It includes both linked and unlinked trips.

Explanatory Variables

Total Commuters – The total commuters variable represents the number of people within the census area unit who reported that they had to commute to work on census day. The theoretically expected parameter sign for this variable is positive.

Cars per Household – This variable represents the average number of cars (including trucks) available to a household within the area unit. Its theoretically expected parameter value is negative.

Population Density – The population density variable represents the number of persons per square kilometer within the area unit. Its theoretically expected parameter sign is positive.

Station Distance – This variable represents the shortest overland distance between the centroid of the area unit and the nearest rail or ferry terminal. The exception was certain area units in the far northern suburbs of Auckland, where the authors deemed it unlikely that commuters to the city center would backtrack to a ferry terminal located northeast of them, rather than one located much farther to the

south, in order to get to work in the city center. The theoretically expected parameter sign for this variable is negative.

Distance to City Center – This variable represents the shortest distance, by road, from the centroid of the area unit to the city center, defined as the intersection of Queen Street and Customs Street downtown.⁵ The more remote area units within the ARC are predominantly rural and contain satellite towns to Auckland City, and commuters in this type of setting are less transit-dependent than those living in metropolitan areas.⁶ The distance-to-city-center variable also serves as a loose proxy variable for the bus and train fare, since the Auckland public bus system uses a stage-based fare scheme for those passengers who do not hold monthly passes. The expected parameter sign for this variable is negative.

Rush Hour Frequency – This variable represents the total number of buses running through and stopping within the area unit, including a 30-meter buffer extending beyond each boundary of the area unit, during the morning and afternoon rush hours combined. Unfortunately, data on service frequency in 2006 for the ferry and rail systems no longer exist, and it was not possible to include these data in the service frequency variable. Given the dominance of the bus system in the overall public transport mode share, with bus trips accounting for 82 percent of public transit trips, however, this may not be a significant handicap. The expected parameter sign of the rush hour frequency variable is positive.

Median Household Income – This variable represents median household income within the area unit. Controlling for the aforementioned car ownership variable, the expected parameter sign for this variable is negative, since, for a given level of car ownership, the more affluent the households are within an area unit, the more affordable is the cost of using a car to get to work. It also is hypothesized that the association, in affluent commuters' minds, of PT, especially public buses, with lower socioeconomic status might deter upper-income commuters from taking PT to get to work.

Analytical Methods and Results

Simple Log-Log Model

The first regression model run on the data was a simple log-log one, without adjustment for spatial autocorrelation. It has the following functional form:

$$\log y_i = \beta_0 + \sum_{j=1}^m \beta_j \log x_{ij} + \varepsilon_i, \quad (1)$$

where y_i is the PT users variable, the x_{ij} 's are the explanatory variables, and ε_i is the error term, which is assumed to be independently, identically, and normally distributed with mean zero and constant variance. The *betas*, of course, are the regression parameters to be estimated. The *i*-subscript refers to the particular census area unit.

The application of the log-log regression model to the data led to the following results indicated in Table 1.

Table 1. Estimated Coefficients, Log-log Regression Model

Independent Variable	Estimated Coefficient (b)	t-Statistic	Probability Value
Log Tot. Comm.	1.039	15.871	0.000
Log Cars per HH	-1.190	-4.024	0.000
Log Pop. Density	0.032	0.975	0.330
Log Stat. Distance	-0.052	-2.207	0.028
Log Rush Hr. Freq.	0.069	2.741	0.007
Log Dist. City Cent.	-0.463	-9.240	0.000
Log Median Income	-0.099	-0.938	0.349
$R^2 = 0.852$	Adjusted $R^2=0.849$	Log Likelihood = -62.551	Link Test Prob. Value = 0.133

The t-statistics have been adjusted for heteroscedasticity using White's heteroscedasticity-consistent errors. The link test is a test for specification error in the form of incorrect functional form and is performed by regressing the dependent variable on its fitted values and the squares of the fitted values. The probability value reported in the table is the significance level of the coefficient estimate for the fitted values squared. One should note that the results have not been adjusted for spatial autocorrelation. Also, the issue of the MAUP remains to be addressed.

As a slight variation on the original model, a modal share model, with the fraction of commuters to work who took PT as the dependent variable, was estimated. The dependent variable was converted to the natural logarithm of the ratio of PT users to total commuters. This model backs out of the R-square calculation the very strong effect of the total commuters variable on the PT users variable, which allows one to ascertain the combined influences of the other regressors on PT usage. Table 2 reports the results when the transformed model is run on the data.

**Table 2. Estimated Coefficients, Log-log Regression Model
Dependent Variable: Log (PT Users/Total Commuters)**

Independent Variable	Estimated Coefficient (b)	t-Statistic	Probability Value
Log Cars per HH	-1.180	-4.060	0.012
Log Pop. Density	0.039	1.403	0.162
Log Stat. Distance	-0.050	-2.140	0.033
Log Rush Hr. Freq.	0.073	3.059	0.002
Log Dist. City Cent.	-0.460	-8.976	0.000
Log Median Income	-0.070	0.638	0.524
$R^2 = 0.666$	Adjusted $R^2 = 0.659$	Log Likelihood = -63.004	

As can be seen, the fit of the model to the data, as measured by the adjusted R-squared, falls, but not precipitously, in the transformed model.

The Modifiable Areal Units Problem

The modifiable areal units problem (MAUP) has two aspects: the “scale effect” and the “zoning effect.” The former refers to the tendency for the results of an analysis of geographic data to depend on the scale of the areal unit used. The zoning effect refers to the tendency for regression results to depend on how the boundaries of the areal units happened to have been drawn, holding the number of areal units constant.

In this paper, no attempt is made to ascertain the significance of the scale effect. The areal unit next smallest to the census area unit is the census meshblock, of which there are 9,855 within the ARC, far too many to make data compilation feasible. The next largest census areal unit beyond the census area unit is the census ward, but there are only 33 of these within the ARC, which is too few to allow statistical inference.

An attempt was made, however, to ascertain the significance of the zoning effect. A synthetic dataset was constructed by using ArcGIS to randomly place one point within each area unit, then interpolate to that point the data from the eight area units whose centroids were closest to the random point, using the inverse distance weighted method with a power factor of 2. The synthesized dataset contains the same number of records as the original dataset but buffers out to a considerable extent the impact of the arbitrariness of the boundaries of the census area units. The regression analysis was then run on the 318 synthesized datapoints. Table 3 reports the results.

Table 3. Estimated Coefficients, Log-log Regression Model Synthesized Dataset

Independent Variable	Estimated Coefficient (b)	t-Statistic	Probability Value
Log Tot. Comm.	1.042	13.813	0.000
Log Cars per HH	-1.345	-5.767	0.000
Log Pop. Density	0.036	1.085	0.279
Log Stat. Distance	-0.038	-1.556	0.121
Log Rush Hr. Freq.	0.095	2.819	0.005
Log Dist. City Cent.	-0.438	-9.563	0.000
Log Median Income	-0.033	-0.299	0.765
$R^2 = 0.855$	Adjusted $R^2 = 0.851$	Log Likelihood = -3.604	

Once again, White’s heteroscedasticity-consistent errors was used to estimate the variances of the parameter estimates.

A comparison of Tables 1 and 3 indicates that, in general, the regression results do not deviate significantly when the analysis is run on the synthetic dataset, as compared to the original results. Each parameter estimate in Table 3 is within one standard error of the corresponding parameter estimate in Table 1, with the exception of the parameter estimates for the rush hour frequency variable, where the difference is 1.04 standard errors. The zoning effect is, thus, unlikely to be substantial in this analysis. The impact of the scale effect, however, remains unknown.

Adjustment for Spatial Autocorrelation

Spatial autocorrelation occurs when either the value of an explanatory variable in one areal unit is correlated with the value of the variable in contiguous areal units, or when the regression error terms are correlated across contiguous areal units. There is reason to suspect that spatial autocorrelation exists in this study. Consider, for example, the station distance variable. Census area units situated relatively close to a certain rail or ferry station are clustered around that station, and thus around one another. As has been documented in the theoretical literature, e.g., by Anselin (1988), spatial autocorrelation violates certain central tenets of Gaussian linear regression models.

The standard test for spatial autocorrelation is Moran’s I, which we applied to the regression residuals in the simple log-log model.⁷ We deemed area units to be contiguous if and only if they shared a common border (which is known rook con-

tiguity of order 1). We next constructed a weight matrix, \mathbf{W} , the elements of which are binary, with a 1 in the w_{ij}^{th} element indicating that the i^{th} and j^{th} areal units are contiguous, and a 0 indicating that they are not. Moran's I was then calculated as:

$$I = \frac{N \sum_i \sum_j w_{ij} (\varepsilon_i - \bar{\varepsilon})(\varepsilon_j - \bar{\varepsilon})}{\left(\sum_i \sum_j w_{ij} \right) \sum_i (\varepsilon_i - \bar{\varepsilon})^2} \quad (2)$$

where ε_i is the regression residual for the i^{th} areal unit. Under the null hypothesis of no spatial autocorrelation, the numerator of the expression is zero, and thus so is I .

Using the permutation approach described in (Anselin 2005), the value of I turned out to be 0.364, which has a probability value of less than 0.000; therefore, we reject the null hypothesis and conclude that positive spatial autocorrelation exists.

Following Anselin (1992), we adjust for the spatial autocorrelation of the regression residuals by using the spatial errors regression model:

$$\mathbf{Y} = \mathbf{X}\beta + \varepsilon \quad (3)$$

where \mathbf{Y} , \mathbf{X} and β are the vector of observations on the dependent variable, the matrix of explanatory variables observations by area unit, and the vector of parameters, respectively. $\varepsilon = \gamma \mathbf{W}\varepsilon + \xi$, where ε is the vector of regression residuals. Each of its elements is spatially autocorrelated with the elements from contiguous area units. The parameter, γ , which measures the magnitude of this autocorrelation, is one of the coefficients to be estimated. ξ , the "white noise" term, is assumed to be normally, identically and independently distributed with mean zero. All variable values are measured in their natural logarithms. Regression equation 3 is estimated using maximum likelihood estimation rather than least squares.

In deciding on a criterion for contiguity for purposes of model estimation, a data-driven approach was pursued and various orders of rook contiguity were applied to the data. Each time, equation 3 was estimated using a different order of contiguity in constructing the weight matrix. Rook order 2, including the lower order of 1, provided the best fit to the data.

Table 4 reports the regression results from the spatial errors model:

Table 4. Parameter Estimates and Significance Levels After Adjustment for Spatial Autocorrelation

Independent Variable	Parameter Estimate (b)	z-Statistic	Probability Value
Log Tot. Comm.	1.014	35.446	0.000
Log Cars per HH	-0.763	-4.815	0.000
Log Pop. Density	0.021	1.320	0.187
Log Stat. Distance	-0.158	-6.263	0.000
Log Rush Hr. Freq.	0.045	2.069	0.039
Log Dist. City Cent.	-0.056	-0.496	0.620
Log Median Income	-0.130	-1.368	0.171
γ	1.006	771.300	0.000
$R^2 = 0.928$	Log likelihood = 45.928	Prob. Value Link Test = 0.365	
Breusch-Pagan test statistic = 259.879 (Prob. Value = 0.000)			
Moran's I Using Rook Order 2 Contiguity = -0.070 (Prob. Value = 0.005)			

The *R*-squared statistic should be interpreted with extreme caution in a maximum likelihood context, but is reported in case the reader wishes to know it. The maximum likelihood statistic, which is -62.551 in the case of the simple log-log model, provides a better standard for evaluating which model fits the data better. Obviously, the model adjusted for spatial autocorrelation fits the data better.

The Breusch-Pagan statistic indicates the presence of heteroscedasticity. Unfortunately, there is currently no known procedure of which the authors are aware for adjusting for heteroscedasticity in a spatial errors model.

One puzzling statistic is that Moran's *I* remains statistically significant after the adjustment for spatial autocorrelation. Moreover, it is negative, which is indicative of a systematic tendency for the adjusted residuals to negatively correlate across contiguous area units. The authors are unable to conjure any sort of economic, demographic, or geographic principle that would lead to such negative autocorrelation. In absolute value, though, the magnitude of the Moran's *I* statistic is very small, and its low probability value may stem in part from the rather large sample size of 318.

There are some notable differences between the parameter estimates derived from the model with spatial autocorrelation and those derived from the simple log-log

model. After adjusting for spatial autocorrelation, the estimated impact of the car access variable becomes much weaker than before, the station distance variable much stronger, and the rush hour service frequency variable weaker. All variables continue to have the expected signs, however. In light of the relative merits of the model adjusted for spatial autocorrelation over the simple model, we place much more credence on the parameter estimates derived from the former than those derived from the latter.

Summary Observations on Analytical Findings

All references to results in this subsection refer to the results in Table 4. All the parameter values have the theoretically-expected signs. However, somewhat unexpectedly, the parameter estimates for the population density, distance from city center, and income variables do not deviate from zero by a statistically significant margin. In an earlier version of this research project, when the dependent variable was bus ridership only, these variables had statistically significant parameter estimates of the expected signs.⁸ This indicates that distance plays a different role in determining bus patronage than ferry and rail patronage in Auckland. It also indicates that income levels have a much stronger negative influence on bus patronage than rail or ferry patronage, a finding that is consistent with the aforementioned reports by Kenworthy (2008) and Litman (2010a).

In interpreting Table 4, the reader is cautioned, however, that there may be an endogeneity problem with the bus service frequency variable. As Holmgren (2007) points out, variables reflecting the extent of PT service actually may be partly endogenous, since public transport providers gear service levels to ridership. Unfortunately, since there currently exist no econometric technique for testing and adjusting for endogeneity within the context of a cross-sectional spatial errors regression model, no such tests or adjustments are undertaken here, and the reader is left with a warning about this potential problem.

Discussion and Relationship to Existing Literature

Many international studies have been done on the determinants of PT ridership. Recently, new studies and some thorough literature reviews have been issued (e.g., Balcombe 2004; Litman 2004; Litman 2010b; Bresson 2004). Two studies were found related to New Zealand. One, using stated preference experiments for Auckland, Wellington, and Christchurch, focuses on factors and potential policy tools that could influence car commuters to shift modes (O'Fallon, Sullivan, and Hensher

2004). The results are interesting, but not exactly comparable. The other (Wang, 2009) uses a time-series approach to model rail and bus patronage over 1997-2008 in the Auckland, Wellington, and Christchurch regions using service, fare, car ownership, and income and fuel prices as independent variables. Each city, having different structural, historic, and institutional characteristics impacting on PT use, returned quite different elasticities. Alas, the dataset for Auckland had several limitations, leading to incomplete or insignificant elasticities for fare, car ownership, and income and fuel price variables and therefore is of limited comparative use.⁹

Our results found here do tend to corroborate certain other, international research that has been done in the field and have the expected signs, although elasticities may vary slightly.¹⁰ The car ownership influence found in our study is similar to others, e.g., Dargay and Hanly (2002) and Zhao et al (2005). Vance and Hedel (2007), using recent German data, report that car usage responds positively—and, presumably, PT ridership negatively—to cars per licensed driver and income among the individuals within their dataset. Bresson et al. (2004) report that rising incomes and increasing motor vehicle penetration both adversely impact PT ridership, although the former influence appears to operate primarily through the motorization effect. As mentioned previously, in an earlier version of this paper on bus patronage only, our analysis clearly showed a separate effect of income from car ownership. Wang (2009) shows a strong impact of car ownership rates in Auckland on bus patronage, but a statistically insignificant one on rail patronage.

Bresson et al. (2004) use different techniques to calculate elasticities for frequency. Short-run elasticities for frequency are around 0.18, which is fairly inelastic, as found in our study. Litman (2004) notes that the average of previously estimated and published elasticities of PT ridership with respect to service frequency (both peak and non-peak) is about 0.5, with the higher estimates usually found in cases where service is infrequent. Although higher than the elasticity calculated here, this average of previously estimated elasticities has the same sign as that found here.¹¹ The results reported in Evans (1999), Kain and Liu (1999), and Vande Walle and Steenberghen (2006) imply that frequency is an important driver of PT ridership.

Conclusions

The findings of this article entail certain policy implications for promoting PT patronage in Auckland. We caution the reader, however, about applying our results to PT planning in other cities, since the findings of Nijkamp and Pepping (1998),

Hensher (2008), and Wang (2009) show that PT elasticities vary considerably from one region to another. Therefore, while we encourage PT planners in other cities to consider adopting our analytical techniques, including the adjustment for spatial autocorrelation and test for the MAUP, local data should be used to estimate the elasticities.

At first glance, the low estimated elasticity for the service frequency variable (each 1% increase in service frequency within an area unit causes only a 0.045% increase in patronage) might lead one to believe that increasing service frequency during rush hour, beyond its current level in Auckland, would not be cost effective. However, one should bear in mind that the unit of analysis is one area unit, and that an additional service run during rush hour would certainly increase frequency in more than one area unit and probably in several. Therefore, even with a low estimated elasticity for the service frequency variable, the increase in number of patrons brought about through the addition of one more service run during rush hour may be quite substantial, depending on route, and more than enough to justify the cost of an additional run.

The estimated elasticity for the car ownership variable indicates that policies to discourage automobile ownership could be fairly effective at promoting PT patronage in Auckland, since it indicates that each 1 percent reduction in cars per household boosts PT patronage by about 0.763 percent. Such policies could include policies that raise the cost of owning a car, such as a substantial increase in vehicle registration fees for cars that are registered to an Auckland address and policies that make vehicle ownership less useful, such as a curtailment in central business district parking spaces.

The estimated elasticity for the station distance variable has interesting implications for policies to promote PT usage in Auckland. The station distance variable measures commuter access to Auckland's commuter rail and ferry system, not to its public bus system. Kenworthy (2008) and Litman (2010a) note how rail stations tend to promote the development of mixed-use, compact development in their immediate environs, which, in turn, promotes PT usage. As mentioned earlier in this paper, they also note how commuter rail systems tend to attract affluent, discretionary riders more effectively than bus systems. The same logic would apply to ferry stations, since ferries offer travel times and comfort levels similar to commuter rail. The statistically significant and negative parameter estimate for the station distance variable indicates that further growth of the commuter rail and ferry systems could, over time, positively impact PT patronage in Auckland.¹² Our

elasticity estimate indicates that each 1 percent reduction in the distance between the centroid of an area unit and the closest rail or ferry terminal increases PT patronage by about 0.158 percent.

Endnotes

¹ Every five years, a national census survey is completed in New Zealand, including questions on transport used to travel to work on census day.

² Wang (2009), using a time-series approach, addresses these issues.

³ Since November 1, 2010, the six City Councils and one Regional Council making up the greater Auckland region have been amalgamated into one "Auckland Supercity." ARTA has been renamed Auckland Transport but, as most documentation relevant for this study still has the old ARTA-reference, we continue to refer to ARTA.

⁴ There was no category for ferry on this item. Considering the otherwise exhaustive nature of the categories and the prominence of the ferry in Auckland's mass transportation system, this study assumes that a respondent who ticked "other" was a ferry rider.

⁵ Dr. Stuart Mitchell of the Department of Engineering Sciences of the University of Auckland deserves credit for making these calculations.

⁶ Litman (2004) mentions some reasons why commuters in small cities are less transit-dependent than those in large cities.

⁷ The diagnostic tests recommended by Anselin (2005) indicated that spatial autocorrelation of the regression residuals was a greater problem than spatial autocorrelation of the regressors.

⁸ The station distance variable had a positive estimated coefficient in that case, as would be expected when the dependent variable excluded rail and ferry patronage. The results from the earlier version of this work are available on request from the authors.

⁹ Interestingly, Wang (2009) finds that inflation-adjusted (real) fares do not have a statistically significant impact on bus patronage in Auckland and speculates that the high concentration of international students and other PT-dependent users accounts for this.

¹⁰ General conclusions from these studies are that long-term elasticities are significantly higher than short-term elasticities, and that the full effect of major changes in routes, frequency, etc., take 1 to 3 years to show their full effect. As this study does not refer to intertemporal but to geographic variation between (established) neighborhood demographics and factors, one should exercise caution in comparing the elasticities found here with those found in time-series analyses.

¹¹ One should also be mindful that the 0.5 average of previously-published estimates includes the estimates from low-frequency service areas, where elasticities have generally been found to be high. By contrast, the 0.045 estimate found here is only for rush hour, when frequency is high.

¹² Subsequent to 2007, a bus rapid transit corridor connecting the northern suburbs of Auckland to the CBD opened. The travel speed on this corridor is comparable to commuter rail, and the stations and buses are new, comfortable, and attractive. Therefore, the findings concerning the station distance variable also may apply to the new bus rapid transit corridor, since it is so similar in essential ways to a commuter rail corridor.

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Authors' Contributions

Mark Greer is the primary contributor to the sections of the paper pertaining to the data and the analytical methods and results. Bart vanCampen is the primary contributor to the sections pertaining to the public transportation system in Auckland and the discussion and relationship to the existing literature. The remaining sections represent a joint contribution by the authors.

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A Composite Index of Public Transit Accessibility

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Abstract

Measuring ease of access to transit services is important in evaluating existing services, predicting travel demands, allocating transportation investments, and making decisions on land development. A composite index to assessing accessibility of public transit is described. It involves use of readily-available methods and represents a more holistic measure of transit accessibility, integrating developer, planner, and operator perspectives. The paper reviews previous and current methods of measuring accessibility and selects three methods for application in a case study in Meriden, Connecticut. Inconsistencies are noted across the methods, and a consistent grading scale is presented to standardize scores. Finally, this paper proposes weighting factors for individual methods to formulate a composite measure based on individual accessibility component measures. The approach aims to provide a robust and uniformly applicable measure that can be interpreted easily by planners to identify shortcomings in service coverage and promote equity in transit accessibility in the community.

