Should Transit Serve the CBD or a Diverse Array of Destinations?
A Case Study Comparison of Two Transit Systems

An Approach to Calculate Overall Efficiency of Rolling Stock for an Urban Rail Transit System

Assessment of Models to Estimate Bus-Stop Level Transit Ridership using Spatial Modeling Methods

Transit Coordination in the U.S.: A Survey of Current Practice

Bus or Rail: An Approach to Explain the Psychological Rail Factor

The Impact of Weather on Bus Ridership in Pierce County, Washington

The Potential Role of Flexible Transport Services in Enhancing Rural Public Transport Provision

Are Smart Card Ticketing Systems Profitable? Evidence from the City of Trondheim
SUBMISSION OF MANUSCRIPTS

The Journal of Public Transportation is a quarterly, international journal containing original research and case studies associated with various forms of public transportation and related transportation and policy issues. Topics are approached from a variety of academic disciplines, including economics, engineering, planning, and others, and include policy, methodological, technological, and financial aspects. Emphasis is placed on the identification of innovative solutions to transportation problems.

All articles should be approximately 4,000 words in length (18-20 double-spaced pages). Manuscripts not submitted according to the journal’s style will be returned. Submission of the manuscript implies commitment to publish in the journal. Papers previously published or under review by other journals are unacceptable. All articles are subject to peer review. Factors considered in review include validity and significance of information, substantive contribution to the field of public transportation, and clarity and quality of presentation. Copyright is retained by the publisher, and, upon acceptance, contributions will be subject to editorial amendment. Authors will be provided with proofs for approval prior to publication.

All manuscripts must be submitted electronically in MSWord format, containing only text and tables—No linked images. If not created in Word, each table must be submitted separately in Excel format and all charts and graphs must be in Excel format. Each chart and table must have a title and each figure must have a caption. Illustrations and photographs must be submitted separately in an image file format, (i.e., TIF, JPEG, AI or EPS), having a minimum 300 dpi, and measuring at least 4.5” x 7” in size, regardless of orientation. However, charts and graphs may be submitted for use as spreads, covering two facing pages of an article. Please include all sources and written permissions for supporting materials.

All manuscripts should include sections in the following order, as specified:
- Cover Page - title (12 words or less) and complete contact information for all authors
- First Page of manuscript - title and abstract (up to 150 words)
- Main Body - organized under section headings
- References - Chicago Manual of Style, author-date format
- Biographical Sketch - of each author

Be sure to include the author’s complete contact information, including email address, mailing address, telephone, and fax number. Submit manuscripts to the Assistant to the Editor, as indicated above.
CONTENTS

Should Transit Serve the CBD or a Diverse Array of Destinations?
A Case Study Comparison of Two Transit Systems
Jeffrey R. Brown, Gregory L. Thompson.................................................................1

An Approach to Calculate Overall Efficiency of Rolling Stock
for an Urban Rail Transit System
Qamar Mahboob, Thomas Stoiber, Stephanie Gottstein, Antonios Tsakarestos........19

Assessment of Models to Estimate Bus-Stop Level Transit Ridership
using Spatial Modeling Methods
Srinivas S. Pulugurtha, Mahesh Agurla.....................................................................33

Transit Coordination in the U.S.: A Survey of Current Practice
Charles Rivasplata, Hiroyuki Iseki, Adam Smith ..................................................53

Bus or Rail: An Approach to Explain the Psychological Rail Factor
Milena Scherer, Katrin Megel Dziekan.................................................................75

The Impact of Weather on Bus Ridership in Pierce County, Washington
Victor W. Stover, Edward D. McCormack...............................................................95

The Potential Role of Flexible Transport Services in Enhancing
Rural Public Transport Provision
Nagendra R. Velaga, John D. Nelson, Steve D. Wright, John H. Farrington ........111

Are Smart Card Ticketing Systems Profitable?
Evidence from the City of Trondheim
Morten Welde.......................................................................................................133
Should Transit Serve the CBD or a Diverse Array of Destinations?
A Case Study Comparison of Two Transit Systems

Jeffrey R. Brown and Gregory L. Thompson
Florida State University

Abstract

This analysis seeks to understand the relative efficacy of two classes of policies intended to increase the ridership and productivity of public transit service. One seeks to improve transit effectiveness by freezing transit service in the older parts of metropolitan areas, such as the CBD and surrounding dense neighborhoods, where growth is to be directed. The other seeks to connect employment and population, wherever it locates, as directly as possible by transit routes. The case study compares transit performance in two regions that pursue these two service approaches. The analysis shows that the transit system that seeks to serve all jobs carries almost 400 percent more ridership per capita than does the transit system that seeks to serve primarily CBD jobs, while each bus mile operated in the dispersed transit system carries about 35 percent more passengers than each bus mile in the CBD-focused transit system.

Introduction

This case study seeks to understand the relative efficacy of two classes of policies intended to increase the ridership and productivity of public transit service. One
class of policies seeks to improve transit effectiveness by freezing transit service in the older parts of metropolitan areas. It is thought that higher densities of population and employment and the presence of pedestrian amenities in older areas induce higher levels of transit demand. Policy should attempt to direct population and employment growth to such areas, particularly around transit stops. The other class of policies seeks to connect employment and population, wherever it locates, as directly as possible by transit routes. The thrust of transit development of this second category of policies is in the newer rather than older parts of metropolitan areas, because it is in the newer areas that most population and employment growth is located.

The analysis contrasts transit development objectives and transit performance in Broward County, Florida, with those in Tarrant County, Texas. Transit development policy in the two counties is comparable, because both counties are similar in population size and growth rates, and both are situated similarly in their respective metropolitan areas, which are Miami and Dallas-Ft. Worth. Their transit systems also are both the second largest in their respective metropolitan areas. They differ primarily in the fact that Tarrant County contains a traditional CBD, and transit is organized around it. Employment in other parts of the county, which are much newer, is overlooked as a transit destination. Transit in Broward County serves all employment. Broward County lacks a CBD and is one vast suburb that developed during the auto era. Transit development objectives in Broward County generally reflect the second category of policies; those in Tarrant County generally reflect the former.

The Debate Over How Transit Should be Organized
The conventional wisdom is that transit works best when it focuses on serving the CBD commute market (Ferreri 1992, Meyer and Gomez-Ibanez 1981, Pisarski 1996, Taylor 1991). One researcher found that CBD employment is an important predictor of transit patronage (Hendrickson 1986); another found that employment decentralization explained transit patronage decline (Gomez-Ibanez 1996). The implication is that transit agencies should structure their service to feed the CBD and provide high quality service to that destination, because, as the literature would suggest, that is where riders wish to travel. An agency decision to serve other destinations, particularly those dispersed throughout the suburbs, is criticized for being an inefficient use of public subsidy (Taylor 1991) and for resulting in low service productivity (Ferreri 1992, Meyer and Gomez-Ibanez 1981).
A problem with all of these studies is that they did not examine the results of transit systems that explicitly attempted to serve suburban employment. Their approach was to track the patronage of CBD-centered transit systems that sent routes ever-farther into the suburbs in attempts to lure passengers to jobs in the CBD. Brown and Thompson (2008), however, found that extension of coordinated rail/bus transit service to jobs in suburban Atlanta resulted in patronage growth, whereas growth of jobs in other parts of Atlanta not served by transit resulted in patronage decline. Controlling for numerous variables in a cross-sectional study of transit patronage in the U.S., Brown and Neog (2007) found that CBD employment had no effect on patronage growth. This study joins the debate by explicitly comparing transit performance in two regions. In one, serving CBD employment is the major objective of transit policy. In the other, serving all employment is the major objective of transit policy.

The Settings
Broward County, Florida, served by Broward County Transit (BCT), lies immediately north of Miami-Dade County, in which lies the city of Miami. Tarrant County, Texas, served by The T, lies immediately west of Dallas County, home to the city of Dallas. Broward and Tarrant counties have similarly-sized populations that have grown at comparable rates (see Figure 1). They differ in one important way, however: Tarrant County contains a large, traditional central business district (downtown Ft. Worth) that emerged in the late 19th century. An electric streetcar system and an electric interurban line running between Ft. Worth and Dallas evolved in symbiosis with downtown Ft. Worth. Broward County has no traditional central business district of the magnitude of Ft. Worth. It does have small downtowns (the largest of which is Ft. Lauderdale) that grew around stations on the Florida East Coast Railroad that linked Miami to Jacksonville in the 1890s, running near the coast, but well into the 20th century, Miami remained as the only traditional central business district of the region.

BCT and The T are the second largest transit systems in their respective metropolitan areas. Both are the primary transit providers in the counties they serve, and they connect with transit systems in other counties. BCT buses enter northern Miami-Dade County where they connect with Miami-Dade Transit (MDT) buses (see Map 1). They also connect with Palm Tran buses in southern Palm Beach County. About half of BCT bus routes also cross tracks of Tri-Rail. Tri-Rail, operated by the South Florida Regional Transportation Authority, is a suburban passenger service using
tracks on the old Seaboard Air Line Railroad, five or six miles inland of the Florida East Coast Railroad. Tri-Rail trains connect Miami to West Palm Beach, stopping at seven stations within Broward County. Tri-Rail currently runs trains hourly in both directions during the week day. These are supplemented by additional trains during peak periods. Service is every two hours on weekends. During early 2008, Tri-Rail boarded about 14,000 passengers per day, with a little more than a third of those boarding at Broward County stations. While the Broward County train boardings are substantial, there is virtually no transfer activity between BCT buses and Tri-Rail trains. Tri-Rail passengers wishing to board BCT buses pay 50 cents to do so, less than half the normal bus fare of $1.25 (as of October 2007); BCT passengers wishing to transfer to Tri-Rail trains pay the full Tri-Rail fare (which is zoned depending upon distance traveled) but get to board BCT for free. Transfers between BCT buses are free. Because of the absence of bus-rail transfer activity, this study focuses on Broward County buses.
The T is more insulated from other bus systems in its metropolitan area (see Map 2), but it is somewhat better integrated with commuter rail service, known as Trinity Railway Express (TRE). TRE began limited service from Dallas Union Station (where it connects with Dallas Area Rapid Transit [DART] light rail trains) to a station south of the Dallas–Ft. Worth airport in 1996; in 2001, TRE service was extended westward into the Ft. Worth central business district, where it connects with The T buses in a large multi-modal transit terminal. TRE trains now run roughly on an hourly headways Monday through Saturday, with more service during peak times. TRE attracted roughly 9,000 passengers per day in March 2008, rising to more than 12,000 passengers per day in July 2008 as gas prices rose. The T and DART share ownership of TRE, and there are free transfers between The T buses and TRE trains. There is some amount of transfer activity between The T buses and TRE trains, but not much. TRE serves few trips within Tarrant County, so this study focuses on The T.
Map 2. The T Adjacent to Dallas Area Rapid Transit and Trinity Rail Express

Transit Development in Broward County

Prior to public involvement in the provision of transit service in Broward County, two private operators offered service in the county. One ran several routes focused on the Ft. Lauderdale downtown; the other ran several routes focused on the Hollywood downtown. Our agency contact person characterized both systems as having skeletal, circuitous routes with hourly headways. He called them “spaghetti networks” that attempted to go “where the riders are”—that is, routes wandered through neighborhoods where riders lived. On the other end, routes served the beaches and were designed to carry domestic employees who worked in condos. Our agency contact person further characterized the systems as “unreliable and inefficient.”

BCT was organized to take over the two private systems in the mid-1970s. Originally, it was a division in the Broward County Office of Transportation but later was moved to Broward County Community Services, reflecting a vision of transit as being a social service. Sometime later, BCT was moved back to the Office of Transportation, where it remains today. At first, BCT expanded upon the route structure that already was in place. One improvement was the creation of an overlay of express bus routes that ran from various parts of the county to downtown Ft. Lauderdale and to Miami International Airport.

Our agency contact person, who joined the system at that time as a bus driver, said that the system carried few riders. Even the modest ridership that the express lines initially attracted dwindled from year to year. Low ridership on all of its services
prompted BCT management to reflect upon how it might do things differently. Service to Miami International Airport was suspended when Eastern Airlines shut down. The director of the system at the time, Houston Miller, determined that the system needed to be gridded, but that it should be changed over incrementally. The process began in 1980 with Operation Changeover. Base headways were reduced from 60 to 30 minutes on what were termed “mainline routes.” Headways were shortened due to recognition that a grid would require many passengers to transfer to complete their trips; hourly headways were felt to be too long for passengers to wait at transfer points.

The gridding of the system happened over a period of 10 to 15 years, beginning in 1980. For many years, some routes still had deviations to serve destinations such as condo complexes. All express routes were gone by the late 1980s. Our agency contact person said that BCT formed its routing decisions with studies by the USF Center for Urban Transportation Research (CUTR) and the National Transit Institute (NTI) that compared BCT to other transit agencies. BCT also used common sense. Broward County has a grid pattern for its arterial roads, so the move to grid transit network seemed logical. Our agency contact person also reported that BCT received positive feedback from its early route straightening that gave it confidence to continue with the process. After BCT did so, they experienced increased ridership. Population growth also was pointed to as a factor influencing steady increase in ridership from 13 million trips in 1984 to around 40 million today.

The busiest bus service today operates on U.S. 441, a high-speed, heavily trafficked multi-lane arterial highway that runs through the middle of the built-up part of the county in a north-south orientation. Two routes operate on this road from one end of the county to the other. Route 18 provides local service on 15-minute headways. “The Breeze” provides limited stop service, stopping every mile or so to interchange passengers with buses on busy east-west routes. Loads are heavy, and BCT uses articulated buses to handle them. The U.S. 441 routes serve no downtown but do serve numerous strip malls, regular malls, and big box stores. Apartment complexes generally are only one to two blocks away on either side. On the south end, the U.S. 441 routes connect with MDT buses. The Breeze picks up 10 to 15 passengers per trip at this point, some of whom are transferees from MDT buses.

When BCT eliminated route deviations by pulling buses out of neighborhoods and putting them on arterial roads, it met some political resistance from users who did not want to walk farther to reach a bus stop. The political solution to this problem was the designation of some transit operating funds to support community circu-
lators, small buses that wander through neighborhoods, taking residents to nearby destinations and to stops on the mainline BCT routes. There are many local governments within Broward County, and evidently the local governments determine how to run the circulators in their jurisdictions. Our agency contact person stated that almost all of the patronage growth for BCT has been on the mainline routes on the arterial roads.

The left panel of Map 3 shows BCT’s route structure in 2006 in relation to employment density in the county. The dispersal of employment sites throughout the county is readily apparent. All employment sites have gridded transit routes passing them. Residents living in most parts of the county can reach employment wherever it is located by using buses running in straight lines along arterial roads.

Map 3. BCT Serves Many Destinations; The T Serves One Destination Well

Transit Development in Tarrant County

The dominance of the Ft. Worth central business district over a long period of time and differences in funding mechanisms for transit between Texas and Florida have influenced The T to evolve very differently than Broward County Transit. Streetcar lines and the Ft. Worth CBD grew hand-in-hand during the early 20th century, with streetcars extending out to suburbs from the CBD in the classic radial pattern. Through the transition from streetcar to bus and to the present day, this pattern of organizing transit routes has not changed (although it has been added to), even though employment and residents have decentralized throughout the region since auto ownership began rising rapidly after World War I.
Finance also affects the pattern of transit development in Florida and Texas. As a County department, BCT receives subsidies from the County in sufficient magnitude to allow it to serve all of those parts of the county that are urbanized. The Florida Department of Transportation (FDOT) also provides some transit operating support through its gas tax. Financing is more difficult for The T and restricts the territory that it can serve. There is no state operating support for transit in Texas, where local sales tax revenues provide the primary source of subsidy for transit operating deficits. Texas transit systems must appeal to individual communities for sales tax revenues, but Texas law imposes a sales tax cap on communities of 8.25 percent. Many communities already were at the limit before transit agencies approached them for funding. If a community chooses not to provide sales tax funding for transit, it gets no service. Because The T historically served the city of Ft. Worth and was a City department before becoming an authority in 1983, it receives tax support from the City (population today of about 700,000). At the time it became an authority, it received a dedicated ¼-cent sales tax from the City to support transit. The T also receives support from the City of Richland (population 7,000). The City of Arlington (population 300,000), in contrast, does not provide sales tax funding to either The T or to DART; Arlington thus receives no transit service. Unfortunately, some of the largest employment concentrations and most rapid employment growth in Tarrant County are in Arlington. Thus, The T does not serve significant parts of the urbanized areas in Tarrant County.

The T’s route structure today is largely radial in nature. The two most heavily-traveled routes operate in straight lines on arterial roads from one side of the city to the other, one north-south and the other east-west. These operate every 15 minutes during weekdays. The two routes intersect in the CBD at the Intermodal Transportation Center, where TRE also stops. Schedules are coordinated so that passengers may transfer in both directions between the two routes and with Trinity Rail trains. The outer ends of these routes serve transit centers from which community circulator routes fan. Again, connections are coordinated. Other routes wind through neighborhoods not served by the first two routes on their way to the CBD. Some operate every 30 minutes; others operate hourly. A major route was implemented relatively recently and operates on arterial roads as it connects transit centers on the east, south, and west ends of the city. This belt route, which operates every 30 minutes, does not serve the CBD but does serve malls. It is the third most-heavily patronized of The T’s routes, and its patronage has been growing briskly. During peak hours, seven express buses operate from outer neighborhoods and transit centers to the CBD. Most express routes consist of a handful of trips in the peak direction during the peak hours. In
addition to regular route services, The T operates vans during shift changes between some major employment centers (particularly in the north) and transit centers.

The right panel of Map 3 shows The T’s route structure in 2006 in relationship to the distribution of employment in Tarrant County. Although Ft. Worth is a central business district, employment is widely scattered throughout the county. While radial routes of The T pass by many of the suburban centers, residents in many parts of Tarrant County cannot reach the jobs without first traveling out of direction to the CBD transfer center, transferring, and then riding back out into the suburbs in another direction. There also are major job concentrations that routes of The T do not serve at all. Those in Arlington are along the eastern border of Tarrant County.

Comparative Transit Performance
Operating statistics for both systems showing performance from 1984 through 2006 and are summarized in Table 1. BCT has been more generously funded than The T, and this is apparent in Table 1 in the amount of service provided, measured as revenue miles. A revenue mile is a bus running one mile in revenue service. In 1984, BCT operated slightly more than twice the revenue miles that The T operated. By 2006, BCT operated almost four times as many revenue miles as The T.

Often times, a system that provides much more service than another will be less productive, because it has saturated the market. This is not the case of BCT compared to The T. Service productivity measures the average number of passengers on board the bus at any given time. For much of the period, BCT buses were 1.5 times to 2 times as full as The T buses, although productivity for The T increased rapidly in 2005 and 2006, greatly narrowing the gap. Figure 2 visually shows the productivity trends. We suspect that the greater productivity of BCT buses arises from the wider array of destinations that they serve relatively well.