Introduction

Public transit is a key component of a sustainable transportation system that improves systemic mobility and can serve to mitigate the economic and environmental burdens that increased auto ownership can impose on the traveling population. Provision of public transit and infrastructure will not, in itself, fulfill public

transit's potential. The system must be accessible and available to the community and its activity centers and connected with the rest of transportation system. In this paper, we consider accessibility to have three primary components: (1) *trip coverage* - travelers would consider public transit accessible when it is available to and from their trip origins/destinations, (2) *spatial coverage* - travelers would consider public transit accessible when it is within reasonable physical proximity to their home/destination, and (3) *temporal coverage* - a service is accessible when service is available at times that one wants to travel. Another key aspect of public transit service is comfort, which addresses the question: "Is sufficient space available on the public transit at the desired time?" (Kittelsohn 2003). Hence, there is a need to assess and quantify public transit access considering the three aspects of public transit accessibility—trip, spatial coverage, and temporal coverage, along with comfort.

Accessibility measures aid public transit operators and local authorities in the development of appropriate transit service expansion plans and policies by recognizing mobility needs and identifying service gaps. For assessing public transit accessibility in a region and the comparison of results with the existing methods, a consistent grading scale across the methods is warranted. Measures with consistent grading scales can facilitate the assessment of the distribution and quality of public transit service provided within an area, and a composite measure (properly weighted) can provide a single, representative measure.

This paper proceeds with a literature review of existing transit accessibility measures, highlighting their scale of analysis and the measures used in their calculation. The Methodology section focuses on the three methods used in the development of the composite measure, which is then applied in a case study. The section also provides a standardized scaling option for comparison of the results. The Results section presents output of the comparative analysis and composite measure. The final section concludes the paper with a summary of major findings and some discussion on future adoption of the examined method to improve the performance of accessibility measures.

Literature Review

The attempt to develop public transit accessibility index has been discussed in several studies since the 1950s and continues to receive growing attention in transit sector (Schoon et al. 1999). Different measures have been designed to reflect dif-

fering points of view. A customer demand-oriented methodology incorporating the three important categories of accessibility measures (i.e., trip, spatial coverage, and temporal coverage) might be the best for measuring the quantity and quality of service. Such a method should not view transit as a last-resort option, but as a service that should be available for heavily-traveled corridors because it is a good option for travelers. Any method identifying service quality must consider the populations being served, meaning that one must consider the equity aspects of service configuration. The method should be easily understandable to public transit operators and contain fundamental information about the system and the community it serves.

Some of the existing measures of public transit accessibility focused on local accessibility and considered both spatial and temporal coverage. The *Transit Capacity and Quality of Service Manual (TCQSM)* (Kittelson 2003) provides a systematic approach to assessing transit quality of service from both spatial and temporal dimensions. This procedure measures temporal accessibility at the stops by using various temporal measures. Assessing spatial public transit accessibility throughout the system is carried out by measuring the percentage of service coverage area and incorporating the Transit Supportive Area (TSA) concept. The calculation of service coverage area using the buffer area calculation (available in GIS software) is presented as an option.

The Time-of-Day-Based Transit Accessibility Analysis Tool (hereafter referred to as Time-of-Day Tool) developed by Polzin et al. (2002) is one measure that considers both spatial and temporal coverage at trip ends. In addition to the inclusion of supply-side temporal coverage, this tool explicitly recognizes and considers the demand side of temporal coverage by incorporating the travel demand time-of-day distribution on an hourly basis.

The transit level-of-service (TLOS) indicator developed by Ryus et al. (2000) provides an accessibility measure that uniquely considers the existence and eminence of pedestrian route connected to stops. It also combines population and job density with different spatial and temporal features to measure transit accessibility. Revealing the association of safety and comfort of the pedestrian route to stops makes this method distinctive in the evaluation of public transit accessibility. Another measure that considers the space and time dimensions of local transit accessibility is the public transport accessibility level (PTAL) index developed in 1992 by London Borough of Hammersmith and Fulham (Cooper 2003, Gent et al. 2005). This index measures density of the public transit network at a particular point (origin), using

walk access time and service frequency and integrating the accessibility index (AI) for all available modes of transport from that point.

Schoon et al. (1999) formulated another set of Accessibility Indices (travel time AI and travel cost AI) for different modes between an O-D pair. Travel Time AIs for a particular mode were calculated by using ratio of the travel time of a particular mode to the average travel time across all modes. Cost AIs were calculated in much the same way. The different methods, their coverage of analysis, the incorporated measures, and the most important features of the methods are summarized in Table 1. Fu et al. (2005) proposed an O-D based approach called Transit Service Indicator (TSI) to evaluate transit network accessibility by combining the various temporal attributes (Table 1) into one composite measure. To develop the Transit Service Indicator (TSI) for a single O-D pair, they used ratio of the weighted door-to-door travel time by auto (WTA) to the weighted door-to-door travel time by transit (WTT).

Hillman and Pool (1997) described a measure to examine how a database and public transit planning software (ACCMAP) comprising GIS can be implemented to measure accessibility for local authorities and operators. This software measured local accessibility as the Public Transport Accessibility Level Index (PTAL), using the combination of walk time to a stop and the average waiting time for service at that stop. Network accessibility was measured between an origin and destination, including walk time from origin to transit stop, wait time at stop, in-vehicle travel time, wait time at interchanges, and time spent walking to destination.

There were few studies that paid attention to the comfort and convenience aspect of transit service. The Local Index of Transit Availability (LITA), developed by Rood (1998), measures the transit service intensity or transit accessibility in an area by integrating three aspects of transit service: route coverage (spatial availability), frequency (temporal availability), and capacity (comfort and convenience). Incorporation of comfort and convenience aspect makes this tool distinctive from the passengers' perspective.

Bhat et al. (2006) described the development of a customer-oriented, utility-based Transit Accessibility Measure (TAM) for use by the Texas Department of Transportation and other transportation agencies. Two types of indices were included in this manual to identify patterns of inequality between transit service provision and the level of need within a population: transit accessibility indices (TAI) and the transit dependence index (TDI). The TAI reveals level of transit service supply and considers various elements of the utility measures in transit service. The transit

Table 1. Summary of Previous Transit Accessibility Measures

Study/ Paper	Type of Measure	Reflecting Local Accessibility		Reflecting Network Accessibility	Incorporated Accessibility Measure(s)	Important Feature	Computational Complexity	Intended Users
		Spatial Coverage	Temporal Coverage					
TCQSM (2003)	LOS	Yes	Yes	No	Service Frequency, Hours of Service, Service Coverage, Demographic Data	LOS Concept	Some Technical Skill	Transit Operator Transit User
Polzin et al. (2002)	Time-of- Day tool (Index)	Yes	Yes	No	Service Coverage, Time-of-Day, Waiting Time, Service Frequency, Demographic Data	Time-of- Day Trip Distribution	Transportation Specialist	Transit Planner
Ryus et al. (2000)	TLOS	Yes	Yes	No	Service Frequency, Hours of Service, Service Coverage, Walking Route, Demographic Data	Availability & Quality of Pedestrian Route	Transportation Specialist	Transit Planner Transit Operator
Schoon et al. (1999)	AI (Index)	No	No	Yes	Travel Time, Travel Cost	Travel Cost	Little Technical Skill	Transit Planner Transit User
Fu et al. (2005)	TSI (Index)	Yes	Yes	Yes	Service Frequency, Hours of Service, Route Coverage, Travel Time Components	Weighted Travel Time	Some Technical Skill	Transit Operator
Hillman and Pool (1997)	PTAL (Index)	Yes	Yes	Yes	Service Frequency, Service Coverage	Agg. Travel Time between O-D Pairs	Transportation Specialist	Transit Planner Transit Operator
Rood (1998)	LITA (Grade)	Yes	Yes	Yes	Service Frequency, Vehicle Capacity, Route Coverage	Comfort and Convenience	Little Technical Skill	Property Developer
Bhat et al. (2006)	TAI & TDI (Index)	Yes	Yes	Yes	Access Distance, Travel Time, Comfort & Parking, Network Connectivity, Service Frequency, Hours of Service, Vehicle Capacity	Transit Dependency Measure	Little Technical Skill	Transit Planner Transit Operator Transit User
Currie et al. (2004)	Supply & Need Index	Yes	Yes	Yes	Service Frequency, Service Coverage, Travel time, Car Ownership, Demographic data	Transport Needs Measure	Some Technical Skill	Transit Planner Transit Operator Property Developer

dependence index (TDI) measures the level of need for transit service as a function of socio-demographic characteristics of potential transit users.

A new approach to identify the geographical gaps in the quality of public transit service was developed by Currie (2004). This “needs gap” approach assesses the service of public transit by comparing the distribution of service supply with the spatial distribution of transit needs. Another study by Currie et al. (2007) quantifies the associations between shortage of transit service and social exclusion and uniquely links these factors to the social and psychological concept of subjective well-being. This study investigates the equity of transit service by identifying the transport disadvantaged groups and evaluating their travel and activity patterns.

Objectives and Organization

The objective of this paper is to describe a method for quantifying public transit access that combines existing public transit accessibility indices to harness the positive features of each. For the development of a performance/accessibility measure, Transit Cooperative Research Program (TCRP) Report 88 (Kittelson et al. 2003) identified eight categories of performance measures (travel time, service availability, service delivery, safety & security, maintenance & construction, economics, transit impact, and capacity) based on underlying goals and objectives of different transit users. The categories are overlapped to some extent and, hence, require some distinct broad categorization (Bhat et al. 2006). Three methods (LITA, TCQSM, and the Time-of-Day Tool) have been selected to assure that three primary accessibility measures (trip, spatial coverage, and temporal coverage) are being considered. The three methods, individually and collectively, are applied to Meriden, Connecticut, as a case study. The results are compared and contrasted for consistency, completeness, and clarity. Finally, this paper evaluates weighting schemes for individual factors for their inclusion in the composite index.

Methodology

The method presented seeks to leverage less data-intensive methods for measuring public transit accessibility into a single, composite index. For simplicity in calculation, more sophisticated probabilistic modeling methods are not incorporated; the composite index presented requires only straightforward calculations and use of some basic GIS software commands. Selection of methods also considers the intended user of this product and the limitation of data sources. This paper

selected existing measures that can address public transit accessibility from differing perspectives (transit planner, transit operator, traveler, and property developer). On this basis, three methods (LITA, TCQSM and Time-of-Day Tool) were selected to characterize the three transit accessibility coverage (trip, spatial coverage, and temporal coverage) aspects.

Analysis was conducted on the 17 census tracts of Meriden. Accessibility calculations were carried out for three (A, B, and C) public bus routes throughout the city provided by CTtransit. The local bus route network and stop locations for this city are shown in Figure 1. The three methods, their data sources, reasons for selection of these particular methods, the intended users, and scales of analysis are explained below.

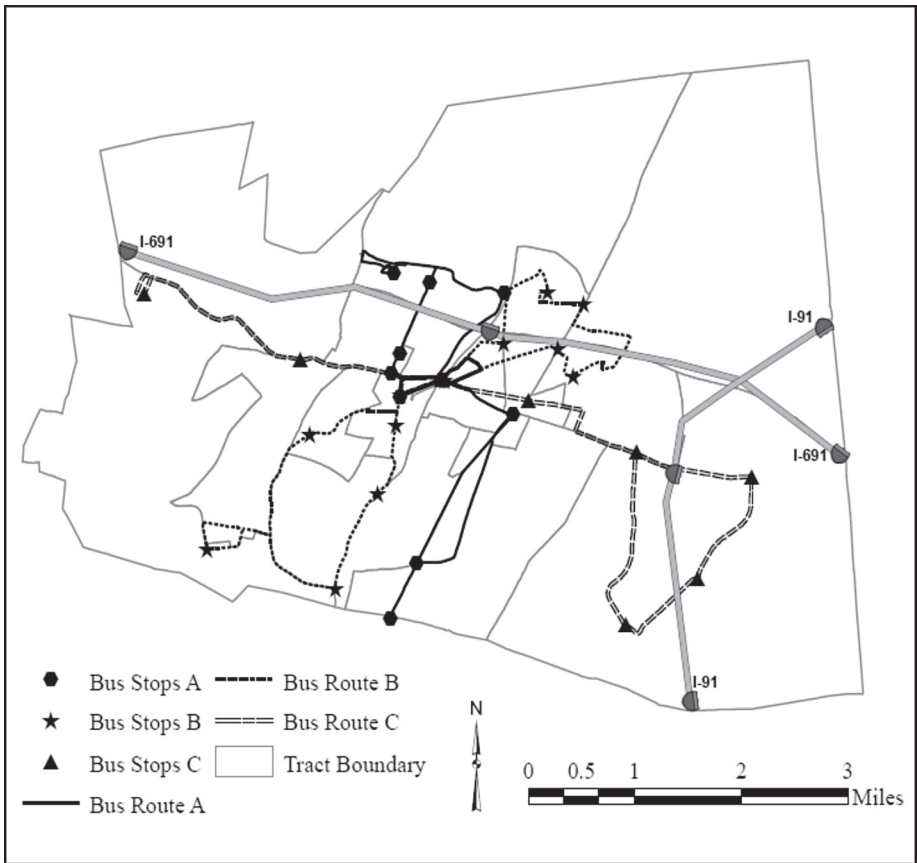


Figure 1. Three local bus routes and stop locations in Meriden, Connecticut.

Method 1: The Local Index of Transit Availability (LITA)

LITA (Rood 1998) measures the transit service intensity of an area, and two basic types of data are required: transit data and census data. Transit data include full route maps and schedules of all transit lines serving the study area, locations of transit stops, and transit vehicle capacities. Census data encompass total land area, resident population, and number of employees in each tract. All transit data were collected from the transit provider, and census data are from the U.S. Census (2000).

This method considers the comfort and convenience facet of transit service by appending the vehicle capacity measure in calculation. LITA scores are intended to be useful to property developers by revealing where transit service is most intense and to aid in the development of land use plans and policies for areas with different levels of transit accessibility. LITA scores can be calculated for any unit of land area (i.e., census tract, traffic analysis zone, etc.), depending on the availability of transit and census data.

Method 2: Transit Capacity and Quality of Service Manual (TCQSM)

TCQSM (Kittelson 2003) incorporates a service coverage measure to assess transit accessibility and requires the same datasets (transit and census data) as LITA. Two methods are used to calculate the service coverage: the GIS method and the manual (graphical) method. For this research, a detailed GIS method was used as it requires less effort to calculate the service coverage area than the manual method, which requires overlying of different maps (i.e., study area map, transit map, etc.). To identify the spatial service coverage area, a 0.25-mile radius buffer area is applied around transit stops. This method was selected for this research to account for spatial coverage in public transit accessibility assessment. TCQSM offers a comprehensive guide for use by the transit operators to make decisions for infrastructure enhancements that could enrich the level of accessibility to the transit system. This method provides the scale of accessibility measure from individual bus stops to individual routes to the entire transit system.

Method 3: Time-of-Day Tool

The Time-of-Day Tool (Polzin et al. 2002) measures transit service accessibility using time-of-day travel demand distribution and provides the relative value of transit service provided for each specific time period. This tool requires data on temporal distribution of travel demand on an hourly basis in addition to the transit and census data required for the previous two methods. The time-of-day distribution of travel demand data and a daily trip rate of 4.09 trips per person were adopted from the 2001 National Household Travel Survey (NHTS). Tolerable

wait time was defined as 10 minutes in accordance with NHTS data. The fractional distribution for each tract that falls within the 0.25 mile buffered transit route was calculated using GIS software.

The Time-of-Day Tool was considered by this paper as the only tool to account for time-of-day distribution of travel demand and reflect the temporal coverage of transit accessibility. The calculation and interpretation of data from several different sources makes this tool more difficult to use and requires some transportation expertise. In spite of having complexity in calculations and difficulty in comparison of accessibility results with other methods, this tool is as straightforward as we found for covering temporal accessibility. This measure is important to public transit planners in determining the importance of transit service provided in each time period of the day. The tool can assess the degree of accessibility of a transit system for an individual zone or at the census tract level, depending on the availability of transit and census data.

Scaling

One purpose of this paper is to examine how consistently the three methods rated transit accessibility for each tract of study area. To do this, accessibility grades from each method were compared for each census tract. This presented some problems, as the results were given on three different scales. In LITA, the overall scores obtained from three standardized scores (frequency, capacity, and service coverage) were rescaled by adding five for greater ease of interpretation. Then, the rescaled LITA scores were assigned to five grades (as shown in Table 2), A through F (excluding E). Grade A corresponded to a LITA+5 rating of 6.5 or higher, indicating the highest level of accessibility.

Table 2. Existing Scaling of Three Methods and the Developed Consistent Grading Scale

Grading Scale of Three Methods			New Consistent Grading Scale	
LITA+5 Score Scale Range (Grade)	TCQSM Score Scale Range (LOS)	Time-of-Day Tool	Scale Range	Grade
≥ 6.5 (A)	90.0 – 100.0% (A)	No Grading Scale	≥ 1.50	A
5.5 – 6.5 (B)	80.0 – 89.9% (B)		0.75 to 1.49	B
4.5 – 5.5 (C)	70.0 – 79.9% (C)		0.00 to 0.74	C
3.5 – 4.5 (D)	60.0 – 69.9% (D)		-0.75 to -0.01	D
< 3.5 (F)	50.0 – 59.9% (E)		≤ -0.76	F
	<50.0% (F)			

TCQSM adopted the level-of-service (LOS) concept, introduced in the *Highway Capacity Manual* (HCM) (Transportation Research Board 2000), for measuring quality of transit service. Scores were measured as the percentage of service area covered by transit system and were grouped in six LOS, A through F, as shown in Table 2. The Time-of-Day-based transit accessibility analysis tool measures transit accessibility by the number of daily trips per capita (in each census tract) that are exposed to transit service. The Time-of-Day Tool did not characterize the accessibility results with any grading system as LITA and TCQSM did.

For a more consistent comparison of accessibility results, the calculated scores for the TCQSM and Time-of-Day Tool methods were standardized (as in LITA) across all the census tracts for relative accessibility scores. To get the standardized score for a tract in a method, first, the difference between the raw score for this tract and the mean of scores for all tracts was calculated, and then the difference was divided by the standard deviation of scores for all tracts. For ease of interpretation of these standardized scores, this paper develops a common grading scale (as shown in Table 2) with five grades A through F (excluding E). Grade A represents a score of +1.5 or higher, indicating the highest level of accessibility, and grade F represents a score lower than -0.75, indicating poor level of accessibility. As an example, the detailed process of standardizing the scores and assigning grade to the standardized scores for census tract 1702 is shown in Table 3. In LITA, the raw score (as shown in Table 3) was already standardized, but for this paper, we ignored the concept of rescaling (i.e., adding 5 to the standardized scores to make all scores positive).

Table 3. Example of Standardization of Raw Scores for Different Methods

Standardization	LITA	TCQSM	Time-of-Day Tool
Raw Score for Tract 1702 (Grade)	5.465 (C)	62.36 (D)	0.0229 (No Grade)
Mean of Scores for All Tracts	-	41.93	0.0113
Std. Deviation of Scores for All Tracts	-	30.55	0.0081
Standardized Score for Tract 1702 (Consistent Grade)	0.465 (C)	0.668 (C)	1.44 (B)

The development of the composite index on the basis of the three selected methods comprises several steps. First, the raw scores were standardized for each method, as mentioned earlier. Next, the accessibility metrics used for calculations across the three methods were identified (see Table 4). Individual weighting factors (WF) were then assigned to each of the individual measures. The summation of all weighting factors for the individual measures was assigned as the final weighting factor for each method.

Table 4. Development of Weighting Factors (WF)

Methods	Accessibility Metrics	Scheme # 1		Scheme # 2		Scheme # 3	
		Metric Weight	Method Weight	Metric Weight	Method Weight	Metric Weight	Method Weight
Time-of-Day Tool	Service Coverage	1	5	3	9	1/3	10/3
	Service Frequency	1		2		1/2	
	Demographics	1		2		1/2	
	Travel Demand	1		1		1	
	Waiting Time	1		1		1	
LITA	Service Coverage	1	4	3	8	1/3	7/3
	Service Frequency	1		2		1/2	
	Demographics	1		2		1/2	
	Capacity	1		1		1	
TCQSM	Service Coverage	1	1	3	3	1/3	1/3

Three weighting schemes were considered to assign weighting factors to the measures. Scheme # 1 assigns a WF of 1 to all measures; in Scheme # 2, WF were allotted according to the occurrence of a measure in the methods (i.e., if a measure is common in all the three methods, then its weighting factor was assigned as 3). Scheme # 3 assigns the WF such that the weights for common measures sum to 1 and unique measures simply receive a weight of 1. The weighting factors of individual elemental measures and the total weighting factors for the three methods are shown in Table 4.

Results

Table 5 depicts the accessibility results for all census tracts in original scales for each method. With the actual scales for an individual method, one can interpret the accessibility results according to that method's grading system. Table 5 shows that the obtained results vary greatly across the methods. To get a comparable picture of accessibility using the results of these methods, the results must be interpreted in terms of the applicable scale. Furthermore, the accessibility results of the Time-of-Day Tool cannot be compared with the other methods because it does not provide any grading or scaling system by which one can easily interpret or compare the accessibility results. Thus, for a meaningful comparison of transit

accessibility between the tracts that can be easily understood, this paper standardizes the results, providing a picture of the relative difference in accessibility between methods. The results of the standardized scores shown in Table 5 provide less variable results across methods.