As a consequence of offering four times as much service combined with the greater productivity of each mile of service, BCT penetrates the travel market in its area to a much greater extent than does The T. We denote the penetration of the travel market as riding habit, a term that the U.S. transit industry once used to this purpose. Historically, the transit industry defined riding habit as revenue passengers divided by population served. The industry no longer collects the statistic of revenue passengers (it is now calls linked trips), so we define the term as revenue passenger miles divided by population served. We also define the population served as that in the county. Even if the transit system does not serve all of the county,
## Table 1. BCT and The T Bus Service, 1984–2006

<table>
<thead>
<tr>
<th>Year</th>
<th>Population</th>
<th>Miles</th>
<th>Miles</th>
<th>Riding Habit</th>
<th>Service Productivity</th>
<th>Operating Expense per Passenger Mile (2006$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1984</td>
<td>1,110,862</td>
<td>72,755,935</td>
<td>6,771,663</td>
<td>65.50</td>
<td>10.74</td>
<td>$0.50</td>
</tr>
<tr>
<td>1985</td>
<td>1,132,921</td>
<td>84,264,996</td>
<td>7,437,629</td>
<td>74.38</td>
<td>11.33</td>
<td>$0.49</td>
</tr>
<tr>
<td>1986</td>
<td>1,154,494</td>
<td>78,991,384</td>
<td>8,375,628</td>
<td>68.42</td>
<td>9.43</td>
<td>$0.59</td>
</tr>
<tr>
<td>1987</td>
<td>1,180,921</td>
<td>61,379,078</td>
<td>8,875,849</td>
<td>51.98</td>
<td>6.92</td>
<td>$0.78</td>
</tr>
<tr>
<td>1988</td>
<td>1,208,428</td>
<td>75,028,484</td>
<td>8,910,748</td>
<td>62.09</td>
<td>8.42</td>
<td>$0.68</td>
</tr>
<tr>
<td>1989</td>
<td>1,233,040</td>
<td>67,589,568</td>
<td>8,973,206</td>
<td>54.82</td>
<td>7.53</td>
<td>$0.68</td>
</tr>
<tr>
<td>1990</td>
<td>1,263,301</td>
<td>81,992,838</td>
<td>8,947,336</td>
<td>64.90</td>
<td>9.16</td>
<td>$0.68</td>
</tr>
<tr>
<td>1991</td>
<td>1,296,261</td>
<td>81,118,030</td>
<td>9,120,846</td>
<td>62.58</td>
<td>8.89</td>
<td>$0.68</td>
</tr>
<tr>
<td>1992</td>
<td>1,325,375</td>
<td>97,622,366</td>
<td>9,134,271</td>
<td>73.66</td>
<td>10.69</td>
<td>$0.55</td>
</tr>
<tr>
<td>1993</td>
<td>1,372,526</td>
<td>96,753,748</td>
<td>9,111,227</td>
<td>70.49</td>
<td>10.62</td>
<td>$0.56</td>
</tr>
<tr>
<td>1994</td>
<td>1,412,641</td>
<td>103,822,086</td>
<td>9,662,692</td>
<td>73.50</td>
<td>10.74</td>
<td>$0.53</td>
</tr>
<tr>
<td>1995</td>
<td>1,447,124</td>
<td>111,004,429</td>
<td>9,767,690</td>
<td>76.71</td>
<td>11.36</td>
<td>$0.50</td>
</tr>
<tr>
<td>1996</td>
<td>1,481,333</td>
<td>109,542,370</td>
<td>9,801,046</td>
<td>72.46</td>
<td>11.25</td>
<td>$0.50</td>
</tr>
<tr>
<td>1997</td>
<td>1,522,179</td>
<td>110,289,977</td>
<td>9,811,227</td>
<td>73.66</td>
<td>11.14</td>
<td>$0.50</td>
</tr>
<tr>
<td>1998</td>
<td>1,560,649</td>
<td>111,568,312</td>
<td>10,410,633</td>
<td>71.49</td>
<td>10.72</td>
<td>$0.53</td>
</tr>
<tr>
<td>1999</td>
<td>1,594,130</td>
<td>114,736,758</td>
<td>10,598,450</td>
<td>71.97</td>
<td>10.83</td>
<td>$0.51</td>
</tr>
<tr>
<td>2000</td>
<td>1,623,018</td>
<td>119,986,652</td>
<td>12,013,192</td>
<td>73.93</td>
<td>9.99</td>
<td>$0.53</td>
</tr>
<tr>
<td>2001</td>
<td>1,670,494</td>
<td>137,200,475</td>
<td>13,245,365</td>
<td>82.13</td>
<td>10.36</td>
<td>$0.51</td>
</tr>
<tr>
<td>2002</td>
<td>1,703,998</td>
<td>142,999,966</td>
<td>14,687,845</td>
<td>83.92</td>
<td>9.74</td>
<td>$0.53</td>
</tr>
<tr>
<td>2003</td>
<td>1,728,336</td>
<td>153,883,282</td>
<td>15,392,404</td>
<td>89.04</td>
<td>10.00</td>
<td>$0.53</td>
</tr>
<tr>
<td>2004</td>
<td>1,777,638</td>
<td>162,688,826</td>
<td>15,760,508</td>
<td>91.52</td>
<td>10.32</td>
<td>$0.53</td>
</tr>
<tr>
<td>2005</td>
<td>1,787,636</td>
<td>168,100,759</td>
<td>16,013,518</td>
<td>94.04</td>
<td>10.50</td>
<td>$0.53</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Population</th>
<th>Miles</th>
<th>Miles</th>
<th>Riding Habit</th>
<th>Service Productivity</th>
<th>Operating Expense per Passenger Mile (2006$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1984</td>
<td>1,001,836</td>
<td>25,996,998</td>
<td>3,146,409</td>
<td>25.95</td>
<td>8.26</td>
<td>$0.62</td>
</tr>
<tr>
<td>1985</td>
<td>1,043,207</td>
<td>23,787,695</td>
<td>3,826,627</td>
<td>22.80</td>
<td>6.22</td>
<td>$0.75</td>
</tr>
<tr>
<td>1986</td>
<td>1,083,641</td>
<td>27,286,469</td>
<td>3,729,784</td>
<td>25.18</td>
<td>7.32</td>
<td>$0.72</td>
</tr>
<tr>
<td>1987</td>
<td>1,116,110</td>
<td>26,077,602</td>
<td>3,513,866</td>
<td>23.36</td>
<td>7.42</td>
<td>$0.73</td>
</tr>
<tr>
<td>1988</td>
<td>1,133,193</td>
<td>26,077,602</td>
<td>3,596,248</td>
<td>19.01</td>
<td>5.99</td>
<td>$0.84</td>
</tr>
<tr>
<td>1989</td>
<td>1,149,530</td>
<td>31,693,345</td>
<td>3,606,597</td>
<td>27.57</td>
<td>8.79</td>
<td>$0.60</td>
</tr>
<tr>
<td>1990</td>
<td>1,177,220</td>
<td>48,894,085</td>
<td>4,217,180</td>
<td>73.93</td>
<td>9.99</td>
<td>$0.53</td>
</tr>
<tr>
<td>1991</td>
<td>1,205,887</td>
<td>41,969,177</td>
<td>4,597,108</td>
<td>34.80</td>
<td>9.13</td>
<td>$0.50</td>
</tr>
<tr>
<td>1992</td>
<td>1,225,543</td>
<td>27,569,034</td>
<td>4,516,312</td>
<td>22.50</td>
<td>6.10</td>
<td>$0.82</td>
</tr>
<tr>
<td>1993</td>
<td>1,243,884</td>
<td>32,344,667</td>
<td>4,827,258</td>
<td>26.00</td>
<td>6.70</td>
<td>$0.73</td>
</tr>
<tr>
<td>1994</td>
<td>1,270,639</td>
<td>34,797,556</td>
<td>4,992,711</td>
<td>27.39</td>
<td>6.97</td>
<td>$0.69</td>
</tr>
<tr>
<td>1995</td>
<td>1,294,453</td>
<td>30,474,382</td>
<td>4,993,480</td>
<td>23.54</td>
<td>6.10</td>
<td>$0.77</td>
</tr>
<tr>
<td>1996</td>
<td>1,323,207</td>
<td>30,275,663</td>
<td>4,754,570</td>
<td>22.88</td>
<td>6.37</td>
<td>$0.73</td>
</tr>
<tr>
<td>1997</td>
<td>1,355,318</td>
<td>28,706,617</td>
<td>4,940,493</td>
<td>21.18</td>
<td>5.81</td>
<td>$0.82</td>
</tr>
<tr>
<td>1998</td>
<td>1,388,366</td>
<td>24,962,373</td>
<td>4,597,262</td>
<td>17.98</td>
<td>5.43</td>
<td>$0.92</td>
</tr>
<tr>
<td>1999</td>
<td>1,422,372</td>
<td>25,375,686</td>
<td>4,657,887</td>
<td>17.84</td>
<td>5.45</td>
<td>$1.00</td>
</tr>
<tr>
<td>2000</td>
<td>1,446,219</td>
<td>27,266,081</td>
<td>4,740,854</td>
<td>18.85</td>
<td>5.75</td>
<td>$0.96</td>
</tr>
<tr>
<td>2001</td>
<td>1,488,780</td>
<td>30,617,583</td>
<td>4,868,114</td>
<td>20.57</td>
<td>6.29</td>
<td>$1.00</td>
</tr>
<tr>
<td>2002</td>
<td>1,525,317</td>
<td>27,362,150</td>
<td>4,750,862</td>
<td>18.12</td>
<td>5.82</td>
<td>$1.17</td>
</tr>
<tr>
<td>2003</td>
<td>1,557,128</td>
<td>24,048,649</td>
<td>3,923,945</td>
<td>15.44</td>
<td>6.13</td>
<td>$1.14</td>
</tr>
<tr>
<td>2004</td>
<td>1,587,019</td>
<td>21,537,919</td>
<td>3,879,328</td>
<td>13.57</td>
<td>5.55</td>
<td>$1.18</td>
</tr>
<tr>
<td>2005</td>
<td>1,620,479</td>
<td>29,106,436</td>
<td>4,459,345</td>
<td>17.96</td>
<td>6.53</td>
<td>$0.89</td>
</tr>
<tr>
<td>2006</td>
<td>1,671,295</td>
<td>31,615,080</td>
<td>4,063,813</td>
<td>18.92</td>
<td>7.78</td>
<td>$0.85</td>
</tr>
</tbody>
</table>

Sources: FDOT (2008), U.S. Census Bureau (2008)
residents that it does serve want to reach destinations throughout the county, so county population is a fair measure. On that basis, we see in Figure 3 that riding habit now is nearly five times greater in Broward County than it is in Tarrant County. We also see in Figure 4 that because of its greater productivity, BCT spends significantly less to move a passenger one mile than does The T.