Table 5. Comparison of Results in Raw Scores and Standardized Scores for Three Methods

Census Tract	Raw Scores					Standardized Scores					
	Time-of-Day Tool Score (Daily Trips per Capita)	LITA Score (Rescaled Overall Score, Grade)		TCQSM Score(% of Service Area Served, LOS)		Time-of-Day Tool Score,Grade		LITA Score, Grade		TCQSM Score, Grade	
1701	0.0273	12.97	A	76.89	C	1.976	A	7.973	A	1.144	B
1702	0.0229	5.46	C	62.36	D	1.44	B	0.465	C	0.668	C
1703	0.0119	3.99	D	40.94	F	0.88	C	-1.001	F	-0.032	D
1704	0.0028	3.45	F	5.23	F	-1.03	F	-1.545	F	-1.201	F
1705	0.0025	4.25	D	11.39	F	-1.072	F	-0.742	D	-0.999	F
1706	0.0062	4.83	C	21.37	F	-0.614	D	-0.161	D	-0.673	D
1707	0.0125	4.85	C	50.65	E	0.162	C	-0.146	D	0.285	C
1708	0.0097	5.25	C	29.21	F	-0.182	D	0.25	C	-0.416	D
1709	0.0196	7.69	A	83.09	B	1.036	B	2.694	A	1.347	B
1710	0.0220	4.72	C	69.63	D	1.327	B	-0.272	D	0.906	B
1711	0.0065	4.20	D	17.10	F	-0.581	D	-0.792	F	-0.812	F
1712	0.0041	3.71	D	13.42	F	-0.876	F	-1.286	F	-0.933	F
1713	0.0086	4.80	C	39.53	F	-0.316	D	-0.194	D	-0.078	D
1714	0.0170	8.16	A	91.28	A	0.712	C	3.164	A	1.615	A
1715	0.0133	5.42	C	83.51	B	0.2586	C	0.42	C	1.361	B
1716	0.0028	4.50	C	14.24	F	-1.03	F	-0.492	D	-0.906	F
1717	0.0007	1.97	F	2.91	F	-1.298	F	-3.023	F	-1.277	F

The standardized scores shown in Table 5 do still show some variation across the methods (e.g., census tracts 1703, 1710, and 1714). Table 6 presents the grades for the composite accessibility scores using the different weighting schemes from Table 4. As an example, in order to calculate the composite score for census tract 1702 in Scheme #1, first, the standardized scores for three methods (1.44, 0.465, and 0.668 from Table 5) were multiplied by the method weights (5, 4, and 1, respec-

tively, from Table 4). After that, the sum of these multiplied scores was averaged over the sum of method weights, and the composite score was found as 0.97, which lies in between the range of 0.75 to 1.49 (Table 2) and was assigned as accessibility grade B (Table 6).

Table 6. Comparison of Results for Three Schemes and Grades for Composite Measure

Census Tracts	Composite Grade		
	Scheme #1	Scheme #2	Scheme #3
1701	A	A	A
1702	B	B	B
1703	C	D	C
1704	F	F	F
1705	F	F	F
1706	D	D	D
1707	C	C	C
1708	D	D	D
1709	A	A	A
1710	C	C	C
1711	D	D	D
1712	F	F	F
1713	D	D	D
1714	A	A	A
1715	C	C	C
1716	F	F	F
1717	F	F	F

The results shown in Table 6 indicate that the composite scores are consistent across the schemes, and the only difference is that Scheme #2 is somewhat more conservative in grading, specifically census tract 1703. In Scheme #1, each individual measure is treated equally, and the presence of a particular measure in all methods gives it additional weight in the combination process. Scheme #2, defined in Table 4, evaluates transit accessibility addressing the spatial aspects (service coverage) extensively, and Scheme #3 reflects emphasis on the temporal dimension of transit accessibility measures. In Scheme #3, temporal distribution of travel

demand and service frequency are used to calculate the transit accessibility more heavily weighted than the spatial data. Therefore, three combinations of accessibility measures (spatial, temporal, and both spatial & temporal) were considered in developing the different schemes.

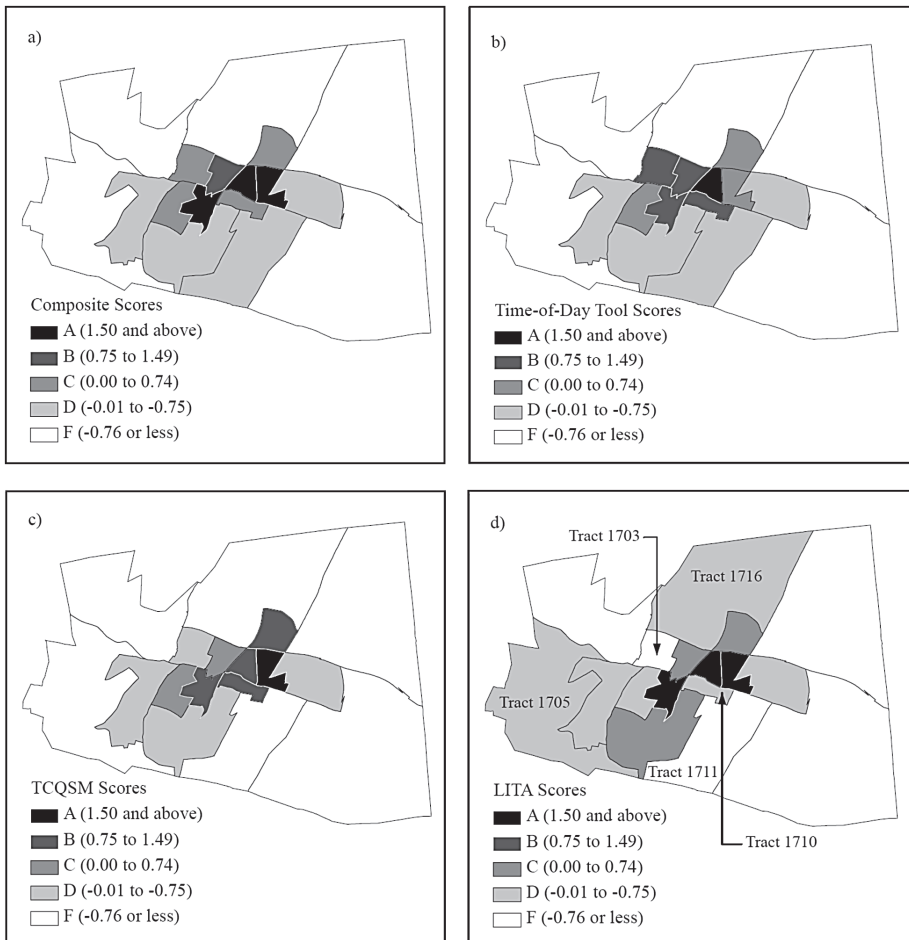
Spatial Distribution of Accessibility Results

TCQSM considers a much smaller coverage area than the other two methods. While there is broad agreement that the best coverage is concentrated in a relatively small area (which is expected, given the service map in Figure 1), there is disagreement on the extent for the middle of the accessibility spectrum (Figure 2). LITA considers a much larger area to have moderate accessibility, but this may be due, in part, to its target audience: developers. LITA is designed to broadly identify good investment possibilities near transit, leaving more detailed analysis to those regions a developer may want to target. TCQSM is concerned with spatial coverage only and, therefore, follows the layout of lines and stops closely. The Time-of-Day Tool considers measures of demand, which reflect that some tracts that are not well-covered spatially may, in fact, serve high demand populations. It is important to remember that these scaled versions are comparing a particular tract against the average measure for the entire system. These values are not absolute.

Comparative Example

Figure 2 maps the grades of accessibility scores across methods and illustrates the grading scale of the accessibility scores. This graphical view shows relative accessibility intensity, which is helpful for the comparison of accessibility between different tracts. Three census tracts (1703, 1710, and 1711) chosen to represent difference in accessibility intensity across the methods are indicated in Figure 2. LITA represents lower scores for tracts 1703 and 1710 than the other methods. This method provides a relatively lower score to the densely populated smaller area (already-developed area) and gives a moderate accessibility result to the larger areas (census tracts 1705 and 1716, Figure 2). This is due primarily to the intended users' viewpoint of this method. A higher LITA score for a census tract indicates that this tract has more potential for future transit oriented development or redevelopment.

The TCQSM method results in higher accessibility scores than the LITA method for census tracts 1703 and 1710. TCQSM is intended to characterize transit accessibility generally by the existence of transit stops and transit lines in the service area and counts for the percentage of 0.25-mile radius buffer area around the bus stops exist in area. Therefore, census tract 1703 results in a higher accessibility score in TCQSM than in LITA.



**Figure 2. Accessibility scores for different methods:
a) Composite, Scheme #1; b) Time-of-Day Tool; c) TCQSM; d) LITA.**

The Time-of-Day Tool considered time-of-day travel demand distribution for an area and did not consider the spatial distribution of transit routes as in TCQSM. Tract 1711 appears as a moderately-accessible tract in the Time-of-Day Tool, but this tract has poor accessibility in the TCQSM and LITA methods. This reveals that some tracts that have poor spatial coverage of transit may have considerable temporal coverage to serve the high demand population for this tract.

The composite scores (Scheme #1) mapped in Figure 2 provide a single accessibility score for tracts that show variability between methods. This score represents three

stakeholder perspectives and, if a single metric is to be used, may be a more robust measure than one of the individual methods.

Conclusions

This paper examined the benefit of a consistent grading scale across different stakeholder groups and formulated a composite accessibility measure. Individual accessibility results were calculated to examine consistency in the results as well as in the grading scales across methods. The composite accessibility measure was developed by integrating three methods, which may be useful as a reliable and defensible measure for stakeholders (i.e., if the composite index obtained from three simple methods indicates high accessibility in an area rather than from one single method, then it is likely that the area truly is highly accessible). From the perspective of policy makers, an assessment of transit accessibility must consider different user viewpoints (i.e., transit planner, provider, property developer, etc.). Therefore, this composite measure is intended to combine the three simple methods that encompass several user perspectives. This paper standardized individual raw scores and adopted a common grade scale. Several permutations of a combined weighting scheme were tested. This paper helps planners select a set of accessibility measures and presents a method of combining them to produce a more defensible and robust accessibility result for their customers. The results of a composite measure can be taken as a basis for adjusting the priorities of public transport services and addressing lack of service in public transport provision. The composite index provides a relative accessibility measure of the degree to which transit is reasonably available at the origin of a trip. This information is important for zonal service equity analysis and understanding transit supply provision in the community.

The limiting feature of this research is that this method cannot be directly generalized to all areas or to those that need to measure the level of transit accessibility with methods that are more sophisticated. This composite accessibility result cannot reflect the changes in accessibility level for the micro-level changes in socio-economic and demographic characteristics (i.e., car ownership, income level, etc.) of transit users. In addition, the composite accessibility index can have different meanings in different areas. The most significant limitation of this method is that it is limited in its ability to determine real accessibility of an area, as it does not consider the transit user beyond the quarter-mile buffer of a stop location.

Further development and refinement of the measure would be useful in several areas. In addition to the accessibility measures in this study, a needs gap (Currie 2004, Bhat et al. 2006) assessment in transit service would address the transportation disadvantaged population and its relationship to systemic spatial coverage.

Acknowledgments

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Tennessee Vans: A User-Based and Financially- Sustainable Approach to Develop Community Mobility Resources

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Abstract

Although substantial resources have been devoted to the provision of the transportation infrastructure needed to support the movement of people, there still exist “mobility gaps,” especially among transportation disadvantaged groups of persons. An approach to fill these community mobility gaps is based on the experimental and evolving development and operations of Tennessee Vans over the past 20 years. The Tennessee Vans fleet has grown to 845 vehicles assigned to more than 300 community groups and organizations as part of its vehicle lease and purchase programs. Program participants include community and economic development agencies, faith-based organizations, commuter vanpools, youth-based organizations, workforce development groups, and public/private transit agencies. A financial analysis indicated that in model year 2007 Tennessee Vans had achieved its major goal of becoming financially self-sufficient through its revenue generation capabilities and recycling of program revenue to procure additional vehicles and finance program operations.

Introduction

In recent years, much has been written about human mobility and its importance for community, economic, and human growth and development for all groups of people (Garrison and Ward 2000; Urry 2007; Jones 2008; Staley and Moore 2009). These discussions point out that, although substantial resources have been devoted to the provision of the transportation infrastructure needed to support the movement of people, there still exist what are termed “mobility gaps.” These mobility gaps occur when the transportation needs of individuals or groups are not being met by current transportation service options. The occurrence of mobility gaps is especially apparent among transportation disadvantaged groups, including persons with disabilities, youth, older adults, and low income workers.

For decades, transportation professionals have designed and developed alternative approaches to address the mobility needs (including mobility gaps) that occur in all communities. In addition to road development approaches that support the use of highway vehicles, various approaches have been used to move people from place to place (Research and Training Center on Disability in Rural Communities 2007). These include public transportation models (fixed-route, demand responsive, deviated fixed-route services), agency-focused models (specialized transit services), cooperative models (coordinated services, brokerages, consolidated services), volunteer and voucher models (volunteer systems, community inclusion drivers, vouchers), and public-private partnerships (taxi coupon models, personal vehicle ownership). The mobility services offered through these and other transportation approaches, such as commuter ridesharing and transportation demand management services, can be found in most communities. Yet there still remains a lack of infrastructure and services to address or fill the mobility gaps that continue to occur. Clearly, there is an ongoing need to design and develop additional mobility resources to address persistent community transportation issues.

The purpose of this paper is to present an approach for the development of community mobility resources. This approach is based on the experimental and evolving development and operations of Tennessee Vans over the past 20 years. Tennessee Vans is a statewide transportation service that provides vehicles for lease and/or purchase to commuter groups, employers, public agencies, and private non-profit community organizations. In exchange for access to vehicles and affordable financing provided by Tennessee Vans, the program participants agree to provide safe and reliable transportation services to meet identified mobility needs.

The characteristics that distinguish Tennessee Vans from other approaches include its flexibility to meet diverse mobility needs and fill mobility gaps, a primary emphasis on user-based service design, serving the basic role as a mobility resource provider, and a central focus on financial self-sufficiency and program sustainability. Tennessee Vans is a human mobility system designed to address the changing nature of mobility needs and the growing demands for transportation resources among diverse population groups throughout Tennessee (Newsom 1999; Wegmann and Newsom 2002). Mobility gaps addressed by Tennessee Vans typically occur when existing urban and rural transit providers are unable to provide access to desired destinations (e.g., work sites, medical facilities, retail stores) when and where they are needed by program participants. Transit service routes and schedules either are inconvenient or the services do not exist at all. Unlike traditional paratransit services with paid drivers, centralized dispatch, etc., Tennessee Vans services are user-centric. The basic premise of allowing program participants to design the mobility services that directly meet their needs is a key to success in terms of assuring accessibility to desired services and activities. Tennessee Vans serves primarily as a mobility resource provider and is available to assist program participants with the implementation of their service designs by providing vehicles and associated services. In addition, a major goal of Tennessee Vans is to become financially self-sufficient and maintain the viability of program services. The financial strategy used for revenue generation and recycling of program funds facilitates program sustainability and cost effectiveness.

The remainder of this paper includes a presentation and discussion about the major features of the Tennessee Vans program, including its basic program services, the involvement of program participants, its revenue generation and financial self-sufficiency strategy, and future plans for program sustainability.

Basic Program Services

The Tennessee Vans program was initiated on February 1, 1990. Its mission is to expand mobility options for persons throughout Tennessee, thereby encouraging community, economic, and human growth and development. The Tennessee Vans program is operated by the University of Tennessee Center for Transportation Research and provides vehicles for lease and/or purchase by commuter groups, employers, private agencies, and public and non-profit community organizations. Tennessee Vans uses grant funds provided by federal, state, and local sources to purchase vehicles for use by program participants. The vehicle costs and operating

expenses for Tennessee Vans are recovered from program participants through fees charged for the lease or purchase of vehicles. These generated funds are in turn used to purchase vehicles to replace older vehicles or add more vehicles to the fleet.

Program participants are identified through contacts with employers, business and community organizations, faith-based organizations, transportation agencies, public promotional activities, and by word of mouth. Interested parties complete and submit a program application for approval to participate in the program and to receive a vehicle assignment. Qualified program participants can lease and/or purchase Tennessee Vans vehicles. Three basic service programs are available: the Employee Vanpool Lease Program, the Agency Vehicle Lease Program, and the Agency Vehicle Purchase Program.

The Employee Vanpool Lease Program provides vehicles, insurance, maintenance, and fleet management assistance to commuter groups who want to travel to and from work in a vanpool. Minivans and 15-passenger vans are provided to groups of commuters who wish to ride together and share the monthly costs of operating the vanpool. The monthly fee covers the vehicle costs, fleet management expenses, maintenance, gasoline, and insurance. Insurance coverage is arranged through Tennessee Vans and paid for by each commuter group. The insurance includes \$1 million liability coverage and \$5,000 medical coverage, and physical damage coverage is self-insured. A member of the commuter group volunteers to drive the van, collect monthly rider fares, and keep the vehicle properly serviced. The typical vanpool monthly lease fee for a current model 15-passenger van traveling 70 miles round trip daily is \$780. Each member of the group pays a portion of the monthly fee (e.g., \$65 each for a group of 12 paying passengers).

The Agency Vehicle Lease Program provides the opportunity for public and private organizations to provide transportation through an affordable vehicle lease plan. Transportation services include transporting persons to and from work, job training sites, work-trip related events, and other activities that facilitate the mobility and meet the travel needs of persons served by the organization. Qualified agencies pay monthly vehicle lease fees on a fixed cost plus mileage basis. The agencies provide their own insurance at program-specific coverage levels (\$1 million liability, \$1 million uninsured motorist, comprehensive and collision with \$500 deductibles). The lease costs include the cost of the vehicle, vehicle maintenance, and fleet management expenses. A typical agency monthly lease fee for a current model 15-passenger van is \$450 fixed cost per month plus \$.10 per mile.

The Agency Vehicle Purchase Program provides the opportunity for program participants to purchase vehicles for transportation purposes through an affordable financing plan. Participants include public and private non-profit organizations that currently provide or would like to provide transportation services. Vans are assigned to participating organizations through simple purchase contracts. The participating organization agrees to pay monthly fees until the vehicle contract is paid in full. Upon payment of the vehicle contract cost, the vehicle title is fully transferred to the participating organization. Under the vehicle purchase program, the program participant provides the vehicle insurance (same coverage as agency lease program), maintenance services, and qualified drivers. The typical agency vehicle purchase contract cost for a current model 15-passenger van is \$25,000. The contract cost is amortized over 72 months with monthly payments of approximately \$348.

Since its inception in 1990 through the 2009 vehicle model year, the Tennessee Vans fleet has grown to 845 vehicles assigned to more than 300 groups and organizations located throughout Tennessee (Figure 1). The total number of vehicles grew rapidly during the 1990s and through 2002, when the economy was relatively strong, vehicle demand was high, and financial resources were available to program participants. From 2003 until 2009, the program growth was slowed due to the sluggish economy and recent financial crisis. During this period, the number of retired vehicles (vehicles sold at auction and paid-up purchase contract vehicles) outpaced the number of new vehicles added to the fleet. The number of vehicles in service decreased, but since 2006 has stabilized at approximately 200 vehicles per year. Program growth for Tennessee Vans follows closely the ups and downs of the economy and associated fluctuations in vehicle market demand.

Figure 2 shows the distribution of vans across the purchase, agency lease, and vanpool service program categories. As shown, most of the vehicles were assigned to the vehicle purchase program (60%). Participants favor the purchase program since they will acquire a real asset when the vehicle contract cost provisions are fulfilled and the vehicle title is transmitted to them. The employee vanpool lease program accounts for 22 percent of the vehicles. Tennessee Vans offers vanpoolers who are not interested in becoming owner operators the option to lease a van on a month to month basis. Eighteen percent (18%) of the vehicles were assigned to participants in the agency lease program. This leasing option provides services for agencies that prefer not to commit to a long-term purchase contract or are unable to purchase a vehicle due to financial constraints or grant funding restrictions.

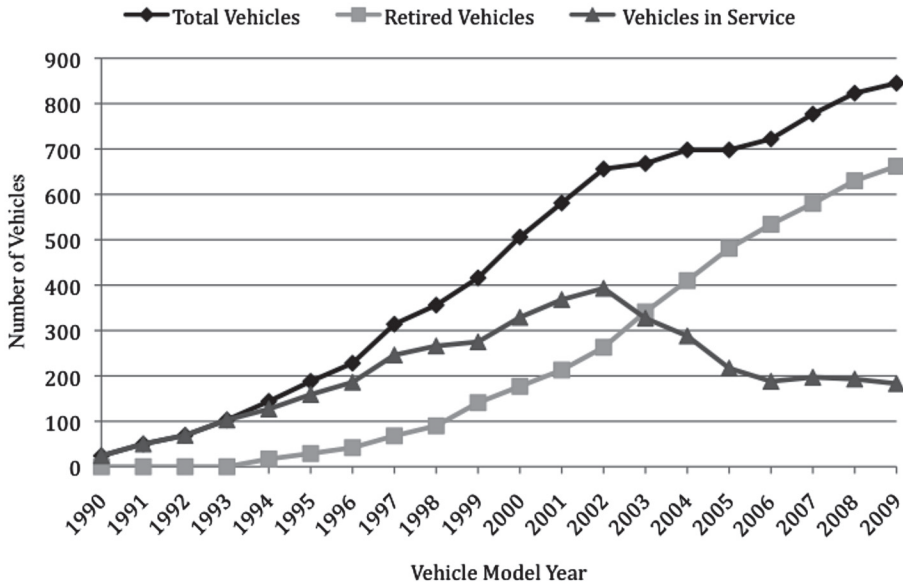


Figure 1. Number of Tennessee Vans.

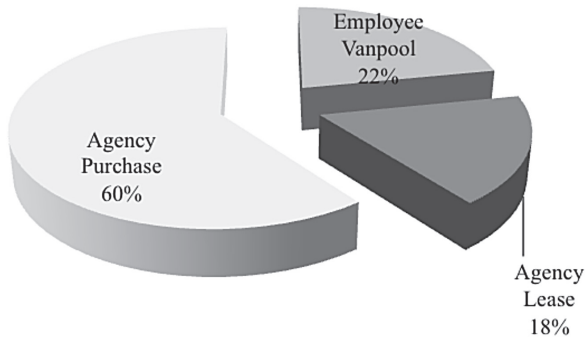


Figure 2. Vehicle distribution by program category.

Figure 3 shows the distribution of the total vehicles across program vehicle fleet categories.

The categories reflect the status of program vehicles and include vehicles that have been sold at auction, vehicles that have been paid in full and titles sent to program participants, and vehicles that remain in current operating service. Of the total number of 845 vehicles in the fleet, 22 percent of the vehicles are in current operating service. Of the remaining vehicles, 40 percent have been sold at auction and

38 percent have been paid in full by participants in the vehicle purchase program. The amount of revenue received was \$8,290,082 for the vehicles sold at auction and \$7,117,340 for the vehicles with paid-up purchase contracts. The vehicles in current operating service generate approximately \$850,000 in revenue per year. The overall program status for vehicles changes from year to year depending on the number of leased vehicles replaced and sold at auction, purchase contracts fulfilled, and new vehicles ordered and placed in service.

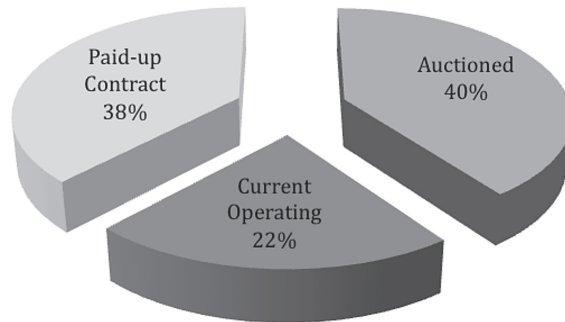


Figure 3. Vehicle distribution by fleet category.

Vehicle Fleet

Vehicles for Tennessee Vans program participants are procured through the University of Tennessee competitive bid process. The primary vehicles used by program participants are the 15-passenger van and the minivan. Table 1 shows the number of vehicles and various vehicle models that have been procured and assigned to program participants from model year 1990 through model year 2009. The vehicles include Ford, Dodge, Chevrolet, and GMC models. Most of the vehicles (69%) used by program participants are 15-passenger vans. Minivans comprise 23 percent of the fleet. Eight percent of the fleet includes alternative vehicles that were procured and used to address specific vehicle safety and child care transportation issues.

The vehicle fleet includes models other than the traditional 15-passenger van and minivan. The Ford 12-passenger van and 14-passenger van (with a center aisle) and the 10-passenger Dodge Sprinter included technical specifications (electronic stability control technology and three-point seat belt systems in all seating positions) to address safety issues related to vehicle rollover problems. The Multi-Function School Activity Bus (MFSAB) was added to meet new state childcare transportation regulations requiring child care agencies to transport children in school-

bus-type vehicles. Working with the various user groups to procure appropriate vehicle technology and develop effective safety information programs to address vehicle safety problems and issues has been an ongoing concern of Tennessee Vans (Newsom and Meyers 2003; Newsom, Meyers, and Gilpin 2005; Wegmann and Noltenius 2008).

Table 1. Tennessee Vans Fleet Composition (MY 1990-2009)

Vehicle Model Type	Manufacturer	Total #	% of Fleet
15-Passenger Van	Ford	188	
	Dodge	386	
	Chevrolet	8	
<i>Subtotal</i>		582	69%
Minivan	Ford	23	
	Dodge	12	
	Chevrolet	122	
	GMC	38	
<i>Subtotal</i>		195	23%
Alternative Vehicle	Ford (12-passenger)	5	
	Ford (14-passenger)	47	
	Dodge Sprinter	3	
	MFSAB (childcare bus)	13	
<i>Subtotal</i>		68	8%
TOTAL		845	100%

The physical locations of the vehicles throughout the state of Tennessee are shown in Figure 4. The majority of the vehicles are located in and around large urban population centers, such as Shelby, Knox, and Davidson counties. The remaining vehicles are spread throughout the small urban and rural counties. At least one vehicle is located in more than half of the 95 counties in Tennessee. The map depicts where vehicles are physically located by county; however, the vehicle service areas are not limited to county boundaries and more often than not the vehicle service areas span adjacent counties.

Program research studies (Wegmann 2001; Wegmann and Newsom 2002) indicate that the average vehicle traveled about 1,102 vehicle miles per month. Approximately 4,308 persons per month were transported, and about 181,667 monthly trips were made (about 2.1 million trips annually). During the time period for these studies, the annual trips for rural transit operators in Tennessee was 1.1 million, 2.8 million for fixed route transit in eight small cities, and 22.6 million for the four large cities. These studies also indicated that the environmental benefits generated by Tennessee Vans include a reduction in air pollution by 44,453,000 grams/day for HC; 418,649,000 grams/day for CO; and 29,330,000 grams/day for NOX; and a reduction in fuel consumption by 1.4 million gallons annually.

Program Participants

The Tennessee Vans program provides vehicles and services to a diversity of participant groups, including community and economic development agencies, faith-based organizations, commuter vanpools, youth-based organizations, workforce development groups, and public/private transit providers. Each category of participants contains a variety of program users. For example, health care facilities, residential group homes, women's shelters, and refugee service programs are included among the participants in the community and economic development category. The work force development category includes participants from educational facilities, supported employment programs, and job training programs. Other examples of the array of participating organizations within each category are shown in Table 2.

The percent of vehicles assigned to each participant group is shown in Figure 5. Participant groups that account for approximately 71 percent of the vehicle fleet include the community and economic development group (29%), faith-based organizations (22%), and commuter vanpools (20%). Youth-based organizations (14%), workforce development programs (8%), and transit providers (7%) account for the remainder of the vehicle fleet.

These participant groups use the Tennessee Vans vehicles for a variety of mobility needs. For example, community and economic development organizations transport program staff and residents to community-based training activities and events. Some organizations provide vehicles to residential group homes to meet mobility needs in support of independent living arrangements. Public transit providers in urban and rural areas transport clients to jobs, employment training, medical

Table 2. Tennessee Vans Participant Categories

Community and Economic Development	Work Force Development
Health Care Facilities	Educational Facilities
Housing Authorities	Private Industry Councils
Environmental Groups	Supported Employment
Community Development	Job Training Placement
City and County Agencies	Employers
Residential Group Homes	Work Release Programs
Drug Elimination Programs	Commuter Vanpools
Women's Shelters	Employee Groups
Refugee Service Programs	Employer Sponsored Groups
Senior Citizen Centers	Ridesharing Agencies
Public/Private Transit Providers	Faith-Based Organizations
Rural Transit Agencies	Social Services
Urban Transit Agencies	Community Outreach
Transportation Businesses	
Youth-Based	
Day Care Centers	
Youth Service Programs	

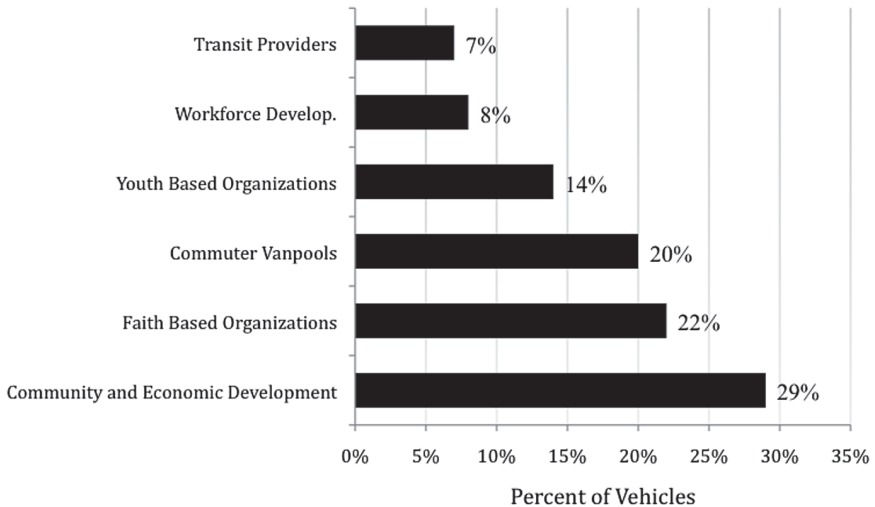


Figure 5. Percent of vehicles by participant group.

appointments, and recreational activities. Work force development organizations use vans to transport clients from community homes to jobs and training facilities. They also transport clients from central training facilities to job interviews and other work-related events and activities. Youth groups use the vehicles to transport their clients to and from activities such as computer training at their central facilities, as well as to community-based activities and for field trips. Faith-based organizations use vans to support their community-based ministries and services. The vehicles are used to meet the mobility needs of youth ministries, after-school service programs, and senior services. Vehicles also are used to transport clients to and from day care centers and other events in the community. The vehicles also are used for commuter vanpooling. Several employee vanpool groups lease vans from the program to travel to and from work and share the travel costs. Employers also have leased vehicles to recruit, hire, and transport employees to worksites.

Periodic surveys, interviews, and focus groups with program participants have been conducted to obtain qualitative information regarding user perceptions and reactions to the Tennessee Vans program (Wegmann and Newsom 2002; Newsom and Meyers 2003; Wegmann and Noltenius 2008). Participant responses during these studies indicated that many of the organizations (34.5%) could not maintain their existing programs without access to a Tennessee Vans vehicle. When asked about the importance of Tennessee Vans to their organizations, typical responses would include, "Without Tennessee Vans we would not be able to do what we're doing. The vans are allowing us to expand our outreach program." and "Our program would come to a screeching halt without the vans. Without the vans, services could not be offered, so they are essential." Participants (23.8%) also stated that some of their clients would be left without mobility and could not participate in the programs. A small number of participants (13.1%) stated that their clients could rely on public transit or walking, and some participants (21.4%) stated that clients would have to rely on private vehicles, parents, or carpooling. Tennessee Vans vehicles are operated by many organizations that provide essential mobility to their clients. Closure and curtailment of services would negatively impact all program participants.

While some organizations use Tennessee Vans vehicles to supplement their fleets purchased from other sources, many had attempted to purchase a vehicle from a private dealership with little success. In most cases, the private sector would not provide the financial flexibility or extend the credit required for the organization to secure a van. Also, about a fourth of the organizations attempted to acquire a

vehicle as part of public capital grant programs, but without success, since these grants are very competitive and the agencies did not meet the applicant qualifications. Almost half of the organizations reported that a Tennessee Vans vehicle replaced an older vehicle. These organizations benefited from acquiring a newer, safer, and more reliable vehicle.

As part of these research studies, program participants were asked about the resources used to pay for the Tennessee Vans vehicles. Program participants reported that these resources include passenger fares (6.1%), program revenue (19.5%), daycare or tuition fees (9.8%), social service grants and state vouchers (23.2%), and donations (41.4%). Participants also indicated that the Tennessee Vans vehicles were used because of the attractive payment plan and reasonable rates (61.0%) and that no down payment was required (35.0%). It is clear that these organizations value the simplicity and financial flexibility provided by Tennessee Vans because many are not financially able to use conventional credit to lease or purchase a vehicle.

Revenue Generation and Financial Self-Sufficiency

The basic framework that guides the Tennessee Vans financial strategy is depicted in Figure 6. This financial strategy for maintaining the viability and longevity of the program is the defining characteristic that sets Tennessee Vans apart from other community mobility resource development programs. The initial seed grants were provided by local, state, and federal governments with the stipulation and expectation that Tennessee Vans will maximize vehicle and operating cost recovery. Tennessee Vans strives to constrain operating expenses, minimize financial losses, and maximize revenue generation. Revenues received from program participants are used to purchase replacement vehicles in the lease program and to procure additional vehicles for the purchase program. The use of these vehicles generates revenue that, in turn, is used to pay expenses and procure additional vehicles for future use. This recycling of revenue contributes to the growth of the program and its longevity into the future.

Program funds to procure and operate Tennessee Vans vehicles have been provided by federal, state, and local agencies and by participants through program generated revenue. Table 3 shows the distribution of capital funds from various funding sources during 1990-2009. Approximately 9 percent of the funds have been provided by the Tennessee Department of Transportation (TDOT) in the form of

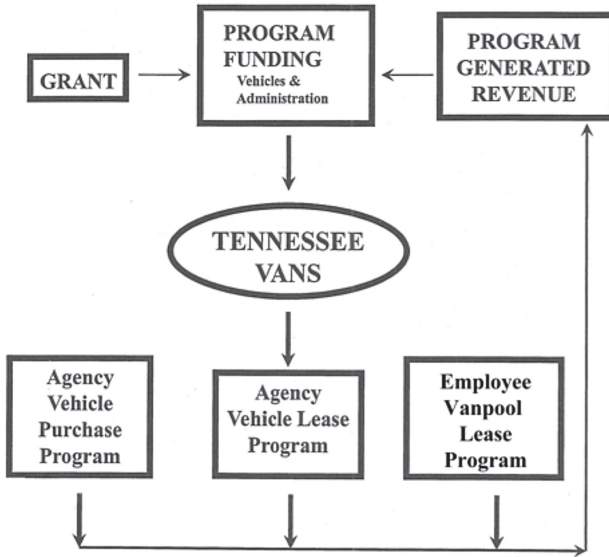


Figure 6. Tennessee Vans financial strategy.

the initial seed grant and periodic supplemental grants. Local Metropolitan Planning Organizations (MPOs) have contributed approximately 42 percent to support local van services as part of federal, state, and local congestion mitigation, air quality, and surface transportation programs. Almost half (49%) of the funds have been received as program-generated revenue in the form of service fees received from program participants. A capital reserve fund account was established as a source of funds to purchase future vehicles. The reserve fund consists of program generated revenue and the current fund amount enables Tennessee Vans to procure up to 175 vehicles to meet future vehicle demand.

Table 3. Source of Vehicle Funds (1990-2009)

Funding Source	Period	Amount	Percent
Program Revenue	1991-2009	\$7,990,106	48.7%
Memphis MPO	1993-2004	\$4,179,807	25.5%
Knoxville MPO	1992-2006	\$2,595,159	15.8%
TDOT	1990-1995	\$1,476,157	9.0%
Nashville MPO	1992-1993	\$175,000	1.0%
Total Vehicle Funds	1990-2009	\$16,416,229	100%

An ongoing financial objective for Tennessee Vans is to maximize the generation of revenue from program participants to cover recurring program costs. Targeted amounts of revenue are estimated for each vehicle assigned to program participants. The targeted estimates include vehicle costs, maintenance expenses, insurance fees, and fleet management expenses. Vehicle lease and purchase pricing strategies are established with the goal of recovering the estimated targeted amounts during the life of each vehicle. A comparison of the revenue generated for the vehicles that have been paid for and sold at auction with the targeted estimates of revenue for these vehicles indicates that 91 percent of the program costs were recovered. Although total cost recovery for program operations was not achieved due to financial losses from vehicle accidents, bad debt accounts, vehicle service demonstration, and pricing experiments, the overall amount of program-generated revenue is exceptionally high compared to most community public transportation program cost recovery rates.

From its inception, a major goal for Tennessee Vans is to become financially self-sufficient, that is, less dependence on government grants and more reliance on program revenue to finance future growth and operations. Substantial progress has been made in achieving this goal, as depicted in Figure 7. A comparison of the expended funds used to purchase vehicles from capital grant resources and program revenue are shown for four vehicle model year periods. During the first period (MY1990-1994), the primary source of funds to procure vehicles was from government seed grants. Program-generated revenue was not sufficient to meet vehicle demand. During the second period (MY1995-1999), both grant funds and program revenue were used to procure vehicles. The program was maturing and vehicle demand was high and producing substantial program revenue. Grant funds were used to a greater extent than program revenue during the third period (MY2000-2004). During this time period, expending remaining grant funds to procure vehicles was the primary objective. The transition from government grant support to primary dependence on program revenue for Tennessee Vans occurred during the fourth period (MY2005-2009). A major program milestone was reached in model year 2006, when the final balance of grant funds was used to procure vehicles. Since model year 2007, only program revenue has been used to procure vehicles and finance program operations.

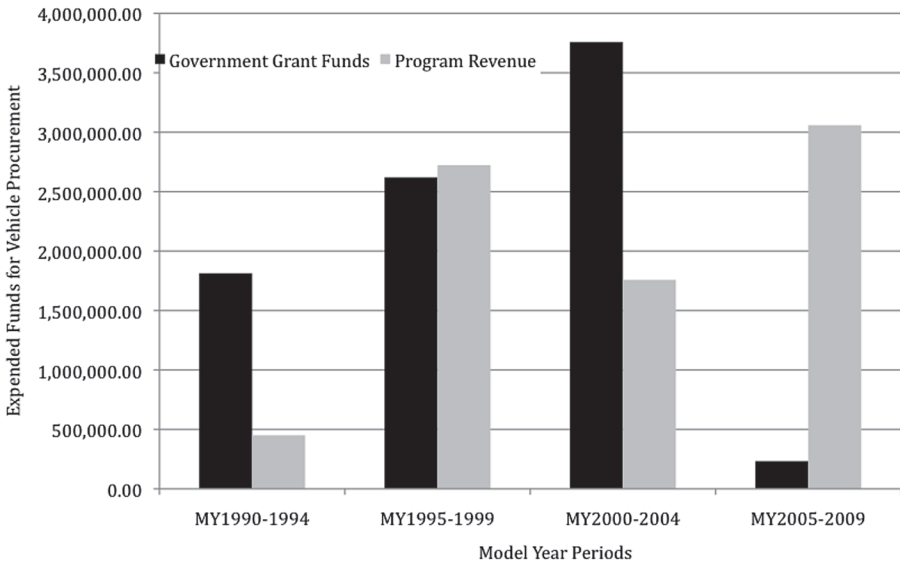


Figure 7. Expended funds used to purchase vehicles.

Future Plans for Program Sustainability

The discussions above summarize and highlight the major service development and implementation activities of the Tennessee Vans program during the past 20 years. Tennessee Vans has experienced a steady and sustainable rate of growth in funding and service development since its implementation in 1990. Financial resources provided during this time have enabled the program to procure 845 vehicles and to assign these vehicles as part of the vehicle lease and purchase programs to a diversity of user groups throughout the state. The lessons learned from program implementation thus far highlight the need for user participation in the design and development of program services, the importance of maintaining the role of mobility resource provider, the requirement to properly generate and manage program revenue to facilitate program sustainability, and the continuation of an evolutionary and experimental planning perspective with regard to future program growth.

Tennessee Vans is helping to fill mobility gaps through the provision of affordable vehicles. The program serves as a vehicle resource provider and assists its participants with the development and implementation of user-based service design travel options. The user-based model enables the participants to have a substantial

degree of input and latitude with regard to providing transportation services. In essence, the service design and delivery approach adopted by Tennessee Vans is highly market driven and very viable because it works directly with its evolving market to meet their mobility needs.

The future growth of the program depends on the continued focus on identifying and addressing the occurrence of mobility gaps that occur throughout the state and to replicate the service strategies to meet these needs. This requires continuous review, documentation, and evaluation of lessons learned from program implementation. It also requires a commitment to maintain the role of a mobility resource provider and allow program participants to design and operate transportation services that directly meet mobility needs.

To assure and sustain program growth in the future, Tennessee Vans must strive to preserve and maintain financial self-sufficiency. Tennessee Vans has initiated the process of transitioning from a government-sponsored program with primary reliance on public grants as a funding source to a transportation service with primary reliance on program-generated revenue for continued operations. The program has established the capability to generate substantial revenue. Effective business practices now must be pursued to render the program operationally and financially sustainable. These practices include containing operating costs, maximizing revenue collections, and minimizing financial losses. Proper stewardship and management of program-generated funds will enable Tennessee Vans to continue to grow and develop important community mobility resources for the future.

Finally, Tennessee Vans must retain its evolutionary and experimental planning perspective. Future growth plans should include the application of program services to meet identified mobility needs in areas of the state that are underserved. Future plans should explore ways to facilitate the identification of mobility gaps and the broadening of trip purposes addressed by past, current, and new program participants. The application of alternative and appropriate service vehicles also should be explored in future plans. These vehicle options should include the incorporation of alternative “green” vehicles into the vehicle fleet to address future energy and environmental issues encountered by program participants.

In conclusion, the Tennessee Vans program provides an affordable option for program participants as they strive to overcome transportation problems that are barriers to achieving their organizational goals (e.g., employment, training, community service, etc.). The program provides essential services to meet the transportation needs of diverse user groups, including employment, job training/education,

health care, and human services. Tennessee Vans is a user-based and financially-sustainable approach that helps to overcome the presence of mobility gaps and meet growing mobility demands in communities now and into the future.

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Identifying Inaccessible Areas with Potential to Enhance Transit Market

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Abstract

The focus of this manuscript is 1) to compute a transit accessibility index based on demographic/socio-economic characteristics and land use characteristics for each transit stop and route and the entire study area, and 2) identify inaccessible areas to provide an improved public transportation system that maximizes market potential. Transit accessibility indices were computed using spatially-extracted data within a pre-defined walking distance or time (0.25 miles or 5 minutes) for each transit stop (bus-stop) and route, and the entire study area. Results from linear regression analysis showed a statistically significant relationship between boardings and alightings, and the computed transit accessibility index based on demographic/socio-economic characteristics and land use characteristics for transit stops. The spatial distributions of computed transit accessibility indices were used to illustrate identification of spatial gaps, selection of ideal locations for transit stops along a route, extension of an existing route, identification of new transit routes, and expansion of transit area coverage.

Introduction

Rapid growth in population and travel demand over the past two decades has led to an increase in road congestion. This has been a major concern for not only transportation system managers but also to the traveling public. Literature documents several solutions to reduce huge economic and environmental losses associated

with congestion. Providing an efficient, accessible, and affordable public transportation system is one such solution.

Increasing traffic volumes, suitable land development strategies, growing oil prices, and air pollution concerns could further contribute to commuters choosing transit as an alternate mode of transportation. However, public transportation systems managers may choke on their success if these systems are not planned, designed, built, and maintained to maximize transit market potential and ridership.

The successful deployment of public transportation systems often depend on adequate funding, service frequency, total travel time, fare, accessibility to the system, security, comfort, and convenience of travel. Building a public transportation system that considers these characteristics allows for provision of an affordable and efficient alternate mode of transportation to the general public. Such a system will not only be sustainable but supports a vibrant economy.