To gain additional insight into the relative performance of the two transit systems, we examined in Table 2 the performance of their various categories of services. At the time we collected data, BCT distinguished only two categories of service: the gridded fixed-bus routes operating on arterial roads and community bus services circulating through neighborhoods. The top panel of Table 5 shows that the fixed routes are far more productive than are the community routes while accounting for about 15 times more patronage than the community services. Moreover, our agency contact person for BCT stated that all of the patronage growth for the system has been accounted for by the gridded mainline routes on arterial roads.
Should Transit Serve the CBD or a Diverse Array of Destinations?

Figure 3. Riding Habit (Passenger Miles per Capita, 1984–2006)


Figure 4. Efficiency (Cost per Passenger Mile, 1984–2006)

Source: FTIS (2008)
Table 2. Transit Performance by Service Type, BCT and The T

**Broward County Transit (BCT)**

<table>
<thead>
<tr>
<th>Service Type</th>
<th>Monthly Boardings</th>
<th>Monthly Revenue Hours</th>
<th>Boardings per Revenue Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed-Route Bus</td>
<td>3,209,681</td>
<td>87,317</td>
<td>36.76</td>
</tr>
<tr>
<td>Community Bus</td>
<td>214,085</td>
<td>21,183</td>
<td>10.11</td>
</tr>
</tbody>
</table>

**Fort Worth Transportation Authority (The T)**

<table>
<thead>
<tr>
<th>Service Type</th>
<th>Monthly Boardings</th>
<th>Monthly Revenue Hours</th>
<th>Boardings per Revenue Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial Routes</td>
<td>355,389</td>
<td>20,036</td>
<td>17.74</td>
</tr>
<tr>
<td>Crosstown Routes</td>
<td>67,247</td>
<td>4,562</td>
<td>14.74</td>
</tr>
<tr>
<td>Express Routes</td>
<td>11,372</td>
<td>1,023</td>
<td>11.12</td>
</tr>
<tr>
<td>Feeder Routes</td>
<td>59,313</td>
<td>4,657</td>
<td>12.74</td>
</tr>
<tr>
<td>Circulator Routes</td>
<td>15,798</td>
<td>675</td>
<td>23.39</td>
</tr>
<tr>
<td>All CBD-serving Routes</td>
<td>366,360</td>
<td>21,311</td>
<td>17.19</td>
</tr>
<tr>
<td>All Non-CBD Routes</td>
<td>142,759</td>
<td>9,642</td>
<td>14.81</td>
</tr>
<tr>
<td>All Fixed-Route Bus</td>
<td>509,119</td>
<td>30,953</td>
<td>16.45</td>
</tr>
</tbody>
</table>

Sources: BCT (2008), FWTA (2008)

Note: BCT and The T statistics are for January 2008

The T operates a wider array of services. Our examination of the performance of individual routes shows only three routes with heavy patronage. The well-performing routes include the east-west and north-south routes that intersection in the CBD and the belt line that connects the east and south suburban transit centers with suburban destinations while intersecting with all routes operating to the CBD from the east, south, and west. These three routes account for just more than 50 percent of the patronage of the fixed-route system in FY 2008. Other radial routes, crosstown routes, circulator routes, and express routes have much lower patronage. The seven express routes contributed only 2.7 percent of system patronage. Table 2 reflects the widely differing performance level in each category of service by showing large differences between mean and median performance in most categories. The mean is heavily weighted by the one or two routes that do well in
the crosstown and radial categories, respectively, whereas the median reflects the performance of the remaining routes in each category. As in Broward County, in Tarrant County the routes that perform the best are those that operate in relatively straight lines on major arterial roads, serving a relatively large array of destinations.

Conclusions
According to much of the literature, Tarrant County offers a better built environment to support greater transit demand than does Broward County. Tarrant County has a traditional central business district and surrounding inner suburbs whose form took shape when streetcars were the dominant urban transport mode. While most of Tarrant County’s growth took place after the automobile became the dominant form of transportation, there exists in Tarrant County a core whose land uses were shaped around transit and that presumably today offers a hospitable environment in which transit can prosper. Planners for The T have taken advantage of this situation and have continued to focus transit routes as connectors between suburban residences and CBD jobs. They further have enhanced transit service by overlaying a network of express buses between outlying neighborhoods and the CBD during week day peak travel periods.

In contrast, no such central business district existed in Broward County, which consisted during the pre-auto era of very small towns strung out along a railroad line. The urban form of Broward County began to take shape later, long after the private automobile became the dominant form of urban transportation. No central business district then emerged. Instead, employment as it grew in Broward County scattered about the county. Private transit service that survived into the 1970s connected residential areas with the small downtown of Ft. Lauderdale, but the private service attracted few riders, prompting planners to think of another way of serving the market when the county took over the service.

So, based on urban form, we would expect transit to perform much better in Tarrant County than in Broward. And yet, just the opposite has transpired. Transit in Broward County carries almost 400 percent more ridership per capita than does transit in Tarrant County, while each bus mile operated in Broward County carries about 35 percent more passengers.

Part of the explanation for this unexpected result derives from organization and funding. As a county-wide agency, Broward County Transit is compelled to think of ways of serving the entire county, not just the small downtowns. The T, in con-
trast, has its organization roots in the city of Ft. Worth, and other jurisdictions in the county do not want to pay for service provided by The T. Consequently, The T thinks of its market much differently than BCT.

We think that it is the difference in thinking that accounts for the rest of the difference in performance between the two systems. Large areas of employment in Tarrant County remain un-served by transit, and much of the suburban employment that is served is done so ineffectively because of circuitous routing. The T serves the Ft. Worth CBD well but other possible destinations less well. In contrast, BCT with its grid route structure on major arterial roads serves most destinations tolerably directly. This contrast suggests that how a transit system uses its route structure to connect origins and destinations is more important to developing ridership than is the design of the origins and destinations.

This is not to say that policies for concentrating development around stops at both the origin and destination of transit trips would not boost transit ridership. Making the walk to transit shorter and more attractive without sacrificing route speeds or headways to accomplish the shorter walks undoubtedly would increase ridership markedly. One way for shortening walks is through transit oriented development (TOD). Over time, if the large-scale application of TODs can accommodate population and employment growth in smaller urban regions than otherwise would be the case, transit ridership would increase substantially. But, currently, transit systems can increase ridership substantially by restructuring routes to make more of the region’s employment accessible by transit.

Endnotes

1 The improvement in productivity for The T is not the result of more passengers riding the system, but the result of passengers riding longer distances. We verified with our contact that express bus riding is not increasing and that the figures do not include TRE riding, so we do not have an explanation for what is causing the recent increases in trip length.

Acknowledgments

The authors wish to thank the Florida Department of Transportation and the Mineta Transportation Institute for grants that made this paper possible. They also wish to thank the staffs of the Ft. Worth Transit Authority (The T), the North
Should Transit Serve the CBD or a Diverse Array of Destinations?

Central Texas Council of Governments, and Broward County Transit (BCT) for interviews and data. We remain responsible, however, for possible errors and omissions as well as for opinion expressed in this document.

References

Broward County MPO. 2007. Employment by traffic analysis zone. Provided by Broward County MPO staff.


Brown, J., and G. Thompson. 2009. The influence of service planning decisions on rail transit success or failure. Mineta Transportation Institute, San Jose, CA.


Fort Worth Transportation Authority (The T). 2008. Transit route shapefile. Provided by The T staff.


---

**About the Authors**

**JEFFREY R. BROWN** ([jrbrown3@fsu.edu](mailto:jrbrown3@fsu.edu)) is Associate Professor and Director of the Master’s Program in the Department of Urban and Regional Planning at Florida State University. His research interests include the early professionalization of transportation planning, the changing nature of street and highway planning in the United States, transportation finance, and the relevance of different service strategies for making public transit more successful in decentralized urban areas.

**GREGORY L. THOMPSON** ([glthompson@fsu.edu](mailto:glthompson@fsu.edu)) is a Professor with the Department of Urban and Regional Planning at Florida State University. His research interests involve understanding the role of public transportation in auto-dominated society using historical case study and quantitative methods.
An Approach to Calculate Overall Efficiency of Rolling Stock for an Urban Rail Transit System

Qamar Mahboob, Technische Universität Dresden & Pakistan Railways
Thomas Stoiber, Ernst Basler + Partner AG
Stephanie Gottstein, Stadtwerke München GmbH
Antonios Tsakarestos, Technische Universität München

Abstract

Inefficiency of urban rail transit systems (URTS) results in a lower standard of service than required and has negative economic impacts. Many efforts have been undertaken to calculate the efficiency of URTS or their subunits. Overall equipment efficiency (OEE) as a measure of efficiency is a simple, flexible, and efficient formula. The OEE measure ensures that equipment is available and fully capable of producing quality goods/services for the maximum time of operation and is being used in a proper way. This paper discusses the idea of the OEE from the field of production and how it can be applied to a URTS. Overall efficiency of rolling stock (RS) is a major influencing factor on the efficiency of URTS. Therefore, the three fundamental parameters of OEE—availability, performance, and service quality—are defined for the RS of a URTS, and a method for their calculation is presented. The usefulness of OEE for URTS is investigated.

Introduction

Improving and maintaining the efficiency of rail transit systems has become important due to limited public funds and an increase in transport demand (Sulek
et al. 2000). There are many ways to calculate the efficiency of a public transport system or one of its subunits. For schedule and operating personnel efficiencies of a transit system, we refer to Vuchic (2005) and Edwards (1992). In terms of economics, technical efficiency is measured by the ratio of output to input (Cooper et al. 2004). Depending on the type of system, there can be single or multiple inputs/outputs. In the case of an urban rail transit system (URTS), multiple outputs are produced by multiple inputs. Currently, several inputs/outputs of a transit system are in use to develop a performance measurement system (Sulek and Lind 2000).

Additionally, each URTS has different subunits, with each subunit having a variety of inputs/outputs. Individual lines of network, transit units of a particular type in a vehicle fleet, parking management, park-and-ride lots, and collection of fares are some examples of subunits. Any subunit of a URTS that runs with low efficiency can cause the following:

- less profit for the transport company
- cost increases due to extra wages for drivers and maintenance and other staff who are in charge of overcoming actual deficiencies
- increase in service costs because of rework
- waste of energy, materials, and work force
- impacts on pricing

Therefore, the focus should be on improving the overall efficiency of URTS. One way of achieving this objective is to identify and improve the efficiencies of the individual subunits (Barnum et al. 2007). Another way to improve would be to adopt strategies that result in the more efficient use of transportation resources (VTPI 2011), which is called transport demand management. It is important that different measures for strategy and input/output for efficiency must correspond to the objectives of the transit agency. However, the core objective of any transit agency is to ensure that the transit system is available, fully capable of producing quality services for the maximum time of operation, and being used properly. This leads us to use a measure that is called overall equipment efficiency (OEE) and is taken from the field of production (Borris 2006). It focuses on the core objective mentioned above. OEE as a measure for efficiency calculation is a simple, effective, and flexible formula. It measures the efficiency of equipment during its planned operation time.

This paper outlines the background of OEE and describes how it can be defined for URTS. Some issues regarding its application to URTS are addressed. It is investigated whether the OEE measure is useful for calculating the overall efficiency of URTS. What kind of information and results will be obtained for the specific case
of URTS if we apply this measure? The rolling stock (RS) is a subunit of URTS and serves as the backbone of any system. To simplify the study, we applied the OEE measure to the RS. In this work, the RS of the Munich URTS was chosen as the real-world application. OEE is defined and calculated by defining and calculating the three parameters—availability, performance, and quality yield—for the rolling stock of the URTS.

Theoretical Background

The overall efficiency of a transit system can be calculated by correctly identifying subunit efficiencies. Each subunit has specific inputs/outputs. For example, Barnum et al. (2007) show that the key outputs for park-and-ride lots of the Chicago Transit Authority are (1) number of parked cars, as a proxy for number of passenger trips, and (2) parking revenues. The key inputs are (1) number of parking spaces and (2) operating expenses. To obtain a comprehensive efficiency measure for comparing the parking lots, each lot's outputs and inputs are aggregated with a relevant weighting scheme, and then the aggregated outputs are divided by the aggregated inputs; see Eq. (1):

$$\text{Efficiency} = \frac{\text{Output Weight}_1 \cdot \text{Output}_1 + \text{Output Weight}_2 \cdot \text{Output}_2}{\text{Input Weight}_1 \cdot \text{Input}_1 + \text{Input Weight}_2 \cdot \text{Input}_2}$$

(1)

The same weights are applied to the inputs and outputs of each parking lot, and then the resulting values are compared. However, one must keep in mind that the weighting scheme is completely dependent on the goals and objectives of the transit authority. Schedule efficiency is one of the important measures of operating efficiency (Edwards 1992). It is defined as the ratio of the sum of operating time (in two directions) to cycle time. Basically, it reflects the terminal time losses. Operating (or travel) time $T_0$ is the scheduled time interval between the departure of a transit unit (TU) from one terminal and its arrival at another. The operating time is, therefore, the sum of station-to-station travel times for all $i$ interstation spacings between terminals.

$$T_0 = \sum_i T_{s_i} = \sum_i (t_{r_i} + t_{s_i})$$

(2)

Where, the station-to-station time $T_s$ is the time interval between a TU’s departures from two neighboring stations; it is equal to the running time $t_r$ plus the station standing time $t_s$ on any spacing $i$. 

An Approach to Calculate Overall Efficiency of Rolling Stock for an Urban Rail Transit System
\[ T_{si} = t_{ri} + t_{si} \]  \hspace{1cm} (3)

Terminal time \( t_i \) is the time a TU spends at a line terminal. This time is provided for vehicle turning or change of driver’s cab, resting of the crew, adjustment of schedule, and recovery of delays incurred in travel. The terminal time \( t_i \) is determined as the percentage of operating time on line (Vuchic 2005). This is minimized in automatic train operation where there is no need for driver breaks, turning of vehicles, etc. Cycle time \( T \) is the total round trip on line, or the interval between the two consecutive times a TU (in regular service) leaves the same terminal. It consists of operating times for the two directions and terminal times.

\[ T = 2(T_0 + t_r) \]  \hspace{1cm} (4)

Another way of calculating the cycle time is to multiply the number of transit units, \( N_{TU} \), with the headway (time interval in minutes between the moments when two successive TUs pass a fixed point on a transit line in the same direction) \( h \). Integer values that are equal to or greater than the computed value are taken for \( T \), \( N_{TU} \) and \( h \). Finally, the coefficient of schedule efficiency \( \eta_t \) becomes

\[ \eta_t = \frac{2}{T} \frac{T_0}{\sum (t_{ri} + t_{si})}{2(T_0 + t_r)} \]  \hspace{1cm} (5)

Another method of efficiency calculation is to use the overall equipment efficiency (OEE). It is a way of calculating the percentage of actual effectiveness of the equipment that is consuming inputs for some outputs (Borris 2006).

**Overall Equipment Efficiency**

All equipment is intended to produce some kind of output. The type of equipment and its inputs and design limitations will determine how much output can be produced per unit time. For example, scheduled maintenance during the service life of equipment is one of the inputs that affects the output rate and the quality of the outcome. The output can be affected by the following failures:

- **The equipment breaks down completely**: This is when the equipment produces no products (i.e., goods or services) at all. This is known as a *total failure*. In this case, times without operation/production may help diagnose the failure easily.

- **The equipment still produces products but it lost speed**: The equipment is running below its capacity and working slower than under normal operating conditions.
The equipment may reduce the quality of the product: Quality can be affected in several ways. One way is that the equipment’s outputs do not meet customer demands or market standards and are rejected. Quality problems result in a loss of profit.

The aim of the OEE measure is to ensure that equipment is available and fully capable of producing quality products for the maximum time of production and is used properly. To ensure this, OEE as a measure of efficiency is been defined as the product of (1) availability, (2) performance, and (3) quality yield of the equipment (Borris 2006; McCarthy 2001). A brief description of each parameter is given below.

### Availability of Equipment
The equipment is not capable of producing goods or services if it is down for scheduled or unscheduled maintenance. Availability of the equipment is the ratio of the amount of time that the equipment is capable of producing quality product to the total time it could be running.

\[
\text{Availability} \% = \frac{\text{Total time available} - \text{Downtime}}{\text{Total time available}} \times 100 \quad (6)
\]

There are two types of downtime—planned and unplanned. Usually, planned downtime is adopted in accordance with manufacturer standards. At some point, planned downtime becomes purely dependent on the running time of the equipment, maintenance standards, and local conditions (Dhillon 2002). Unplanned downtime arises due to various uncertainties in the design, operation, maintenance, and environment of the equipment that affects the availability of the equipment.

### Performance of Equipment
If the equipment is running at a speed lower than its capacity, this causes a loss of production. Equipment that is running at half its normal speed is equivalent to 50 percent downtime. Therefore, the performance of equipment is defined with reference to production. It is the ratio of the amount of the manufactured products (for a given production uptime) to the amount of products that could have been manufactured.

\[
\text{Performance} \% = \frac{\text{Number of units produced}}{\text{Possible number of units}} \times 100 \quad (7)
\]

### Quality Yield of Equipment
Generally, quality is conformance to requirements or the degree to which a produced unit, function, or process satisfies the needs of users (Omdahl 1988). It is the
intention of equipment owner to constantly produce accurate products that users need. Rejection or failure of the product often causes unavailability of the equipment. For example, when equipment produces substandard products, more testing has to be done to fix the problem. This implies that the availability of the equipment is also affected. Additionally, any equipment with usability of less than 100 percent is rarely accepted. Therefore, Borris (2006) and McCarthy (2001) define the quality yield of the product as the ratio of the amount of acceptable products made to the total amount of products made (including any unacceptable products).

\[
\text{Quality yield(\%)} = \frac{\text{Number of units produced} - \text{Number of defective units}}{\text{Number of units produced}} \times 100 \quad (8)
\]

Finally, the OEE becomes

\[
\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality Yield} \quad (9)
\]

From the data in Table 1, it can be clearly seen that even if the equipment has no downtime (100% availability), the OEE can still be unacceptably low because of the losses of performance and quality yield. With no downtime and both performance and quality reduced to 50 percent, the resultant OEE falls to a value as low as 25 percent. This illustrates how the parameters are correlated and a loss in any of the three parameters can drastically affect the OEE, which is the aim of OEE measure.