Accessibility depends on demographic/socio-economic characteristics and land use characteristics within the vicinity of a transit stop (say, a bus-stop). This manuscript focuses on 1) estimating a transit accessibility index based on demographic/socio-economic characteristics and land use characteristics, and 2) identifying inaccessible areas in transit accessibility in order to enhance its market potential. It proposes a Geographic Information System (GIS) based methodology to compute a transit accessibility index for each transit stop (bus-stop), route, and study area as a whole (transit network-level performance). In this manuscript, spatial gaps or inaccessible areas are defined as areas with potential for transit market but do not have a transit stop within an acceptable walking distance and are not being served currently.

The spatial distributions of computed transit accessibility indices for transit stops and routes provide valuable insights in order to identify spatial gaps, select ideal locations for transit stops along a route, extend an existing route, identify new transit routes, and expand transit area coverage. Public transportation system managers can use these outcomes to better plan and serve the population in areas without transit service. This helps maximize transit market potential and ridership.

The working of the proposed GIS-based methodology is illustrated using bus transit system data for the city of Charlotte, North Carolina. The results obtained are assessed by examining the statistical relationship between 1) average daily boardings and the computed transit accessibility index for transit stops and 2) average daily alightings and the computed transit accessibility index for transit stops.

The city of Charlotte does not have an extensive rail transit system (only one light rail corridor connecting South Charlotte to downtown/uptown, referred to as the Lynx Blue Line; opened in November 2007) at the time of this research. Rail transit system/ridership, therefore, has not been considered or discussed in this paper.

Literature Review

Past research on transit planning and accessibility dealt with various ways to measure an accessibility index. Sanchez (1998) suggested that transit access is a significant factor for assessing the average rate of labor participation. Pulugurtha et al. (1999) defined a measure for accessibility to a transit service facility based on potential captive riders with certain demographic characteristics such as age group, household income, ethnicity, household auto ownership, unemployment, and persons with physical disabilities living in a household.

Bhat et al. (2002) developed an urban accessibility index based on factors (such as information available, hours of operation, travel time choice models, and opportunities that vary with distance) and found varying results depending on the type of measure used. Beimborn et al. (2003) used accessibility and connectivity to identify potential captive riders. Lee (2004) recommended a parcel level measure of public transit accessibility to destinations using GIS. This method considered walk time, waiting time, and travel time using transit service and by walking. Kuby et al. (2004) developed a raster-based algorithm for determining off-network routes to identify trip origins and destinations.

Kimpel et al. (2007) used GIS to measure the effect of overlapping service areas on passenger boarding at transit stops. A distance decay function was used to calculate walking accessibility from dwelling units to transit stops.

Spacing between transit stops is another criterion that affects accessibility and transit planning. Research by Ammons (2001) on transit stop spacing standards recommended that the range of spacing in urban areas should be from 656 ft to 1,968 ft. Saka (2001) developed an optimization model to determine the optimum spacing between transit stops in urban areas. Murray (2003) developed a coverage model to improve public transit system accessibility by minimizing the number of transit stops (bus stops) and maximizing the proportion of population covered by the transit stops.

Limitations of Past Research

Research in the past focused primarily on accessibility for either a single transit stop or facilities along a transit route. Very little has been done to compute transit accessibility and compare it for multiple routes. In addition, not many authors focused on network-level performance that allows decision makers to analyze and assess the overall performance of a transit system to maximize market potential.

Demographic/socio-economic characteristics and land use characteristics of an area can be used to compute transit trip-related productions (number of boardings) or attractions (number of alightings). The type of transit activity (boardings or alightings) at a transit stop varies by the time of the day. As an example, a transit stop in a residential area may generate boardings during the morning peak hour but may attract alightings during the evening peak hour. Likewise, a transit stop in downtown/uptown or an office area may attract alightings during the morning peak hour but may generate boardings during the evening peak hour. On the other hand, there may be a few transit stops with similar ridership patterns (alightings and boardings) during regular travel hours on a day (example, near shopping malls). Not many authors in the past considered factors related to productions and attractions while defining a transit accessibility index.

This manuscript illustrates the working of a GIS-based methodology to compute transit accessibility index based on demographic/socio-economic characteristics and land use characteristics for all transit stops and routes in the study area. It also discusses an accessibility index as an area-wide measure to indicate a transit system's performance at a network level. The computed transit accessibility indices help not only to identify new transit stops, new routes, or the need for extension of an existing route but also increases market potential by minimizing spatial gaps and inaccessible areas. The subject research effort is an extension to transit stop accessibility based on demographic data discussed in Pulugurtha et al. (2011).

Methodology

The proposed GIS-based methodology to compute a transit accessibility index comprises the following steps:

1. Select variables.
2. Conduct spatial analysis.
3. Process data.

4. Compute accessibility index for each transit stop.
5. Compute accessibility index for each transit route
6. Compute accessibility index for entire study area.

Each of the above steps is discussed next in detail.

Selection of Variables

The focus of this step is to select variables to compute the transit accessibility index based on demographic/socio-economic characteristics and land use characteristics that typically are used to estimate trip productions and attractions in a traditional four-step planning process. The variables to compute the transit accessibility index may vary from one area to another area. The thresholds or criterion (such as age group and income level) may also vary from one to another area.

As an example, the demographic/socio-economic characteristics to compute bus transit accessibility for a city of size and characteristics similar to city of Charlotte may include the unemployed, the population that belongs to households with 0 or 1 automobiles, the population by age group (15 – 64), and low income population (< \$25,000).

The land use characteristics to compute the transit accessibility index for a city of size and characteristics similar to Charlotte may include residential, heavy/light commercial, heavy/light industrial, and institutional (comprising major educational, medical, government, cultural and religious, and other institutions) areas within the accessible area.

Transit riders can be categorized into captive riders and preferred riders. Captive riders are potential riders who do not have a choice other than to use transit system for travel to their destination. Preferred riders, on the other hand, are transit riders by choice, irrespective of their socio-economic status (such as household income). Variables pertaining to demographic/socio-economic characteristics and land use characteristics that are selected to compute the transit accessibility index should, therefore, account for both the categories of riders.

Spatial Analysis

Spatial analysis is carried out to compute the transit accessibility index based on demographic/socio-economic characteristics and land use characteristics. In this research, transit accessibility is defined in terms of walking distance or time for a rider to/from a transit stop from/to an origin/destination. Buffers representing this pre-defined walking distance (0.25 miles) or walking time (5 minutes) are generated

around each transit stop/route in the transit system. A 0.25 mile buffer was considered as anecdotal evidence indicates that this is an acceptable walking distance to access bus-stops considered in this research. A larger (or different) buffer width needs to be considered if acceptable walking distance is longer/shorter or when analyzing other forms of transit systems such as commuter rail.

Figure 1 shows an example 0.25 mile buffer around a bus-stop. The data layers with demographic/socio-economic characteristics and land use characteristics are then overlaid on the generated buffers to extract/capture data pertaining to variables that help compute the transit accessibility index.

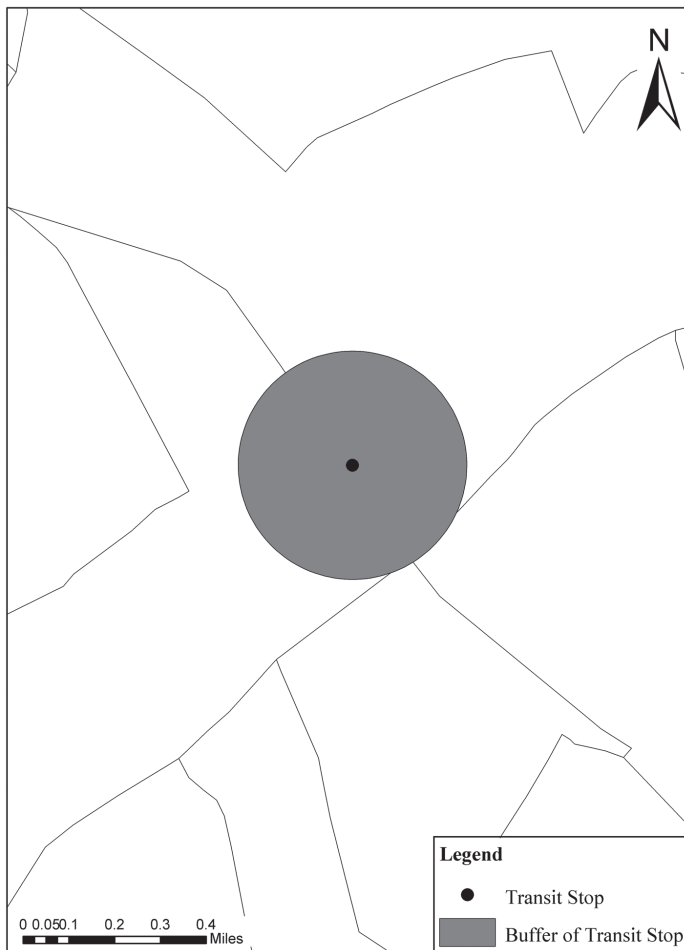


Figure 1. Buffer around a transit stop.

Data Processing

The spatial overlay of data on generated buffers does not automatically adjust/re-calculate the data attributes based on the area that falls within a buffer around a transit stop or a route. Data are therefore processed to compute values pertaining to each selected variable. As an example, the demographic/socio-economic data layer is overlaid on the generated buffers to compute the total number of unemployed in each buffer around each transit stop. The total number of unemployed in a buffer around a transit stop is then computed using the following equation.

$$U_i = \sum_j \frac{A_{j,i}}{A_j} * U_j \quad (1)$$

where,

U_i = total number of unemployed in the buffer “i” around transit stop “s”

U_j = total number of unemployed in census block “j”

$A_{j,i}$ = area of census block “j” in buffer “i” around transit stop “s”

A_j = area of census block “j”

Similarly, equations are developed to extract the population that belongs to households with 0 or 1 automobile, population by age group, and low income population in each generated buffer.

To extract office and commercial type land use characteristics, the land use data layer is overlaid on the generated buffers to compute the area of each land use characteristic within each buffer.

Compute Accessibility Index for Each Transit Stop

The extracted demographic/socio-economic characteristics and land use characteristics around each transit stop are normalized with respect to the value of the same characteristic to compute the transit accessibility index for a transit stop. As an example, the normalized score for the number of unemployed in the buffer “i” around transit stop “s” is computed as shown in the Equation (2).

$$U_s = \frac{U_i}{\text{Maximum}(U_i)} \quad (2)$$

where,

U_s = normalized score for the total unemployed in the buffer around transit stop “s”,

U_i = total number of unemployed in the buffer “i” around transit stop “s”, and,

Maximum (U_i) = maximum number of unemployed considering all the buffers around transit stops.

The accessibility index for each transit stop “s” based on demographic/socio-economic data are computed using the following equation.

$$A_{d,s} = U_s + AO_s + AG_s + I_s \quad (3)$$

where,

$A_{d,s}$ = transit accessibility index based on demographic/socio-economic characteristics for transit stop “s”

U_s = normalized score for the total number of unemployed in the buffer for transit stop “s”

AO_s = normalized score for population with auto-ownership 0 or 1 in the buffer for transit stop “s”

AG_s = normalized score for population with age group between 15 to 64 in the buffer for transit stop “s”

I_s = normalized score for low income population in the buffer for transit stop “s”

Similarly, the accessibility index based on land use characteristics for transit stop “s” is computed using following equation.

$$A_{l,s} = HC_s + LC_s + HI_s + LI_s + I_s \quad (4)$$

where,

$A_{l,s}$ = transit accessibility index based on land use characteristics for transit stop “s”

HC_s = normalized score for total heavy commercial land use area in the buffer for transit stop “s”

LC_s = normalized score for total light commercial land use area in the buffer for transit stop “s”

HI_s = normalized score for total heavy industrial land use area in the buffer for transit stop “s”

LI_s = normalized score for total light industrial land use area in the buffer for transit stop “s”

I_s = normalized score for total institutional land use area in the buffer for transit stop “s”

The computed transit accessibility indices in this step can be used to eliminate any transit stops with very low values for improving transit operations. This will help lower travel or run time, making the system more attractive. Eliminating stops with very few users also improves transit operational performance.

Compute Accessibility Index for Each Route

Buffers generated for all transit stops along a transit route are dissolved to compute transit accessibility index indicators for route “r.” Demographic/socio-economic and land use data layers are then overlaid to extract data pertaining to various characteristics for measuring transit accessibility index indicators at the route level.

To assess route level accessibility, the total accessibility index based on dissolved buffers around transit stops is compared to the total transit accessibility index based on demographic/socio-economic data for the same route “r” extracted by generating a buffer around the route.

The transit accessibility index based on demographic/socio-economic data for route “r” is computed using the following equation.

$$A_{d,r,t} = U_{r,t} + AO_{r,t} + AG_{r,t} + I_{r,t} \tag{5}$$

where,

$A_{d,r,t}$ = transit accessibility index based on demographic/socio-economic data for transit route “r”

t = type (based on dissolved buffers around transit stops or a generated buffer along transit route “r”)

$U_{r,t}$ = total number of unemployed in buffer type “t” along transit route “r”

$AO_{r,t}$ = population with auto-ownership 0 or 1 in buffer type “t” along transit route “r”

$AG_{r,t}$ = population with age group between 15 to 64 in buffer type “t” along transit route “r”

$I_{r,t}$ = low income population in buffer type “t” along transit route “r”

Apart from indicating the level of accessibility to a transit system along a route, spatial overlay of accessibility indicators based on demographic/socio-economic characteristics for route “r” helps to identify spatial gaps or inaccessible areas along the route. The information can be used to add, remove or relocate existing transit stops so as to maximize ridership (market potential) along the route.

Similarly, the transit accessibility index based on land use characteristics for transit route “r” using dissolved buffers around transit stops and buffer around the transit route are computed using Equation (6) and compared to identify spatial gaps or inaccessible areas along the route.

$$A_{l,r,t} = HC_{r,t} + LC_{r,t} + HI_{r,t} + LI_{r,t} + I_{r,t} \quad (6)$$

where,

$A_{l,r,t}$ = transit accessibility index based on land use characteristics for transit route “r”

t = type (based on dissolved buffers around transit stops or a generated buffer along transit route “r”)

$HC_{r,t}$ = total heavy commercial land use area in buffer type “t” for transit route “r”

$LC_{r,t}$ = total light commercial land use area in buffer type “t” along transit route “r”

$HI_{r,t}$ = total heavy industrial land use area in buffer type “t” along transit route “r”

$LI_{r,t}$ = total light industrial land use area in buffer type “t” along transit route “r”

$I_{r,t}$ = total institutional land use area in buffer type “t” along transit route “r”

Compute Accessibility Index for Entire Study Area

Buffers generated around each transit stop in the study area are dissolved to compute transit accessibility indicators for the entire study area (transit network level performance). Demographic/socio-economic and land use data layers are then overlaid to extract data pertaining to various characteristics for measuring transit accessibility index indicators at the network level.

To assess network level accessibility, the total accessibility index based on demographic/socio-economic data for the entire study area using dissolved buffers around transit stops is compared to the total accessibility index based on demographic/socio-economic data for the entire study area using census block level data.

The accessibility index based on demographic/socio-economic data for the entire study area using dissolved buffers or census block level data is computed using the following equation.

$$A_{d,e,o} = U_{e,o} + AO_{e,o} + AG_{e,o} + I_{e,o} \quad (7)$$

where,

$A_{d,e,o}$ = transit accessibility index based on demographic/socio-economic data using option “o” for the entire study area “e”

o = type (first one is based on dissolved buffers around transit stops while second one is based on census block level data)

$U_{e,o}$ = total number of unemployed using option “o” for the entire study area “e”

$AO_{e,o}$ = population with auto-ownership 0 or 1 using option “o” for the entire study area “e”

$AG_{e,o}$ = population with age group between 15 to 64 using option “o” for the entire study area “e”

$I_{e,o}$ = low income population using option “o” for the entire study area “e”

The spatial overlay of transit accessibility indicators based on demographic/socio-economic data by transit stop on the map based on census block level data and street network helps identify possible new transit routes or possible extensions of existing routes for improved coverage.

Similarly, the transit accessibility index based on land use characteristics for the entire study area based on dissolved buffers around transit stops are computed using Equation (8) and compared to identify spatial gaps or inaccessible areas along the route.

$$A_{l,e,o} = HC_{e,o} + LC_{e,o} + HI_{e,o} + LI_{e,o} + I_{e,o} \quad (8)$$

where,

$A_{l,e,o}$ = transit accessibility index based on land use characteristics using option “o” for the entire study area “e”

o = option (based on dissolved buffers around transit stops or study area level land use data)

$HC_{e,o}$ = total heavy commercial land use area using option “o” for the entire study area “e”

$LC_{e,o}$ = total light commercial land use area using option “o” for the entire study area “e”

$HI_{e,o}$ = total heavy industrial land use area using option “o” for the entire study area “e”

$LI_{e,o}$ = total light industrial land use area using option “o” for the study area “e”

$I_{e,o}$ = total institutional land use area using option “o” for the entire study area “e”

Analysis and Results

Bus transit network data for the city of Charlotte are used to illustrate the working of the methodology. The data obtained and used in the analysis includes 2008 bus transit network and ridership data from Charlotte Area Transit System (CATS), 2008 land use data from the Charlotte Department of Transportation, and the census block level data (2008).

The bus transit system in the city of Charlotte is operated by CATS. There are 80 transit routes and 3,645 bus stops in the study area. As stated previously, the existing light rail corridor (referred to as the Lynx Blue Line) was not considered, as the emphasis of this research is more on a bus-operated transit system.

Demographic/socio-economic and land use characteristics were extracted for all the 3,645 bus-stops in the study area. Data extracted include the unemployed, the population that belongs to households with 0 or 1 automobiles, the population by age group (15 – 64), low income population (< \$25,000), heavy/light commercial area, heavy/light industrial area, and institutional area.

Findings from a report published by Acs and Loprest (2005) based on National Survey of American Families was used to establish the criterion for low income population. Residential land use characteristics were not considered as they were found to have a strong correlation with demographic/socio-economic characteristics. Anecdotal evidence as well as discussions with staff of local agencies indicates that these are reasonable assumptions for the study area considered for illustration of the GIS-based methodology discussed in this manuscript.

Transit accessibility indices were then computed for each transit stop and route and the entire study area.

Transit Accessibility Index for Transit Stops

Figure 2 depicts the transit accessibility index based on demographic/socio-economic data by transit stop in the study area. The size of the point representing each transit stop is defined as a function of its transit accessibility index – the higher the value of the transit accessibility index, the larger the size of the point. The average transit accessibility index value based on demographic/socio-economic data is 0.72, whereas the maximum value is 3.28. Similarly, the average and maximum transit accessibility index based on land use characteristics are 0.30 and 1.10, respectively.

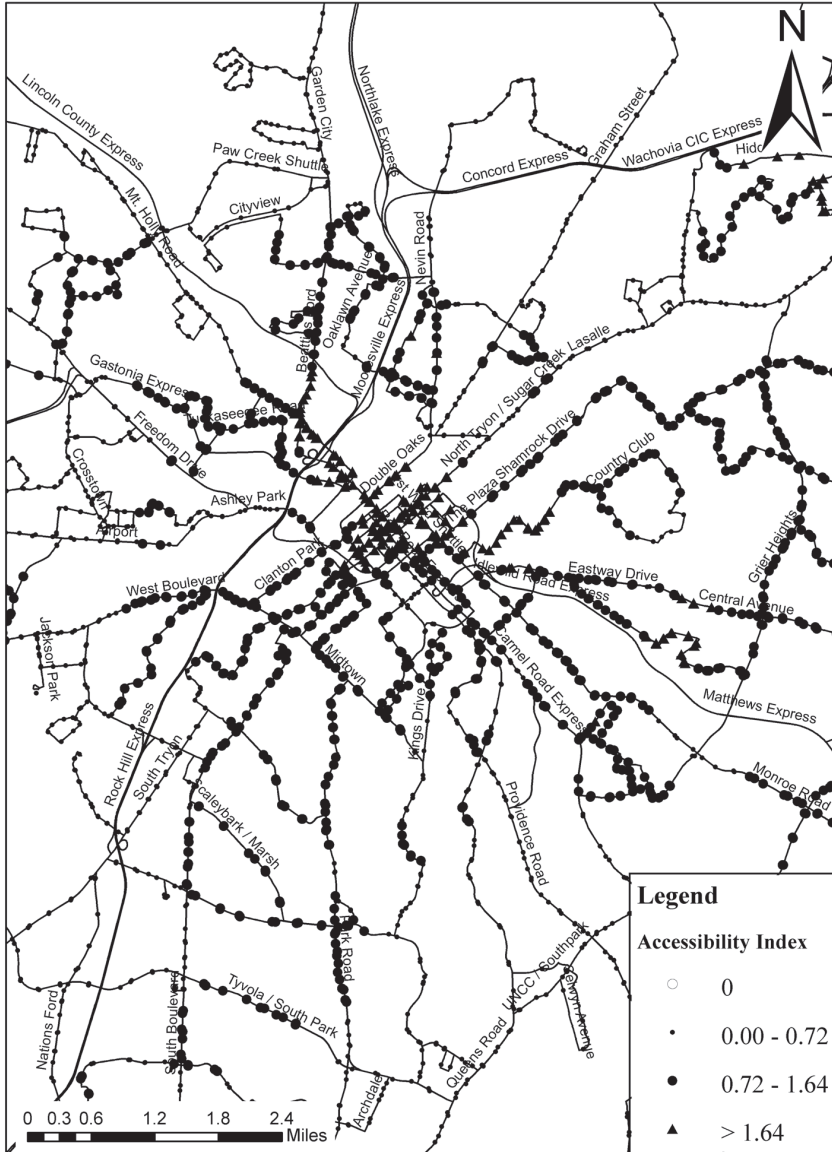


Figure 2. Spatial distribution of accessibility index based on demographic/socio-economic data for transit stops.

Table 1 summarizes both the computed transit accessibility indices by range for all the transit stops. The transit accessibility ranges in the table are divided based on average and standard deviation values. Results shown in Table 1 indicate that 57.07 percent and 58.65 percent of transit stops have transit accessibility index values less than the average value of the transit accessibility index based on demographic/socio-economic data and land use characteristics, respectively. On the other hand, 6.06 percent and 5.02 percent of transit stops have transit accessibility index values greater than the average plus two standard deviations based on demographic/socio-economic and land use characteristics, respectively.

Table 1. Summary of Accessibility Index by Transit Stops

Transit Accessibility Index Range	# Transit Stops	% Transit Stops
<i>Demographic/Socio-economic</i>		
0	0	0.00
0.01 to 0.72	2,090	57.07
0.72 to 1.64	1,333	36.40
> 1.64	222	6.06
<i>Land Use</i>		
0	470	12.83
0.01 to 0.30	1,678	45.82
0.30 to 0.86	1,313	35.85
> 0.86	184	5.02

The spatial overlay of transit accessibility indices and information from Table 1 (with more breakdown in range) assists in the decision making process. As an example, one can remove transit stops with 0 transit accessibility index based on land use characteristics and very low transit accessibility index based on demographic/socio-economic characteristics to improve transit operation or service along a transit route (say, reduce travel or run time).

Transit Accessibility Index by Route

Transit accessibility indices are computed for each route in the study area using the proposed methodology. As an example, Table 2 summarizes the computed accessibility indicators based on demographic/socio-economic characteristics and land use characteristics along Route 2 in the study area.

Table 2. Route Level Analysis Summary - Example Route 2

(a) Demographic/Socio-economic

Category	$U_{r,t}$	$AO_{r,t}$	$AG_{r,t}$	$I_{r,t}$	$A_{d,r,t}$
Based on dissolved buffers along transit stops of Route 2	487	1,959	4,103	968	7,517
Based on buffer generated along Route 2	558	2,349	5,119	1,168	9,194
% Not Served	12.64	16.61	19.85	17.14	18.24

(b) Land Use

Category	$HC_{r,t}$	$LC_{r,t}$	$HI_{r,t}$	$LI_{r,t}$	$I_{r,t}$	$AI_{r,t}$
Based on dissolved buffers along transit stops of Route 2	0.56	0.14	0.15	0.26	0.09	1.21
Based on buffer generated along Route 2	0.69	0.33	0.40	0.43	0.10	1.95
% not served	18.69	56.64	62.57	38.85	4.37	37.93

Along Route 2, 12.64 percent of unemployed, 16.61 percent of population with auto-ownership 0 or 1, 19.85 percent of population between 15 to 64 years of age, and 17.14 percent of population with income less than \$25,000 are not being served along this route. The overall transit accessibility index based on existing transit stops along Route 2 (7,517) is 81.76 percent of the maximum potential transit accessibility index based on criteria used in this manuscript (9,194).

The results obtained indicate that 18.69 percent, 56.64 percent, 62.57 percent, 38.85 percent, and 4.37 percent of heavy commercial, light commercial, heavy industrial, light industrial, and institutional land use areas, respectively, are not being served currently along Route 2. Overall, 37.93 percent of these land use types are not being served by transit stops along the route.

Figure 3 shows the dissolved buffer along transit stops and the buffer generated along Route 2. The figure can be used to identify spatial gaps (inaccessible areas) based on demographic/socio-economic and land use characteristics along the route. Possible addition of new transit stops (based on optimal stop-spacing) in these gaps along the transit route could potentially increase transit market potential.

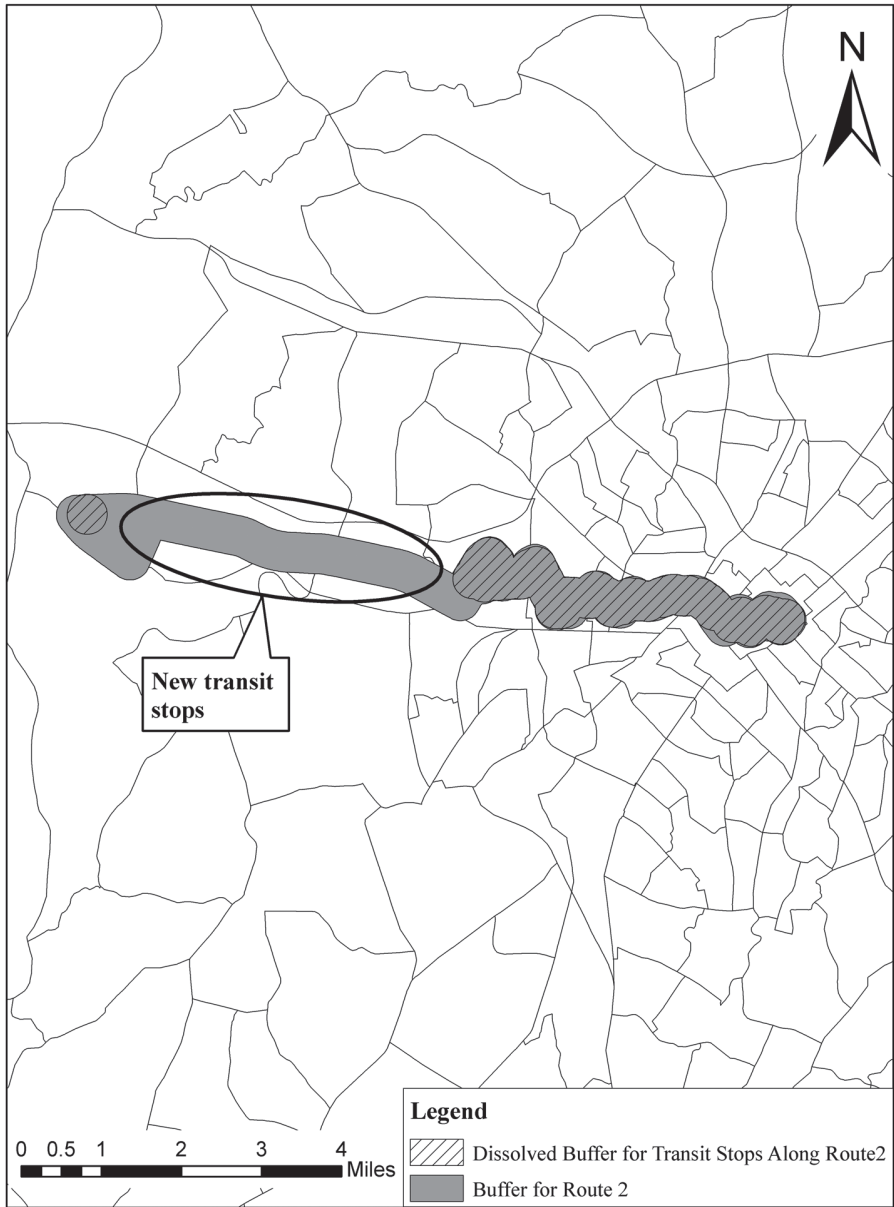


Figure 3. Identifying spatial gaps along Route 2.

Area-wide Accessibility Index

Table 3 summarizes the computed transit accessibility indicators based on demographic/socio-economic characteristics and land use characteristics for the entire study area.

Table 3. Network Level Analysis Summary

(a) Demographic/Socio-economic

Category	U _{e,o}	AO _{e,o}	AG _{e,o}	I _{e,o}	Ad _{e,o}
Based on dissolved buffers along transit stops in the study area	18,686	79,442	248,053	30,369	376,550
Based on study area census block level data	36,197	150,979	604,556	50,888	842,620
% Not Served	48.38	47.38	58.97	40.32	55.31

(b) Land Use

Category	HC _{e,o}	LC _{e,o}	HI _{e,o}	LI _{e,o}	I _{e,o}	AI _{e,o}
Based on dissolved buffers along transit stops in the study area	5.77	11.09	5.85	6.43	3.04	32.18
Based on study area land use data	7.29	14.84	11.40	10.14	5.33	48.99
% not served	20.75	25.24	48.68	36.65	43.00	34.32

Analysis indicates that 48.38 percent of unemployed, 47.38 percent of population with auto-ownership 0 or 1, 58.97 percent of population between 15 to 64 years of age, and 40.32 percent of population with income less than \$25,000 in the entire study area are not being served by the transit system. The transit accessibility index based on demographic/socio-economic data for the entire study area by dissolving barriers for all transit stops (376,550) is 55.31 percent of the of the maximum transit accessibility index based on demographic/socio-economic data at census block level (842,620).

The results obtained also indicate that 20.75 percent, 25.24 percent, 48.68 percent, 36.65 percent and 43.00 percent of heavy commercial, light commercial, heavy industrial, light industrial, and institutional land use areas, respectively, are not being served currently in the study area. Overall, the transit accessibility index based on land use characteristics at the study area level is computed equal to 48.99. The same index for the entire study area based on dissolved barriers around transit stops is computed equal to 32.18. This indicates that 34.32 percent of the considered land use categories are not being served by the existing transit system in the study area.

Figure 4 depicts transit accessibility indicators based on census block level data. Dark shaded census blocks are the ones with a high number of potential captive riders based on demographic/socio-economic data. Overlaying the existing transit route network clearly shows areas with greater number of potential captive riders that are not being served by the existing transit system. The figure provides valuable insights into extending existing routes or adding new routes to capture additional riders and increase transit market potential. Some examples for extension of an existing route and addition of a new route in Charlotte region are shown in Figure 4.

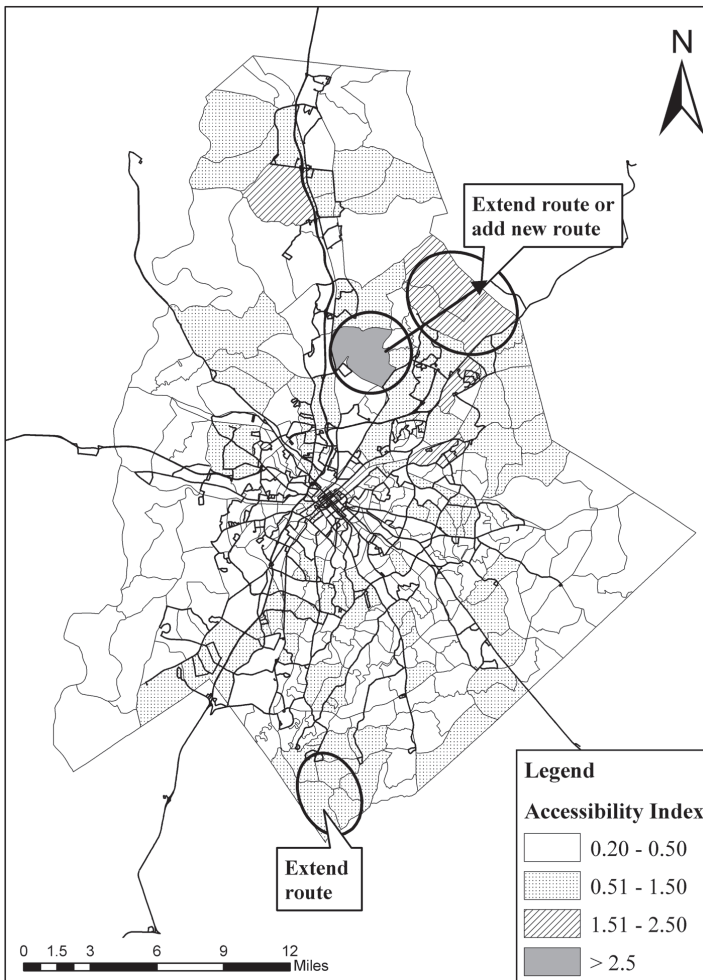


Figure 4. Map depicting accessibility index based on demographic/ socio-economic data and suggested extensions/new routes.

Statistical Analysis

Statistical analysis (simple linear regression) was conducted to examine the relationship between 1) average daily boardings and the computed transit accessibility index based on demographic/socio-economic characteristics and land use characteristics for transit stops, and 2) average daily alightings and the computed transit accessibility index based on demographic/socio-economic characteristics and land use characteristics for transit stops.

Ridership data (boardings and alightings surveyed at transit stops) obtained from CATS were processed to estimate average daily boardings and lightings for each transit stop in the study area. The average daily boardings or alightings at a transit stop was considered as the dependent variable while the transit accessibility index based on demographic/socio-economic or land use characteristics was considered as the independent variable.

If a statistically significant relationship exists between the dependent and independent variables at a 95 percent confidence level (or level of significance lower than 0.05), then one can be fairly confident that the methodology developed can be used to compute the transit accessibility index and in the decision making process.

Statistical parameters (Table 4) obtained from linear regression analysis indicate that there is a statistically significant relationship between boarding or alightings and computed transit accessibility indices based on demographic/socio-economic and land use characteristics for transit stops. The T-Statistic is greater than 2, the P-value is less than 0.01 (99 percent confidence level), and the F-Statistic is greater than 4 (high) for all the tested scenarios shown in Table 4. Overall, results obtained show that there exists a statistically significant relationship between boardings or alightings and the transit accessibility index developed and used for analysis in this research.

The coefficient is positive, indicating that boardings or alightings increase as the transit accessibility index increases. In other words, one can say that having transit stops in locations with a high transit accessibility index based on criteria defined in this manuscript for a city similar in size and characteristics of Charlotte possibly increases market potential and ridership. Likewise, selecting routes with high transit accessibility indices based on criteria defined in this manuscript for a city similar in size and characteristics of Charlotte possibly increases market potential and ridership.

Table 4. Statistical Analysis—Boardings or Alightings vs. Accessibility Index

Category	Constant	Coefficient	T- Stat	P - Value	F - Stat
<i>Boardings vs. Transit Accessibility based on Demographic/Socio-economic</i>					
Transit stops	-10.70	39.37	14.16	< 0.01	200.56
<i>Boardings vs. Transit Accessibility based on Land Use</i>					
Transit stops	-3.68	70.57	15.52	< 0.01	241.04
<i>Alightings vs. Transit Accessibility based on Demographic/Socio-economic</i>					
Transit stops	-9.99	38.54	6.65	< 0.01	44.34
<i>Alightings vs. Transit Accessibility based on Land Use</i>					
Transit stops	-3.71	70.99	7.47	< 0.01	55.88

Conclusions

This manuscript presents a GIS-based methodology to compute an accessibility index for a transit stop and route and an entire study area. The methodology is illustrated using the city of Charlotte transit network that comprises 80 routes and 3,645 transit stops. The average transit accessibility index based on demographic/socio-economic data for the transit stops in the study area is 0.72, whereas the average transit accessibility index based on land use characteristics for the transit stops in the study area is 0.30.

Analysis and assessment indicates that the transit accessibility index based on demographic/socio-economic data and land use data in the entire study area are 55.31 percent and 34.32 percent lower than the corresponding maximum potential transit accessibility index values, respectively. The computed transit accessibility indices were used to illustrate the identification of spatial gaps in transit accessibility so as to select new transit stop locations or relocate existing transit stops along a route. Illustrations also include area level analysis to identify new routes or to extend an existing route.

Statistical analysis conducted to assess the strength of the relationship indicates that a statistically significant relationship exists between boardings or alightings and accessibility index computed for analysis in this manuscript. This shows that adopting the proposed methodology to minimize spatial gaps and inaccessible areas increases transit ridership and market potential.

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Selecting Bus Stops for Accessibility Improvements for Riders with Physical Disabilities

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Abstract

Bus stops are key links in the journeys of riders with disabilities. Inaccessible bus stops prevent people with physical disabilities from using fixed-route bus services, thus limiting their mobility. Due to limited budgets, transit agencies must select bus stops for which their improvements, as part of the effort to comply with the Americans with Disabilities Act (ADA), can maximize the overall benefits to riders with physical disabilities. In this paper, an analytic hierarchy process (AHP) was applied to combine the factors affecting the benefits to riders with physical disabilities, and a binary linear programming model was used to identify bus stops for ADA improvements based on budgetary and construction cost constraints. As an application example, the optimization model was applied to the 5,034 bus stops in Broward County, Florida. Compared to the usual approaches, the optimization model provides a more objective platform on which to identify bus stops for ADA improvements.

Introduction

Bus stops are key links in the journeys of bus riders and are, therefore, a critical factor in evaluating the efficiency of a bus transit system. Because of physical, sensory, or mental difficulties, people with disabilities often rely on public transit as their primary source of transportation. However, inaccessible bus stops, as a result

of poor design, physical barriers, topographical conditions, or lack of a sidewalk infrastructure, prevent riders with physical disabilities from using fixed-route bus services. Inaccessible bus stops can limit the mobility of people with physical disabilities, lower the efficiency of public transit, and encourage riders to use other transit services such as paratransit, which are more expensive to operate.

Accessible design generally focuses on compliance with laws and regulations as well as state or local building codes. The laws and regulations are intended to eliminate certain physical barriers that limit the usability of the built environment for people with disabilities. The Americans with Disabilities Act (ADA) of 1990 prescribes the minimum requirements for bus stop accessibility by riders with disabilities. Although the accessibility improvements mandated under the ADA have enforceable regulations and standards, many bus stops still have not met the minimum ADA standards (National Council on Disability 2004). For example, the results from the bus stop maintenance database in Broward County, Florida, show that, by 2006, only 51 percent of its bus stops met the minimum ADA standards.

Obviously, one way for transit agencies to meet the ADA requirements is to add to every bus stop ADA-compliant features such as curb cuts, sidewalks, loading pads, etc. However, due to limited budgets, transit agencies can select only a limited number of bus stops for ADA improvements each year. How best to select bus stops for ADA improvements is the focus of this paper.

In practice, many factors can affect the decision. They may include the spatial distribution of riders with physical disabilities, transit ridership, wheelchair ridership, customer complaints, facility deployment costs, service area demographic information, etc. Most of these factors are related to geography, and each factor has its own evaluation standards. An optimization process can help take into account these factors objectively and determine the best locations for ADA accessibility improvements.

This paper introduces an optimization model developed to help transit agencies to identify a priority list of bus stops for annual ADA accessibility improvements. The model aims to maximize the overall benefits to riders with physical disabilities within the constraint of an annual available budget. The next section introduces the bus stop accessibility standards. The overall methodology for the model development is then described. This is followed by the acquisition and integration of data for the factors considered, and, subsequently, the formulation and evaluation of the optimization model.

Bus Stop Accessibility Standards

The ADA is the most important design reference for transit stop inventories, as it outlines the minimum requirements for bus stop accessibility by people with disabilities. Title II of the ADA covers sidewalk and street construction and transit accessibility, referencing the ADA Accessibility Guidelines (ADAAG) or the Uniform Federal Accessibility Standards (UFAS) for new construction and alterations undertaken by or on behalf of a state or local government (Federal Transit Administration 1992). In addition, the Department of Justice (1994) Title II regulation specifically requires that curb ramps are provided when sidewalks or streets are newly constructed or altered.

Figure 1 illustrates the ADA minimum requirements for bus stop accessibility. Based on practical experience of transit agencies (Transit Cooperative Research Program 1996), 5 ft is the preferred width for sidewalks for accommodating patrons with physical disabilities as opposed to the typically-used 3-ft clear passage width. This is because 5 ft of sidewalk is the actual construction width, and some acceptable roadway facilities such as utility poles often occupy the clear width within the sidewalk's area. According to the minimum ADA requirements and the *Design Handbook for Florida Bus Passenger Facilities* (Florida Planning and Development Lab 2004), 5-ft sidewalks (with a 3-ft clear accessible route), with existing curb cuts and a 5×8 sq ft loading pad are the standards for all bus stops.

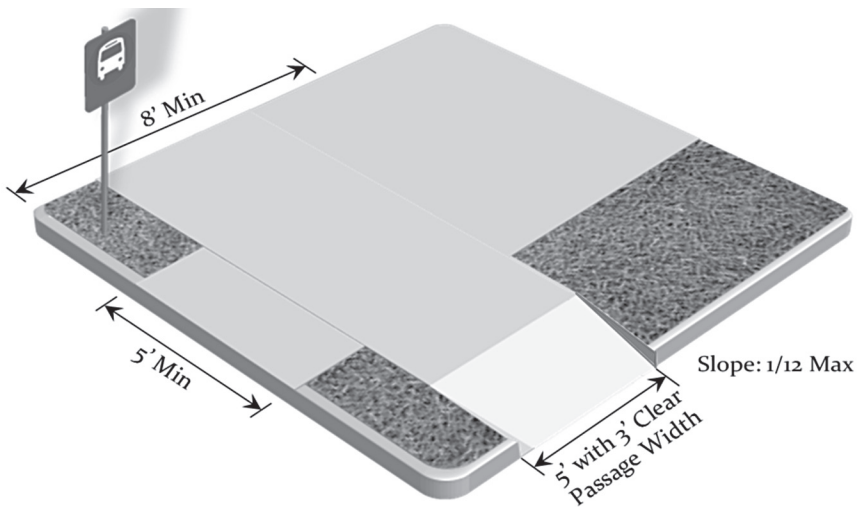


Figure 1. Bus stop design to meet minimum ADA requirements.

Methodology Overview

In this paper, the optimization model for determining locations for bus stop accessibility improvements is developed under the framework of spatial multicriteria decision making (MCDM)—an application of multicriteria analysis in a spatial context. MCDM (Thill 1999) has been applied since the development of GIS in the late 1980s and early 1990s. Banai (2000), for example, developed a prototype that integrated GIS with an expert system to assess light rail transit stops with multiple criteria. Additionally, Zhu et al. (2005) developed a GIS-integrated multicriteria analysis model to evaluate accessibility for a housing development in Singapore. The analysis involved a number of criteria related to the convenient access of public transport facilities and amenities, with local residents polled to determine which criteria should be given priority. Eldrandaly et al. (2005) developed a strategy to integrate GIS and analytical hierarchy process analysis (AHP) by using Component Object Model (COM), two major tools commonly used in solving spatial decision-making problems. As mentioned, many factors can affect optimum bus stop investment decisions. The spatial attributes of bus stops and geographic factors make spatial MCDM an ideal means by which to build decision tools for bus stop facilities allocation.