<table>
<thead>
<tr>
<th>Table 1. Effects of Parameters of OEE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability</td>
</tr>
<tr>
<td>--------------</td>
</tr>
<tr>
<td>100%</td>
</tr>
<tr>
<td>100%</td>
</tr>
<tr>
<td>100%</td>
</tr>
<tr>
<td>75%</td>
</tr>
<tr>
<td>50%</td>
</tr>
</tbody>
</table>

**Overall Efficiency of Rolling Stock**

OEE as a measure of calculating efficiency is a simple, effective, and flexible formula. It measures the efficiency of the equipment during its planned operation time; planned downtime does not affect OEE. This motivates an investigation into the use of the OEE measure for calculating the overall efficiency of URTS to ensure that a URTS is available, has full operational capability for the maximum time of operation, and is being used properly. This approach can be applied to any individual transit line or extended to a complete URTS. Since it is not possible to discuss the overall efficiency of a complete URTS, our study is restricted to the rolling stock
(RS) that is a vital subunit of a URTS. Hence, OEE parameters are considered for the rolling stock of a URTS.

**Availability of Rolling Stock**

The availability of RS corresponds to the number of TUs that are available for service each day. When a transit unit remains in the maintenance workshop/depot for extra (i.e., other than standard) inspections and checkups and can therefore not be put into service, this is regarded as an availability problem. The maintenance department plans how many hours each transit unit has to spend for checkups and other maintenance per unit time. It implies that TUs should be available for operation in periods other than that reserved for standard maintenance work and checkups. In case of extra inspections and maintenance, the total time available for operation will be less than usual. Hence, availability of the RS can be defined as the ratio of the amount of time that the TUs are capable of producing quality services to the total time they could be running.

\[
\text{Availability(\%)} = \frac{\text{Total time available for operation}}{\text{Schedule time}} \cdot 100
\]  

When a TU is out of service due to unforeseen and unavoidable reasons, it causes unplanned downtime. The total time available for operation is the difference between scheduled time and unplanned downtime. It can be calculated by multiplying the total number of TUs available for service (and ready to be put in service at any time) within a transit agency and the number of service hours per day. Scheduled time is the difference between total time and planned downtime. Normally, it depends on the number of years a TU has been in use, the care and maintenance history of a TU, the complexity and variety of the components used in the unit, and the time required for the individual planned activity. A way of deciding to go ahead with a planned downtime activity is described by Levitt (1997). The maximum preventive maintenance time required to carry out a given percentage of all scheduled preventive maintenance actions is given in Dhillon (2002).

**Performance of Rolling Stock**

Performance of the rolling stock is defined with respect to its output. One of the key RS outputs is the number of kilometers traveled per unit time. More kilometers per unit time offers more spaces per unit time; thus, ridership can be increased and more revenue is generated. A fault in a component of the TU can reduce its speed and cause it to run at a speed lower than its capability. If fewer kilometers per unit time than planned are caused by slower TUs, this is a performance loss. In other
words, a transit unit running at half speed is the same as having 50 percent downtime for a particular period of time. However, in case of performance losses, passengers remain in the system, and the financial result would not be worst. Keeping in view the above facts, we can define the performance of the rolling stock as the ratio of actual kilometers (after considering the time loss) and standard kilometers (when there is no time loss due to any failure).

\[
\text{Performance(\%)} = \frac{\text{Actual kilometers}}{\text{Standard kilometers}} \cdot 100
\]  

(11)

Where, actual kilometers = standard kilometers – kilometers lost; standard kilometers = \(N_{TU} \cdot N \cdot \text{average distance per trip}\); \(N\) = total number of (round) trips (per unit time) completed by the individual TU. The number of TUs, \(N_{TU}\), can be calculated as discussed in Section 2.

Any loss of kilometers (during operation) can occur due to a variety of problems in the RS components. These problems may not appear during the scheduled maintenance in the workshop. This implies that the performance of the RS is the function of the operating time when the RS is performing its intended function. In other words, the performance of the RS cannot be judged unless we put it into service. Operational data of transit units can be analyzed to determine the kilometers lost. One way of calculating these kilometer losses is to calculate the loss of cycle time. In this way, the percentage loss of cycle time represents the percentage loss of kilometers for the respective trip.

**Quality Yield of Rolling Stock**

Based on different user, owner, and stakeholder expectations, the quality of the rolling stock can be defined in many ways. In reference to the quality yield described previously, a complete failure of one of the TUs during operation is regarded as a quality issue. In case of a complete TU failure, passengers are forced to leave the TU. Additionally, a complete TU failure (during operation) has the potential to prevent other TUs from moving into the network. This kind of service usability is rarely accepted by passengers and can lead to rejection of the service. Here, financial results may be worse because it is more likely that passengers will leave the system. In this respect, the quality of the RS can be defined as the ratio of the transit units actually working during operation time without failure to the total of maintained units put into service.

\[
\text{Quality (\%)} = \frac{\text{Number of T. U worked}}{\text{Total T. U in service}} \cdot 100
\]  

(12)
Where, number of cars worked = total of cars put in service – cars failed during service.

It is important to note that losses of kilometers are not taken into account here, as they are relevant to performance issues.

**Overall Efficiency of Rolling Stock of Urban Rail Transit System in Munich**

The RS of the URTS in Munich has three types. The A-type was introduced in 1972 and has 360 cars (one TU contains six cars), which constitutes 62 percent of the total RS. The B-type was introduced in 1981 and has 114 cars, which is 19.5 percent of the total RS. The C-type was introduced in 2002 and has 108 cars, which is 18.5 percent of the total RS. As a result, the total number of cars that the Munich public transport authority (MVG) has available is 582. However, the maximum number of cars required during peak hour periods does not exceed 470.

To show the application of the OEE measure, we considered the data for only one hour (4 PM to 5 PM) of every Monday in the year 2008. The reason for choosing this particular interval is that there is maximum utilization of the RS during this hour. Additionally, one hour of data is easy to handle to calculate the distance traveled by TUs during operation time, cycle time, headway time for all TUs, and number of TUs for different headways, distance per trip, total trips, and failed TUs for the specified period. Taking the previous definitions as a basis, the three parameters of OEE for the RS are calculated in the following way:

$$\text{Availability} = \left( 0.62 \cdot \sum_{a=1}^{360} \frac{\text{Tsch}(a) - \text{Tup}(a)}{\text{Tt}(a) - \text{Tpl}(a)} \right) + 0.195 \cdot \sum_{b=1}^{114} \frac{\text{Tsch}(b) - \text{Tup}(b)}{\text{Tt}(b) - \text{Tpl}(b)} + 0.185 \cdot \sum_{c=1}^{108} \frac{\text{Tsch}(c) - \text{Tup}(c)}{\text{Tt}(c) - \text{Tpl}(c)} \right) \cdot 100$$

Where, the lower-case letters a, b, and c represent the three types of rolling stock A, B and C; the weightings 0.62, 0.195 and 0.185 are the percentages of each type of rolling stock in the whole fleet; Tsch = scheduled time for operation; Tt = total time for operation; Tpl = planned downtime. After inserting the values into the equation, we get availability:
To obtain the performance of the URTS, it is necessary to calculate the number of TUs in operation, the total trips covered by all TUs, and the average distance covered per trip. Since the URTS in Munich has six underground lines, \((U_1, \ldots, U_6)\) \(T, N_{T,U},\) and \(h\) were calculated for each line according to the formulas given earlier. Finally,

\[
\text{Total trips by all TUs} = \sum_{U} \left( \frac{T}{h} \cdot N \right) = 66.07 \quad , \quad U = 1, 2, \ldots, 6
\]

The geographical map of the transit network is used as the basis to calculate the distance traveled by each TU for an individual line. The average distance per trip (for all TU of the six lines) is, thus, the standard kilometers that the RS could run. Depending on the number of the different types of TUs introduced into service, the A, B and C types could run 1442.19, , and km, respectively. The actual number of kilometers traveled by all TUs (A-type=, B-type=, C-type=) in the specified peak hour are less due to the lower speed of some TUs during operation. Losses of kilometers due to losses in cycle time were calculated from the operational data. By inserting values of standard kilometers and actual kilometers for the individual type of rolling stock, we get the performance of the RS:

\[
\text{Performance} = \left[ \left(0.62 \cdot \frac{1419}{1442.19}\right) + \left(0.195 \cdot \frac{417}{438.47}\right) + \left(0.185 \cdot \frac{408}{409.26}\right) \right] \cdot 100 = 97.99\%
\]

As mentioned earlier, the total number of cars put in service during the one selected peak hour is 470. Some of the cars suffer complete breakdowns during operation. Consequently, these TUs were withdrawn from or not admitted to service. According to the definition the quality yield becomes

\[
\text{Quality yield} = \left[ \sum_{n=1}^{470} \left( \frac{n w}{n} \right) \cdot 100 = \left[ \sum_{n a=1}^{296} \left( \frac{n w a}{n a} \right) + \sum_{n b=1}^{90} \left( \frac{n w b}{n b} \right) + \sum_{n c=1}^{84} \left( \frac{n w c}{n c} \right) \right] \cdot 100 \right]
\]

Where, \(n = \) the total number of cars put into service and \(n w = \) the number of cars actually operated during operation time. There are three compositions; therefore, \(n = n a + n b + n c\) and \(n w = n w a + n w b + n w c\). After inserting the values, we get

\[
\text{Quality yield} = \left[ \left(0.63 \cdot \frac{295}{296}\right) + \left(0.1914 \cdot \frac{89}{90}\right) + \left(0.1787 \cdot \frac{84}{84}\right) \right] \cdot 100 = 99.57\%
\]
Finally, the OEE of the RS as a product of availability, performance and quality yield is

\[ OEE = (0.8958 \cdot 0.9799 \cdot 0.9957 \cdot 100) = 87.40\% \]

**Discussion and Future Work**

The OEE measure can be used to calculate the overall efficiency of the RS and gives useful information. It measures the efficiency of the equipment during its planned operation time, while the planned downtime does not affect the OEE, no matter how long it is. Different inputs/outputs of the parameters have lead to different methods for their calculation; the flexibility of the OEE measure allows this. After the OEE measure has been obtained, any type of RS with low scores in parameters can be carefully studied to develop plans of action aiming to improve the OEE. In the case study above, availability of the RS is the main factor responsible for the lower OEE.