As the first step in the optimization model development, a bus stop accessibility checklist based on ADA minimum requirements is created. After the checklist specifying each minimum ADA requirement is established, a bus stop inventory with detailed bus stop features for each bus stop is then used to compare against the checklist to determine if a bus stop meets the minimum ADA requirements and what additional features must be installed to make the stop ADA-compliant.

The next step is to select the factors that will serve as the surrogate measures of benefits to riders with physical disabilities. The benefits to riders with physical disabilities reflect the level of potential for a bus stop selected for ADA improvements to meet the greatest need of those riders with additional accessibility requirements. Bus stop, transit ridership, and socioeconomic data from three main sources then are collected. As an application example, data from Broward County Transit (BCT) are used. BCT possesses a comprehensive bus stop inventory, a detailed ridership at the bus stop level, various GIS maps that include bus routes and bus stops improvements, and budgetary information. In addition, the 2000 Census offers information on the spatial distribution and types of populations with disabilities. These will be described in more detail in the next section.

AHP, which is an MCDM technique, then is used to (1) combine different factors for prioritizing, ranking, and evaluating alternatives; (2) compare and evaluate different criteria such as the distribution of persons with physical disabilities, ridership, and land use; and (3) assign weights to bus stops.

A binary linear programming model then is formulated. Within the constraint of a given budget for ADA improvements, the model aims to select bus stops for which the improvements will maximize the total benefit to riders with physical disabilities. The benefits are measured based on the scores derived through AHP for the individual candidate bus stops. The model is formulated such that all selected bus stops can be brought into full compliance with minimum ADA accessibility standards. In other words, the process will not output decisions to add features to bus stops that do not result in full ADA compliance.

Data Preparation

Budget and Cost Estimates

Budgetary information was mainly derived from the Broward County Transit Development Plan (Broward County Transit 2005) and the Broward County Metropolitan Planning Organization Transportation Improvement Program. The assigned budget for transit ADA improvements is \$2.0 million per year between the years 2006 and 2010.

Cost calculations for ADA bus stop improvements cannot assure that the projected cost will be exactly the same as that for the actual construction work. Construction costs vary with different contractors, and costs with regard to bus stop improvements likely will change during construction, due to inflation or other unforeseen factors. Accordingly, this study can make only reasonable cost estimates for each bus stop. Design, maintenance of traffic, and construction usually make up the general cost of improvements. Sidewalk length was considered the sidewalk distance from the bus stop to the nearest intersection. Table 1 gives the costs for different facilities with regard to ADA improvements at bus stops. In sum, minimum ADA improvement concentrated on sidewalks, loading pads, and curb cuts. Based on the cost information and the existing stop inventory, the total cost required to meet the minimum ADA standards for each bus stop was calculated and available for use in the optimization model to be described next.

Table 1. Cost Estimates of ADA Bus Stop Improvements

ADA Bus Stop Improvement Type	Unit	Unit Price
Maintenance of Traffic	Each	\$500.00
Concrete material and installation (6") thick, 1-500 SF	Square Foot	\$13.75
Concrete material and installation (6") thick, 501-1000 SF	Square Foot	\$8.25
Concrete material and installation (6") thick, 1001-9000 SF	Square Foot	\$8.00
Subgrade Preparation for Concrete Pour	Square Yards	\$2.00
Curb Cuts, Drawing I	Each	\$800.00
Concrete removal	Square Foot	\$4.50
Curb removal	Foot	\$11.00

Bus Stop Inventory and Ridership

BCT possesses a bus stop inventory that includes data on 5,034 bus stops serving 43 different bus routes. The inventory includes all of the bus stop facilities' information and ADA accessibility status. There were 1,616 bus stops designated as not fully accessible and 849 as inaccessible for people with physical disabilities, for a total of 2,465 bus stops (49%) that do not meet the minimum ADA requirements. "Not fully accessible stops" are stops that do not fully comply with the ADA requirements, yet can be accessed by people with physical disabilities. Figure 2 shows the current bus stop distribution in Broward County, where dark nodes represent ADA-incompliant bus stops and white nodes represent ADA-compliant bus stops.

Because some bus routes cross the county boundary into the neighboring Miami-Dade and Palm Beach counties, a quarter-mile radius buffer along those routes has been developed to maintain the integrity of the entire bus stop system. It is easy to see that ADA-incompliant bus stops pervade the whole bus stop system. Since 1996, BCT has been in the process of improving the accessibility of bus stops, with a target of making 300-500 additional bus stops accessible each year. BCT also provides Automatic Passenger Counter (APC) datasets that could be used to weigh the importance of accessibility for bus stops. The dataset includes the ridership based on bus stop IDs, which were collected from May 2008 through September 2008.

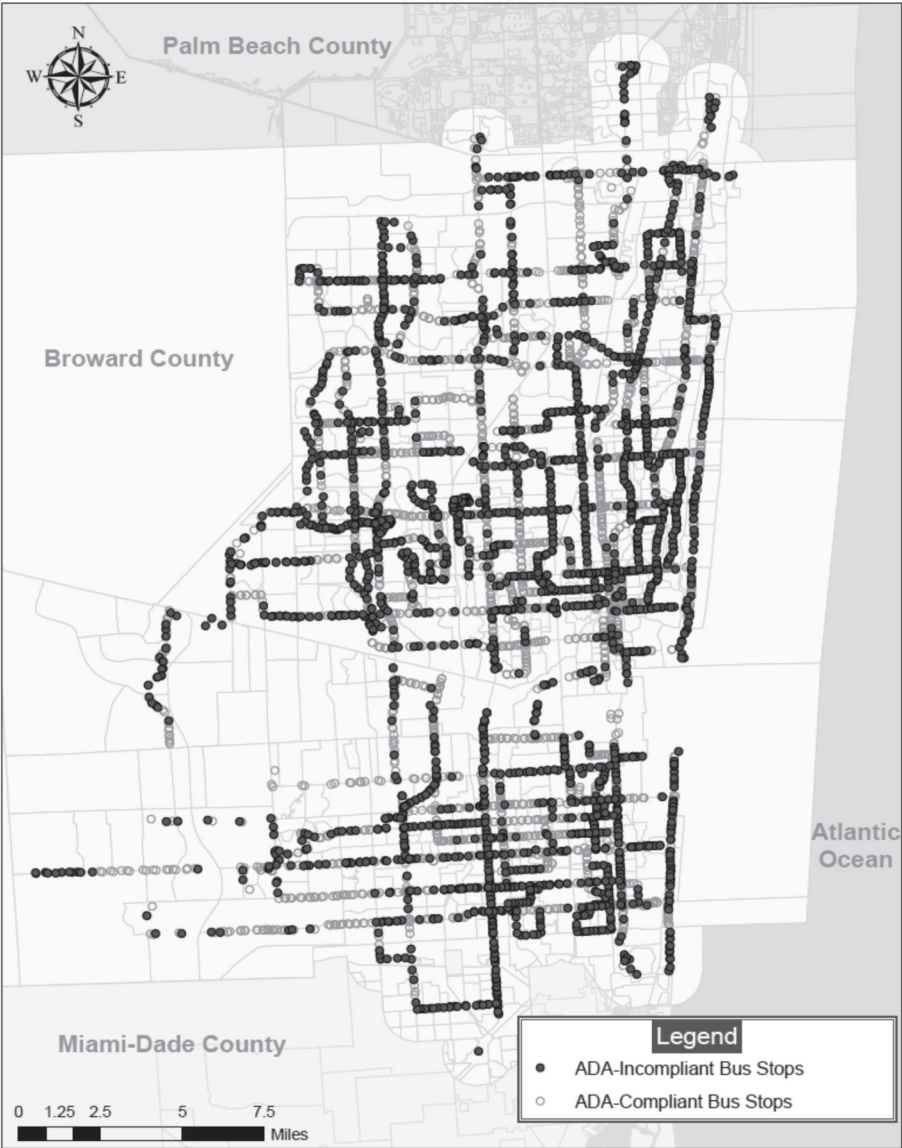


Figure 2. ADA status of bus stops of Broward County Transit.

Data for Demographic and Other Factors

The location(s) of the population with physical disabilities is the most important factor in deciding bus stop ADA improvements. Obviously, those areas that have a greater percentage of persons with physical disabilities deserve to have higher quality transit services. Hence, the population with physical disabilities 5+ years of age was extracted from the 2000 Census Summary Tape File #3. Apart from the original locations of the population with physical disabilities, several surveys and studies (Collia 2003, Scottish Executive Social Research 2006, U.S. Department of Transportation 2003) have been undertaken to examine the travel patterns of people with physical disabilities who use public transit to establish which bus stops are near common destinations. These bus stops should get priority for ADA accessibility improvements. Work-related place, school, health care facilities, and shopping centers (including supermarkets) should be treated as common destinations for people with physical disabilities. Census Transportation Planning Package (CTPP) 2000 provided the data regarding ridership to work by bus for the population with physical disabilities based on Traffic Analysis Zones (TAZ). The Florida Geographic Data Library (FGDL) provides GIS layers of school, health care facilities, and shopping centers for the weighting of bus stops. Table 2 shows a detailed description of the data.

Table 2. GIS Layers and Data Sources

Content Title	Source	Feature Type	Extent	Data Years
Population with Physical Disabilities	US Census Bureau	polygon	Broward County	2000
Ridership per Stop	Broward County Transit	dBASE	Broward County	05/2008-09/2008
Work Trips by People with Physical Disabilities	Census Transportation Planning Package	polygon	Broward County	2000
Schools	UF GeoPlan Center*	point	State	2008
Health Care Facilities	UF GeoPlan Center	point	State	2005
Shopping Centers	UF GeoPlan Center	point	State	2003

*University of Florida GeoPlan Center

Data Extraction and Integration

To study the service scale of bus stops, the service buffer area based on the actual street network is introduced for this analysis. With ArcGIS Network Analyst, the service areas around any location can be built on a region that encompasses all accessible streets (i.e., streets that are within specified impedance), called a network service area. For instance, the five-minute service area for a given point includes all the streets that can be reached within five minutes from that point. Because a standard for the minimum walking distance to transit stops for people with physical disabilities cannot be found in the literature, this paper assumes the standard quarter-mile walking distance that is usually used for the general population.

A VBA script was developed using ESRI's ArcObjects preceding the combination and joining of the data. Buffer zones were created as well. As shown in Figure 3, the process involves the following five steps:

1. Filter the original bus stop database against ADA accessibility standards to determine candidate bus stops that need accessibility improvements.
2. Create a service area based on the quarter-mile walking distance around every candidate bus stop.
3. Combine the ridership and candidate bus stop databases based on bus stop IDs.
4. Calculate the population with physical disabilities, work trips by people with physical disabilities, the number of schools, the number of health care facilities, and the number of shopping centers within each service area.
5. Apply the combined database in an analytical hierarchy process (AHP) analysis.

As mentioned, the AHP is an MCDM technique that can combine different factors for prioritizing, ranking, and evaluating alternatives (Malczewski 1999). In this paper, AHP was used to compare and evaluate the different criteria within every candidate bus stop buffer zone. Six factors considered: 1) distribution of the population with physical disabilities, 2) ridership, 3) work trips by people with physical disabilities, 4) health care facilities, 5) schools, and 6) shopping centers. These criteria were then assigned weights based on their relative importance.

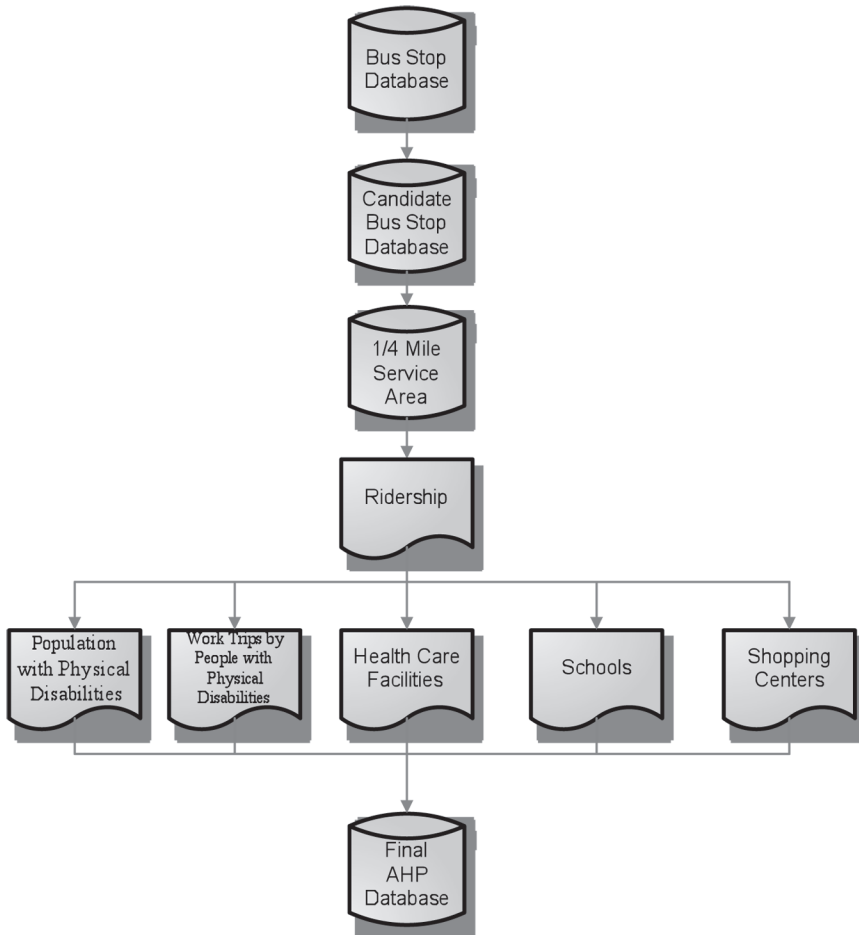


Figure 3. Data integration framework.

The AHP process consists of three steps as described here.

Step 1: Standardizing Factors

The raw score of each factor for each candidate bus stop was first standardized using the equation below:

$$x'_{ij} = \frac{x_{ij}}{x_j^{\max}} \tag{1}$$

where:

x'_{ij} is the standardized score for candidate bus stop i for criterion j ,

x_j^{\max} is the maximum score for criterion j , and

x_{ij} is the raw score for candidate bus stop i for criterion j .

The benchmark score (x_j^{\max}) was used to compare the scores among the candidate bus stops. x_j^{\max} is the maximum score among the bus stops that did not meet the minimum ADA standards based on factor j .

Step 2: Weighting Standardized Factor

The AHP uses composite weights to represent ratings of alternatives with respect to an overall goal. The weights, also referred to as decision alternative scores, are the basis for making decisions. They serve to rate the effectiveness of each alternative in achieving the goal. The overall score for a candidate bus stop is defined as follows:

$$R_i = \sum_j w_j x'_{ij} \quad (2)$$

where:

R_i is the overall score of candidate bus stop i , and

w_j is the vector of priorities associated with factor j , $\sum w_j = 1$.

Note that w_j is an important factor in AHP. It requires assessing the relative importance of different factors, and different assigned w_j will result in different output selections. Hence, w_j is usually assigned by an experienced transit planner. The default weight used for each factor shown in Table 3 is derived from the survey on travel patterns and percentage of riders with physical disabilities (15). Given that bus stop service areas that have higher populations with physical disabilities necessitate meeting ADA accessibility service requirements directly, residential locations in areas that have a high population of people with physical disabilities should receive the highest weight. Ridership represents the number of boardings for each bus stop; hence, this number was considered the second most important factor. Although the locations of schools, health care facilities, shopping centers, and the work trips by people with physical disabilities are not directly related to the boardings at every bus stop, they have the potential to attract riders as common origins and destinations. These four factors were considered in the process, with each given a lower weight than the first two factors.

Table 3. Weights Used for Different Factors

Factors	Weights (w_j) for Minimum ADA Standards
Population with Physical Disabilities Location	0.30
Ridership per Stop	0.20
Work Trips by People with Physical Disabilities	0.16
Schools	0.12
Health Care Facilities	0.11
Shopping Centers	0.11

Step 3: Standardizing Weighted Factor

The overall score R_i from the second step was further standardized for all six factors using the equation below:

$$R'_i = \frac{R_i}{\sum R_i} \tag{3}$$

where:

R'_i is the standardized overall score of candidate bus stop i , and

R_i is the overall score of candidate bus stop i .

A VBA program was developed to perform all of the calculations involved in the above three steps. The program produced a final score for each candidate bus stop. The scores serve as one of the two major inputs to the optimization model to be described below. The other major input involves the project budget and construction cost estimates described in the previous section.

Optimization Model

The main objective for the optimization model is to maximize the overall benefits at the bus stop level (i.e., total R'_i) to the riders with physical disabilities. This is achieved by attempting to meet the minimum ADA improvements under the constraints of the budget available for such improvements annually. The analytical hierarchy process (AHP) pre-processes the different factors and generates a single weight for each candidate bus stop. This weight (R'_i) then becomes the only standard by which to evaluate a given bus stop’s importance, or priority over other stops, regarding accessibility improvements. This method simplifies the final opti-

mization model such that the objective function is the summation of the R_i' values of selected bus stops.

Within the constraints of this model, only complete ADA accessibility improvements were allowed for each bus stop. Single improvements, such as only building a loading pad without making other improvements to fully meet the minimum ADA requirements, were not allowed. In other words, the transit agency could either choose to make a candidate bus stop fully ADA accessible by adding all the required improvements, or do nothing to the candidate bus stop. Another constraint stems from the limits of the budget available for ADA improvements. Accordingly, the optimization model is formulated as a binary linear programming model, shown below:

$$\max \sum_{i=1}^n R_i' y_i \quad (4)$$

Subject to:

$$y_i \in \{0,1\}$$

$$\sum_{i=1}^n c_i y_i < B$$

where:

- R_i' is the standardized overall score of candidate bus stop i ,
- y_i is 1 if candidate bus stop i is selected for improvements and 0 otherwise,
- n is the total number of candidate bus stops,
- c_i is the required ADA improvement cost based on minimum ADA standards for candidate bus stop i , and
- B is the total available budget for ADA improvements.

Model Application and Assessment

The model was implemented in General Algebraic Modeling System (GAMS), version 2.50 (GAMS Development Corporation 2007). GAMS is specifically designed for modeling linear, nonlinear, and mixed integer optimization problems. Given BCT's total available budget of \$2.0 million for the next budget year and the associated construction costs, the output from the model shows that a total of 519 bus

stops will get priority for ADA improvements for the next budget year. The maximum total R_i for each stop is 3,521.13, and the total cost is \$1,999,578.

Figure 4 shows the bus stops selected for ADA improvements as dark nodes. The figure was compared to the distribution of the population with physical disabilities.

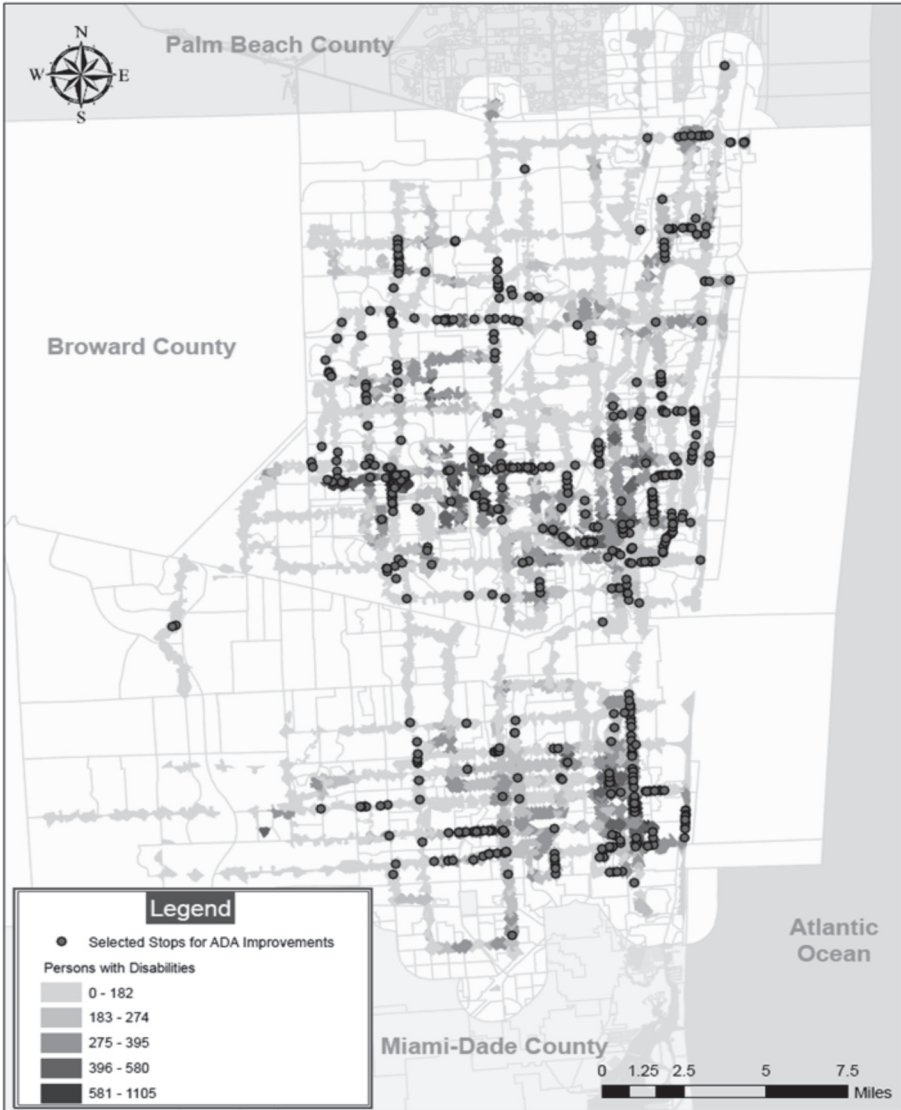


Figure 4. Selected bus stops for ADA improvements.