It is difficult to defend this percentage of OEE. There can be a number of values of the three OEE parameters that can all lead to the final result of 87.40 percent. The studies carried out worldwide by researchers indicate that the average OEE rate for any production plant is 60 percent, and an OEE percentage that is equal to or greater than 85 is considered a World Class OEE (Vorne 2002).

Nevertheless, these results are not applicable for the OEE of the RS. It is the task of URTS management to decide upon the OEE level of the rolling stock. The worth of gain in a single percentage of availability, performance, and quality yield should be linked with their objectives and requirements. For example, one agency gives priority to availability at the cost of an acceptable reduction in performance, whereas a second agency does not compromise on performance. The success and failure criteria for the OEE and its parameters for a particular rolling stock of a URTS vary from system to system and represent the priorities and limits of that system.

The OEE cannot be used to rank two RS that differ in availability, performance, and quality yield but have the same OEE percentages. In this case, it would be highly subjective to differentiate the overall efficiency of two rolling stocks with different characteristics. One way to deal with this problem is to define standards for the OEE and its parameters for different URTS and their subunits. These standards will work as a reference for the comparison of different URTS with similar characteristics.

There may be discussion about the percentage point improvement in availability, performance, or quality yield and whether it is worth improving the OEE. What
is the acceptable percentage of availability, performance, and quality yield for a specific URTS? Similarly, what percentage of OEE is better for which type of rolling stock, and what type of rolling stock is technically suitable for future service? Such questions are part of modeling decision problems regarding the OEE and its parameters for a particular URTS and could be part of future work. The OEE measure is a simple and effective formula that can be used to easily handle the decision problems described. The flexibility of the OEE approach makes it applicable to other forms of public transport, provided that the inputs and outputs of the parameters of OEE exist. It is important that inputs and outputs of the three parameters of the OEE are defined clearly. If the definitions of the parameters are interrelated, then they could be measuring the same things more than once, which could lead to incorrect conclusions.

Conclusions
The overall efficiency of the rolling stock (RS) of urban rail transit system (URTS) was defined. Various types of inputs and outputs of the RS were considered for three parameters of the overall efficiency, and a method for their calculation was presented and illustrated by providing a real-world application. The simplicity, flexibility, and efficiency of the measure of overall efficiency make it applicable and useful for any kind of RS or other subunits of URTS where decision problems need to be solved.

Acknowledgments
The authors would like to thank Prof. Jochen Trinckauf of TU Dresden for his input to the research described in the paper. Financial support of the Higher Education Commission (HEC) Pakistan and the public transport company of Munich (MVG) is acknowledged.

References


**About the Authors**

**M.Sc. Qamar Mahboob** (qamarmahboob.pk@gmail.com) earned a B.Sc. in Mechanical Engineering from UET Lahore, and M.Sc. in Total Quality Management from PU Lahore, and an M.Sc. in Transportation Systems from Technische Universität München (TUM). He has been with Pakistan Railways as a Maintenance and Planning Engineer since 2000. Presently, he is on study leave to work towards his Ph.D. in safety, risk and reliability in railway systems from the Technische Universität Dresden, Germany.

**Dipl.-Geogr. Thomas Stoiber** (thomas.stoiber@gmx.net) studied geography at the University of Augsburg and worked as a researcher at Technische Universität
München in the Department of Urban Structures and Transport Planning between 2007 and 2010. His primary activities were in the fields of accessibility planning and integrated spatial and transport development in public transport corridors. Since September 2010, he has worked for Ernst Basler + Partner AG, a planning consultancy in Zurich, Switzerland.

Dipl.-Ing. **Stephanie Gottstein** (gottstein.stephanie@swm.de) studied electrical engineering at the Technische Universität München (TUM). She has been KVP-Manager (continuous advancement process manager) since 2006 at Stadtwerke München GmbH (SWM), Department of Transport Services. She is responsible for rolling stock advancement and project management for rebuilding and deals with the problem of obsolescence in electronical spareparts.

Dr.-Ing. **Antonios Tsakarestos** (tsakarestos@vt.bv.tum.de) studied civil engineering at the Technische Universität München (TUM). Since 2002, he has been a scientific assistant for the chair of Traffic Engineering and Control at TUM, where he is in charge of the research group for public transport systems. In 2010, he completed his Ph.D. on the methodology of public transport planning for rural areas.
Assessment of Models to Estimate Bus-Stop Level Transit Ridership using Spatial Modeling Methods

Srinivas S. Pulugurtha, Ph.D., P.E., and Mahesh Agurla, M.S.
The University of North Carolina at Charlotte

Abstract

The objective of this research is to develop and assess bus transit ridership models at a bus-stop level using two spatial modeling methods: spatial proximity method (SPM) and spatial weight method (SWM). Data for the Charlotte (North Carolina) area are used to illustrate 1) the working of the methods and 2) development and assessment of the models. Features available in Geographic Information System (GIS) software were explored to capture spatial attributes such as demographic, socio-economic, and land use characteristics around each selected bus stop. These, along with on-network characteristics surrounding the bus stop, were used as explanatory variables. Models were then developed, using the generalized estimating equations (GEE) framework, to estimate riders boarding (dependent variable) at the bus stop as a function of selected explanatory variables that are not correlated to each other. Results obtained indicate that Negative Binomial with log-link distribution better fits the data to estimate ridership at the bus-stop level (for both SPM and SWM) than when compared to linear, Poisson with log-link and Gamma with log-link distributions. Although SPM models demonstrated distance decay behavior, statistical parameters indicate that SWM (based on functions 1/D, 1/D², and 1/D³) does not yield better or more meaningful estimates than when compared to SPM using 0.25-mile buffer width data.
Introduction

Transit systems support a broad range of goals that include air quality improvement, energy conservation, congestion reduction, provision of mobility to the disadvantaged, access to employment or attraction centers, the promotion of economic development, sustainability, and enhanced livability. Understanding the factors that influence transit ridership is very important to achieve these goals and increase transit market potential. The Bureau of Transportation Statistics (2010) reports that 6,922,000 people (~5% of the nation’s overall trips) used public transportation as their principal means of transportation to work each day during 2009.

Transit system managers and planners often rely on statistical models that are cost effective, developed in a reasonable amount of time using available data inventories, and provide a good understanding of the relationship between the dependent variable and explanatory variables. This research aims to develop statistical models to estimate riders boarding at a bus stop using spatial data and on-network characteristics around/near the bus stop. The data required to develop these models are typically available with most state Departments of Transportation and local agencies as well as in many open source data inventories.

The use of bus transit depends on accessibility to a bus stop. Accessibility could be defined in terms of walking time (say, 5, 10, 15, or 20 minutes from an origin to a bus stop) or walking distance (say, 0.25, 0.5, 0.75, or 1 mile from an origin to a bus stop). To better comprehend the substantial effect and area of influence of spatial attributes (includes explanatory variables such as demographic, socio-economic, land use, and on-network characteristics) on ridership (dependent variable), a spatial analysis needs to be conducted at several different buffer widths (say, 0.25, 0.5, 0.75, and 1 mile) to identify the ideal spatial proximity distance to extract data for modeling. The maximum buffer width for consideration depends on the acceptable maximum walking distance to access a bus stop (generally, 1 mile).

In general, the number of riders who use bus transit system decreases as the distance from the bus stop increases. Integrating data pertaining to demographic, socio-economic, and land use characteristics from different buffer bandwidths (say, 0–0.25, 0.25–0.5, 0.5–0.75, and 0.75–1 mile) based on this distance decay effect, and using it to develop ridership models may yield better and accurate estimates.

The objective of this research is 1) to identify explanatory variables and distribution functions and 2) to develop and assess ridership models at a bus-stop using two spatial modeling methods: spatial proximity method (SPM) and spatial weight
method (SWM). In this research, the number of riders boarding a bus transit system at a bus stop is considered as bus-stop ridership. Data for Charlotte (North Carolina) are used to illustrate 1) the working of the methods and 2) development and assessment of the models.

**Literature Review**

As congestion in urban areas continues to worsen and highway solutions become less effective, many local governments and communities are turning their attention to public transit. With the increasing pressure on transportation agencies to find ways to alleviate congestion and compete for limited federal funds to build premium transit systems that offer higher levels of service and a greater impact on ridership, there is an urgency to improve transit ridership analysis tools and models (Zhao et al. 2005).