The results indicate that the selected bus stops are generally located in those areas with a higher population of physical disabilities density—a factor given the highest weight ($w_j = 0.3$) within the AHP process. The population with physical disabilities averages about 272 people living near the selected bus stops, as compared to an average population with physical disabilities of about 143 for the remaining bus stops. The significance of bus ridership ($w_j = 0.2$) was also reflected in the final map when compared to the ridership database. The average ridership is 951.64 for all the selected bus stops vs. 639.75 for the rest. The selected bus stop locations also were found to match the distribution of health care facilities, schools, and shopping centers.

The model outputs also show that many selected bus stops need only minor investments to provide significant benefits to riders with physical disabilities. The model tends to select bus stops with higher benefit-cost ratios for the current budget year and leaves the bus stops with lower benefit-cost ratios for the next year, so that the maximum total R_i' and the number of selected bus stops are not the same for each budget year. Note that for practical purposes, it is convenient to organize the work for ADA improvements by grouping bus stops that are close together.

Summary and Conclusions

In this paper, a binary linear programming optimization model was developed to select bus stops for ADA improvements. In making the selection, the model aims to optimize the benefits to the riders with physical disabilities, given an available annual budget for such improvements. Bus stops from Broward County Transit in Florida were used as an example to describe the model development procedure and its application.

Based on an analysis of the ADA minimum requirements and current bus stop inventory of BCT, the construction cost was estimated for every candidate bus stop. The AHP was then used to combine and generate the overall weights for every bus stop, given the different factors. In deriving the data for the factors considered, a quarter-mile walking distance typically used for the general population was used in this research. Future research should attempt to identify other distances that could better reflect conditions for riders with different types of disabilities. A sensitivity analysis should also be performed on these walking distances to assess how the optimization output is impacted.

The final optimization model showed that approximately 500 bus stops would receive priority ADA improvements and that the selected bus stop locations were consistent with the factors considered. Compared to the usual basis for bus stop improvement selection, such as staff experience or requests from elected officials, this optimization model prioritizes bus stops that are more beneficial to the majority of people with physical disabilities and provides transit agencies with a more objective platform on which to make bus stop improvement suggestions to meet minimum ADA standards.

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An Overview of Yield-to-Bus Programs in Florida

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Abstract

This paper presents an overview of Yield-to-Bus (YTB) programs in Florida, including a review of bus operator surveys, operational and safety effects of YTB signage, and Florida YTB statutes. The statewide bus operators' survey highlighted different aspects of YTB programs in Florida. First, it was apparent that bus operators often have difficulty moving back into the flow of traffic from any off-line position, including bus pull-out bays, right-turn lanes, and wide paved shoulders. Even with the law implemented, motorists typically do not yield to the bus. The study found that the decal currently implemented on the back of the bus has no significant safety or operational effects, and there are no roadside signs or pavement markings for YTB laws.

Introduction

According to previous studies, a high percentage of bus crashes in Florida are caused by rear-end collisions with private automobiles. A 2004 study done by Luke Transportation Engineering (Luke Transportation Engineering Consultants, Inc. 2004) showed that the most common cause of bus crashes was inattentive or careless driving on the part of private automobile operators. The transit agencies surveyed in this study recommended the installation of more bus pull-out bays on state roads, more effective lighting configurations on the rear of buses, and statewide bus stop design standards (Luke Transportation Engineering Consultants, Inc. 2004). The Luke

Transportation Engineering study put high crash locations into four categories, one being crash records that included a public transit bus within 80 ft of a bus stop or bus station (Category 4). Bus accidents in Category 4 accounted for 47 percent of the severe crashes that occurred within the visual influence or the rear of the bus. Having buses pull into a specially-designated pull-out bay may reduce these rear-end collisions; however, operators often complain of the difficulty in returning to the flow of traffic. This may be the impetus for the yield-to-bus (YTB) law.

YTB legislation was enacted in Florida in 1999. Florida Statute 316.0815 states that “vehicles must yield the right-of-way to a publicly owned transit bus traveling in the same direction which has signaled and is reentering the traffic flow from a specifically designated pull-out bay. The operator of the bus must also drive with due regard for the safety of all persons using the roadway.” This is commonly referred to as the YTB law. Transit agencies throughout Florida have implemented this law in several ways, but the most common application includes a single decal placed on the back of the bus.

YTB Legislation

In the United States, seven states have passed laws requiring motorists to yield to buses attempting to merge back into traffic, including Florida, Washington, Oregon, New Jersey, California, and Minnesota; Colorado recently passed a law to allow transit agencies to post LED yield signs on the backs of buses and require drivers to yield the right-of-way to transit buses entering traffic.

The laws vary in requirements for transit agencies and the circumstances under which motorists are required to yield. No fines or penalties have been specified for violators of these laws, and they are largely unenforced. Oregon, Washington, Minnesota, and Florida share the basic elements of the law by stating that motor vehicles should yield to publicly-owned transit buses. Oregon, Washington, and Florida also state that the bus driver should operate with due regard for the safety of all persons using the roadway. Oregon and California, however, are more specific by defining the yield signal. They also class overtaking a bus as failure to yield the right-of-way under certain conditions. Originally, the New Jersey bill for the new YTB law specified a yield sign, but this was omitted from the law in 2004. A survey conducted for bus operators in Florida showed that over 60 percent of the bus drivers felt that very few motorists were aware of YTB laws. In Washington State, where the law was in existence before the Florida law, 40 percent of operators felt that very few motorists were aware of YTB laws (King 2003).

The *Manual on Uniform Traffic Devices* (MUTCD) (Federal Highway Administration 2009) does not address traffic control devices for the YTB law; however, it does specify pavement markings, signs for yielding at intersections, yielding for pedestrians, and yielding for bicyclists.

Methodology

To understand the impacts of the YTB laws in Florida, a statewide bus operators' survey was conducted to evaluate bus operators' perceptions of the law, as well as the effectiveness of different signs and lights. To supplement bus operator surveys, field data were collected at eight locations in three Florida counties.

Bus Operator Survey

The questionnaire was divided into three sections. The first section consisted of questions pertaining to bus operations and perceived motorist yield behavior. The second section pertained to different technologies available on the back of the bus for merging the bus back into traffic safely. The third section pertained to the current Florida laws and any additional safety concerns. At the end of the questionnaire was a narrative portion where bus operators were able to make recommendations for their own bus safety program as well as any additional comments and concerns.

Field Observations

To supplement bus operator surveys, observations in the field can provide valuable information on current conditions and driver behavior. Three variables that can be recorded in the field are re-entry delay, yield behavior, and conflicts.

Re-Entry Delay

Re-entry delay is the amount of time a bus waits before finding a suitable gap to re-enter the traffic stream. Re-entry delay is the variable portion of the clearance time. The clearance time is defined as the minimum time required for one bus to accelerate out of and clear the loading area and for the next bus to pull into the loading area, including any time spent waiting for a gap in traffic (Kittelson & Associates, Inc. 2003). Part of the clearance time is fixed and consists of the time it takes the bus to start up and travel its own length. The variable part of clearance time is apparent only for off-line stops when a bus must wait for a suitable gap in traffic. The *Transit Capacity and Quality of Service Manual* suggests that in states with YTB laws, the re-entry delay can be minimized or eliminated depending on how well motorists comply with the laws (Kittelson & Associates, Inc. 2003).

Conflict Study and Yield Behavior

A conflict study can be used to determine hazardous locations and situations. A traffic conflict is a situation in which a collision would have occurred if road users had continued with unchanged speeds and directions. Counting the number of serious conflicts that occur at a location can be used to determine the level of traffic hazard (DeLangen and Tembele 1994). Traffic Conflict Techniques (TCTs) have been developed in a number of European and North American countries to add relevant information to existing accident data or to replace missing accident data (Muhlrad 2007). A conflict is often determined by an abrupt braking maneuver; vehicle tail-lights are observed and any rapid deceleration is noted.

Yield behavior is determined by reviewing videos recorded in the field. A traffic conflict due to improper yield behavior is determined by the observer and is a subjective measure of traffic safety. Yield behavior may vary by location since intersections affect driver behavior. Yield behavior at mid-block locations are, therefore, expected to be different than at far-side and near-side bus stops.

Data Collection

Bus Operator Survey

Preliminary bus operator questionnaires were distributed at the State Bus Roadeo in Jacksonville, Florida, in March 2007. Additional surveys were conducted at the bus operator facilities for LYNX in Orange County and Hillsborough Area Regional Transit (HART) in Hillsborough County. At these locations, questionnaires were completed in two ways: questions were read directly to the bus operator and the responses were completed by the person administering the survey, or surveys were handed directly to the bus operator to be completed. Surveys were conducted at LYNX on Wednesday, March 28, 2007, between 12 noon and 2 PM. HART surveys were conducted on Thursday, April 26, 2007, between 2 PM and 4 PM. Data collection dates and times were suggested by transit agency supervisory staff. The method of survey administration also was dependent on the preference of transit agency staff. Additional questionnaires were left at the LYNX and HART facilities for operators who were not present at the time of the survey but wished to participate. The additional LYNX questionnaires were mailed back, while the HART questionnaires were collected at a later date.

Additional questionnaires were mailed and e-mailed to transit agencies for responses to be mailed back when completed by the bus operators. Mailed questionnaires were received from Lee County Transit (Lee Tran), Volusia County Transit (VOTRAN),

Pinellas Suncoast Transit Authority (PSTA) in Pinellas County, and Star Metro in Leon County, all in Florida. Surveys from Lee County and Volusia County were completed between March and April 2007. Surveys from Pinellas County were completed in May 2007, and surveys from Leon County were completed between May and June 2007.

The transit agencies chosen for the survey represented a range of practices in Florida. The Jacksonville Transportation Authority (JTA) in Duval County did not have any YTB decals or LED lights; therefore, their responses represented operators who were not using any YTB technologies. PSTA and HART both had YTB decals on their entire fleet; therefore, their responses represented agencies with a widely-used YTB technology. LYNX in Orange County had three different YTB decals, but they were not installed on all buses. Operators from LYNX were able to compare the different YTB decals and comment on their effectiveness. Lee Tran used both YTB decals and “Yield” LED signs but not on their entire bus fleet. VOTRAN never had any YTB decals, but they did have “Yield” LED lights on a few of their buses. Lee Tran and VOTRAN represented the only agencies in Florida that employed a technology other than the decal for YTB laws.

A total of 277 bus operator questionnaires representing 12 counties were obtained. Only one questionnaire was received from Polk, Manatee, Broward, Brevard and Alachua counties during the preliminary survey in March 2007; therefore, information from these counties was not greatly represented. Table 1 shows the transit agencies and the number of responses received.

Table 1. Transit Agencies Surveyed

Transit Agency	County	Number of Participants
Regional Transit System	Alachua	1
Space Coast Area Transit	Brevard	1
Broward County Transit	Broward	1
Jacksonville Transportation Authority	Duval	12
Hillsborough Area Transit Authority	Hillsborough	27
Lee Tran	Lee	22
Starmetro	Leon	44
Manatee County Area Transit	Manatee	1
LYNX	Orange	29
Pinellas Suncoast Transit Authority	Pinellas	112
Polk County Transit Services	Polk	1
VOTRAN	Volusia	26

Field Observation

Field data were collected using a video camera positioned at an appropriate distance to capture buses moving in and out of bus pull-out bays. Locations, therefore, had to be selected where a camera could be mounted and positioned with a clear view of the buses and cars. Far-side bus stop locations posed a particular challenge since the camera had to be located across the intersection. At certain times, the cross street traffic blocked the view of the buses at the far-side.

Site Selection

Three locations were chosen in Hillsborough County for field studies of HART buses, and three locations were also chosen in Orange County for field studies of LYNX buses. From each county, one far-side, one mid-block, and one near-side bus stop were studied. The locations were chosen based on traffic conditions and the existence of a bus pull-out bay. The locations chosen in Orange County were based on recommendations by LYNX staff.

Field studies in Hillsborough County were conducted during the afternoon peak hours on a typical weekday in December 2006. Field studies in Orange County were conducted during morning and afternoon peak-hours in April 2007. At least three hours of video were recorded at each location. Table 2 shows the sites selected for field data collection.

Table 2. Site Locations

County	Location	Location Type	2006 AADT
Hillsborough	Fletcher Ave and Bruce B Downs Blvd	Near-side	23,500
Hillsborough	Hillsborough Ave and Florida Ave	Far-side	29,500
Hillsborough	Fletcher Ave and Dale Mabry Blvd	Mid-block	21,000
Orange	Kirkman Rd and Conroy Rd 1	Near-side	30,000
Orange	Kirkman Rd and Conroy Rd 2	Far-side	30,000
Orange	Orange Blossom Tr and Holden Ave	Mid-block	33,500

Conflict, Yield Behavior, and Re-entry Delay

From the videos taken in the field, the re-entry delay, conflicts, and yield behavior of motorists were recorded. Different types of conflicts were observed in the field, including hard braking maneuvers and weaving into oncoming traffic. Changing lanes behind the bus into a clear lane was considered a minor conflict. Secondary conflicts were created when motorists weaved into another lane, causing drivers

in that lane to abruptly apply the brakes. Yield behavior was determined by cars slowing down to allow the bus back into traffic.

The purpose of the YTB law is to make motorists yield to the bus when it attempts to re-enter traffic from a specifically-designated bus pull-out bay. The number of motorists who passed a bus attempting to merge back into traffic also was used as a measure of yield behavior. The number of motorists who passed a bus attempting to merge is dependent on several variables, including the traffic volume, road geometry, and general visibility of the bus. The travel speed and awareness of the YTB law also influence motorist yield behavior.

Motorist yield behavior has a significant impact on the re-entry delay of buses. The re-entry delay for this study was used to evaluate the difficulty of bus operations in traffic. The re-entry delay of buses with different YTB technologies was compared to ascertain whether there was any noticeable difference in motorist reaction to merging buses with and without YTB decals.

Data Analysis

Survey Results

According to the survey results, most (74%) bus operators had bus pull-out bays on their routes. A significant number of bus operators also use wide shoulders or right-turn lanes to pull out of through-traffic while loading and unloading passengers. Over 90 percent said they have difficulty moving back into traffic at least some of the time, and over 70 percent of operators responded that few people yield to the bus re-entering traffic.

Based on the literature review, electronic signs on the back of the bus are favored more than the decals. The bus operator survey produced these similar results. When asked which technology they preferred, the majority (73%) chose the LED merging sign. The bus operators perceive the electronic sign to be more helpful in bus operations, and they also perceive it to help with safety more than the decal. The only positive responses for the decals were in mentions of the large 69-inch decal present on some of the LYNX buses in Orlando. When asked if there was a noticeable difference in motorist yield behavior compared to before the implementation of the YTB technology, the bus operators with experience using the decal were more inclined to answer negatively.

In the narrative portion of the questionnaire, the most common recommendation for a bus safety program was better police enforcement of the laws and more public service announcements about the presence of the YTB laws. Other recommendations made by the bus operators were to install stop arms similar to school bus stop arms and to improve the existing lighting and signs on the back of the bus. When asked about the current Florida laws, 50 percent of bus operators felt that the current laws were insufficient, and 5 percent had no response. When asked about the conditions in which motorists should yield to the bus, 76 percent of operators felt that there are other conditions in which motorists should yield, apart from at specifically-designated bus bays. Table 3 shows a summary of the questionnaire results.

Field Observations

From the field data collected, it was apparent that the location of the bus pull-out bay and the traffic volume affected the yield behavior of other motorists. Far-side bus stop locations had the unique problem of being located where drivers would have to yield in the physical area of the intersection to allow buses to enter. Motorists, therefore, never yielded to the bus at a far-side stop unless the bus did not use the pull-out bay, forcing traffic to accumulate behind the bus. This location may be a dangerous place to attempt to yield since motorists do not expect other motorists to slow down in the middle of an intersection.

As expected, more conflicts were observed with smaller headways. It appears from these results that delay and yield behavior are dependent on a variety of variables, which may include the number of lanes, location of bus stop, hourly traffic volumes, speed, and the public's attitude towards buses in that specific location. It should be noted that when traffic volumes increase, the re-entry delay will significantly increase.

Dangerous weaving and conflicts were observed as cars attempted to move out of the outside travel lane to avoid buses that are merging into traffic. There appears to be no difference in motorist yield behavior with the presence of a decal. The observed weaving behavior often caused conflicts with other vehicles on the road, not only buses. The number of conflicts observed during a specific time period was dependent on the traffic conditions and headway of the bus. The field study indicated that higher traffic volumes and smaller headways will increase the number of conflicts.

Table 3. Questionnaire Results

RESPONSE	PERCENTAGE
Are there any bus pull-out bays on any of the bus routes you have been assigned?	
Yes	74.4
No	20.9
No response	4.7
Do you ever have difficulty while attempting to merge back into traffic when the bus is out of the traffic lane?	
Always	39.4
Most of the time	30.7
Some of the time	24.2
Rarely	3.2
Never	0.7
No response	1.8
Is there a noticeable difference in the percentage of motorists who would yield to the bus as it attempts to merge before the implementation of the decal?	
No decal	7.9
Yes	26.7
No	52.3
No response	13.0
Which of these yield-to-bus signs do you think would be most effective for bus operations and improved safety?	
Decal	9.0
Flashing yield sign	7.2
Merge alert	73.3
Two technologies	4.7
No response	5.8
Do you think that the current Florida Statutes are sufficient for increasing the safety of bus operations?	
Yes	45.5
No	49.5
No response	5.1
Do you think there may be other conditions in which motorists should yield to a public transit bus apart from when the bus is re-entering from a specially designed pull-out bay?	
Yes	75.5
No	18.5
No response	6.1

There were no occurrences observed of drivers yielding to the bus. The only time drivers were seen yielding to a bus that has signaled to merge into traffic was during congested traffic conditions where bus operators could merge in-between two stopped cars. In this scenario, there were no conflicts recorded, which was the situation often observed at the Florida Ave and Hillsborough Ave location in Hillsborough County. Table 4 shows a summary of the observations in the field.

Table 4. Field Data Collected

County	Location	Location Type	Peak Hour Volume per Lane	Average Re-entry Delay (s)	Average Headway (mins)	Conflicts Per Hour	Avg. # Cars That Pass After Left Signal
Hillsborough	Fletcher Ave and Bruce B Downs Blvd	Near-side	1,106	13	22	0.50	9
Hillsborough	Hillsborough Ave and Florida Ave	Far-side	1,388	32	30	0	6
Hillsborough	Fletcher Ave and Dale Mabry Blvd	Mid-block	988	15	34	0.90	3
Orange	Kirkman Rd and Conroy Rd 1	Near-side	859	13	24	0.20	10
Orange	Kirkman Rd and Conroy Rd 2	Far-side	859	13	25	0.80	0
Orange	Orange Blossom Tr and Holden Ave	Mid-block	959	36	9	2.25	9

Summary and Discussion

The statewide bus operator survey highlighted different aspects of the YTB program in Florida. First, it was apparent that bus operators often have difficulty moving back into the flow of traffic from any off-line position, including bus pull-out bays, right-turn lanes and wide paved shoulders. Even with the law implemented, motorists typically do not yield to the bus. The study found that the decal currently implemented on the back of the bus has no significant safety or operational effects, and there are no roadside signs or pavement markings for YTB laws.

From video collected in the field, the literature review, and survey results, the following is an overview of the issues observed with the YTB program in Florida and recommendations to improve the practice.

Signage and Lighting Configurations

Although a basic configuration is observed based on National Highway Traffic Safety Administration (NHTSA) standards, the colors and types of lights vary greatly within the limits of NHTSA. The amber strobe lights can be confused with turning signals if only half of the bus rear is visible, which is the situation at some bus bay locations. In this situation, it is difficult to tell if a bus is stopped and picking up passengers or trying to merge into traffic. The typical motorist does not have time to decipher the bus's actions; therefore, guidelines are needed for the placement of optional lights on the back of the bus.

The majority of bus operators surveyed preferred a flashing sign with the word "MERGING." This technology has been proposed but is awaiting approval from NHTSA. If this technology is implemented, clear guidelines are needed as to what other optional lighting can be added to the bus. If a dynamic LED sign is placed on the back of the bus, it probably should not be used simultaneously with flashing hazard lights or deceleration lights.

Roadside Signs

Since the MUTCD currently has no signage or pavement markings for the YTB law, new signage and pavement markings should be developed based on the existing practices for yielding to pedestrians and bicyclists. Many roads are already congested with roadway signs and pavement markings that give drivers more information than they are able to digest; therefore, additional signs and pavement markings should be used with caution. Additional signs and pavement markings for the YTB law should be used under strict engineering judgment in areas where other measures may have failed.

Additionally, flashing beacons that are activated by a bus in a bus pull-out bay can be explored. One limitation of the beacon is that it can be installed only at mid-block bus stop locations where it will not conflict with intersection lights.

Yield-to-Bus Laws

The current Florida statutes make no mention of how the YTB law is to be implemented, and this possibly contributes to the lack of law enforcement. Taking the example of other states, the Florida Statute could be expanded to include a penalty for not yielding to a bus or a classification for the type of offense committed. The

viability of the law is partially dependent on how well it can be enforced; therefore, adding more information on the implementation and penalties may be beneficial. Other states require a public awareness campaign to inform motorists about the YTB laws; this is something that can be pursued in Florida. As in other states, a system should be set up to evaluate the necessity of the law based on the total number of traffic collisions, traffic congestion issues, public opinion, and the efficiency of transit operations.

According to the bus operator survey, the majority of operators believe that there are other conditions in which motorists should yield to a public transit bus. The bus operators also reported that they use shoulders and right-turn lanes to pull out of traffic, not just the specifically-designated bus pull-out bay. A detailed look into Florida bus crashes and delay problems can be used to determine whether it is necessary for motorists to yield under other conditions. Other states have not specified that motorists should yield at specifically-designated bus pull-out bays, therefore buses that pull over in any off-line stop would be covered under the laws. Removing the requirement of a designated bus bay could be considered since some counties do not have many bus bays, but still have difficulty merging into traffic after loading and unloading passengers.

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