Dajani and Sullivan (1976) conducted a study to develop a causal model for estimating public transit ridership using 1970 census data. Median income, percent central city workers, density, level of transit service, percent of African-American population, percent above age 65, and auto ownership were observed to be critical variables to estimate transit ridership. Nickesen et al. (1983) researched to develop a simple transit ridership estimation model for short-range transit planning. To ensure that the model can be applied easily and to produce accurate patronage estimates, the authors chose five component models (trip generation, trip distribution, modal split, linear programming, and pivot point analysis) and applied them in a sequence.

Peng and Dueker (1995) studied relationships between inter-routes and the extent to which routes were independent, complementary, or competitive using spatial data integration of Portland (Oregon) data. The analyzed relationships were then used for route-level ridership modeling and to predict the ridership impacts of service changes, not only on the routes with service change but also on other related routes.

Kikuchi and Miljkovic (2001) developed transit ridership estimation models at a bus stop considering attributes pertaining to the bus stop (such as accessibility to the bus stop, demographic condition around the bus stop, conditions of the bus stop, and the transit service quality provided at the bus stop). T-BEST, a transit ridership estimation model, was developed by the Florida Department of Transportation (FDOT 2004; FDOT 2005) to estimate ridership by route, direction, and
time-of-day based on frequency, bus stop buffer characteristics, accessibility characteristics, and the effects of alternative routes and network design configurations. Chu (2004) generated a transit ridership model at the bus stop for an average weekday boarding. Transit level-of-service (TLOS) based on transit availability and mobility and demographic characteristics, pedestrian environment, interactions with other modes, and competition from other bus stops were considered and found to play a significant role in predicting the ridership. Kimpel et al. (2007) examined the effects of overlapping walking service areas of bus stops on the demand for bus transit during the morning peak hour. Accessibility for each parcel to each bus stop was measured compared to other accessible bus stops in a GIS environment.

Sketch-level ridership forecast models for light or commuter rail (Lane et al. 2006) and heavy rail (Lane et al. 2009) for smaller- and medium-size cities were also developed in the past. The model developed was inexpensive compared to the traditional four-step modeling approach, since the data required to develop these models are readily available or can be easily obtained from Metropolitan Planning Organizations (MPOs) and/or the U.S. Census Bureau.

Transit ridership models were developed using a geographically weighted regression (GWR) method exploring the spatial variability in the strength of the relationship between transit use and explanatory variables that included demographics, socio-economic, land use, transit supply and quality, and pedestrian environment characteristics (Chow et al. 2006; Chow et al. 2010). The coefficients in a GWR model are local and vary from one location to another location (unlike in ordinary least square regression models where coefficients interpret a global relationship between a dependent variable and explanatory variables). A comparison between the sub-regional GWR model (Chow et al. 2010) and the original regional GWR model (Chow et al. 2006) showed that the sub-regional GWR model performed better than the original regional GWR model in terms of model accuracy.

Cervero et al. (2010) recently developed a Direct Ridership Model (DRM) for Bus Rapid Transit (BRT) patronage in Southern California. The DRM was developed as a function of three key sets of variables related to bus stops or stations and their surroundings. The authors developed two linear regression models—ordinary least square (OLS) and hierarchical linear model (HLM). OLS was found to better fit the data than HLM. Results obtained from the study showed a strong influence of service frequency on BRT patronage in Los Angeles County.
Stover and Bae (2011) studied the impact of gasoline prices on transit ridership in Washington State by measuring the price elasticity of demand with respect to gasoline price. The results obtained indicate that transit ridership increased as gasoline prices increased during the study period.

Tang and Thakuriah (2011) examined if psychological effects of real-time transit information on commuters will lead to transit ridership gain. Findings from the study showed that the provision of real-time transit information might serve as an intervention to break current transit non-user travel habits and indeed increase the mode share of transit use. The study even suggested that real-time transit information would be more useful if it is combined with facilitating programs that enhance commuter opportunities to be exposed to such systems first.

**Limitations of Past Research**

A review of past literature gives an understanding of the research methodologies that were adopted to estimate bus transit ridership at different levels (stop, route, city, and county). However, not much was documented based on spatial modeling, in particular, buffer or proximity analysis and spatially varying relationships. The effect of all the three characteristics (demographic and socio-economic, land use, and on-network) on bus transit ridership and the effect of correlation that could exist between these variables were not investigated widely in the past. Further, most of the transit ridership models developed in the past considered a linear relationship between ridership and explanatory variables. While OLS, HLM or GWR-based OLS seem to be promising, non-linear or count models (such as generalized linear models) may be more appropriate for modeling in this case, as bus transit ridership are counts. This research attempts to address these above-mentioned limitations of past research (bus-stop non-linear ridership models exploring spatially varying relationships).

**Methodology**

A GIS-based methodology was adopted to extract spatial data and develop bus-stop ridership models using SPM and SWM. The methodology comprises the following steps:

1. Identification of data elements for model development.
2. Spatial analysis, data processing and spatial modeling methods.
3. Statistical analysis and model development.
Identification of Data Elements for Model Development

Typical spatial data used to develop ridership models include demographic, socio-economic, land use, and on-network characteristics. Ridership depends on demographic information such as population (by gender, ethnicity, and age), household size, and socio-economic characteristics such as income, employment, and auto ownership within walkable distance from a bus stop. Such data are available at the census block level. Similarly, land use characteristics such as residential, industrial, commercial, and institutional areas within walkable distance from a bus stop also have significant bearing on transit ridership. The proportion of increase or decrease in ridership could vary geographically (downtown/uptown versus urban versus suburban areas) for the same type of land use by the time of the day.

Transit routes generally are provided along major (high speed, high traffic volume) roads. Characteristics such as presence of a median, speed limit, one-way or two-way street, number of lanes, and road classification may have an effect on transit ridership. These characteristics could be identified using aerial photographs or conducting field visits or are available in regional transportation databases.

Table 1 summarizes demographic and socio-economic characteristics at the census block level, land use characteristics, and on-network characteristics that were used considered for analysis and model development in this research.

<table>
<thead>
<tr>
<th>Demographic and Socio-Economic</th>
<th>Land Use (in thousand sf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population (by gender, ethnicity and age)</td>
<td>0.25 acre residential/apartments</td>
</tr>
<tr>
<td>Households, mean household income</td>
<td>0.25 – 0.5 acre residential</td>
</tr>
<tr>
<td>Auto-ownership (0, 1, ... vehicle/household)</td>
<td>0.5 – 2 acre residential</td>
</tr>
<tr>
<td>Total employment</td>
<td>&gt; 2 acre residential</td>
</tr>
<tr>
<td><strong>On-Network</strong></td>
<td>Institutional</td>
</tr>
<tr>
<td>Speed limit (mph)/functional class</td>
<td>Light commercial</td>
</tr>
<tr>
<td>Presence of median</td>
<td>Heavy commercial</td>
</tr>
<tr>
<td>One-way or two-way street</td>
<td>Light industrial</td>
</tr>
<tr>
<td># lanes</td>
<td>Heavy industrial</td>
</tr>
</tbody>
</table>

Spatial Analysis, Data Processing and Spatial Modeling Methods

Buffers (0.25, 0.5, 0.75, and 1 mile) were generated around each selected bus stop in the study area. Layers pertaining to census data and land use data were then overlaid on the generated buffers. The data were intersected using the “intersect” feature and then processed in a GIS environment. A database with demographic,
socio-economic, and land use information in the vicinity of each bus stop, for each buffer width, was then generated. The spatial overlay and data processing approach is similar to the one used by Pulugurtha and Repaka (2009, 2011) to develop pedestrian activity models for signalized intersections. On-network characteristics from aerial photographs, field visits, and the regional transportation network database were then added to these databases for each buffer width.

In this research, the working of two spatial modeling methods (SPM and SWM) to estimate ridership at the bus stop was evaluated.

**Spatial Proximity Method (SPM)**

The first method, SPM, was used to evaluate the best proximity distance that has a strong influence on estimating ridership at a bus stop. Databases, as stated previously, were generated to develop models to estimate bus-stop transit ridership for each buffer width (0.25, 0.5, 0.75, and 1 mile) discretely in this case. The model with buffer width data that has better goodness of fit statistics was selected as the best model. This buffer width was considered as the best ridership influence area (proximity distance) to estimate ridership for a bus stop.

**Spatial Weight Method (SWM)**

The second method, SWM, is a spatial modeling method that accounts for spatially-varying relationships. A weight pattern/procedure based on three spatially-decreasing functions ($1/D$, $1/D^2$, and $1/D^3$) were considered to evaluate and identify the function or weight combination that better estimates ridership at a bus stop. The data sets for 0.25-, 0.5-, 0.75-, and 1-mile buffer widths were used to create data for buffer bandwidths (0–0.25, 0.25–0.5, 0.5–0.75, and 0.75–1 mile). These bandwidths were given weights such that the total summation of weight is equal to 1. The calculation of weights for functions $1/D$, $1/D^2$, and $1/D^3$ are mathematically shown in Equations 1 to 3.

\[
\text{Bandwidth Weight} \left( \frac{1}{D} \right) = \frac{1/D}{\sum 1/D} \quad \ldots \ldots \text{Equation 1}
\]

\[
\text{Bandwidth Weight} \left( \frac{1}{D^2} \right) = \frac{1/D^2}{\sum 1/D^2} \quad \ldots \ldots \text{Equation 2}
\]

\[
\text{Bandwidth Weight} \left( \frac{1}{D^3} \right) = \frac{1/D^3}{\sum 1/D^3} \quad \ldots \ldots \text{Equation 3}
\]

where, $D$ is the buffer width (0.25, 0.5, 0.75, or 1-mile).

Table 2 summarizes bandwidth weights for the three different functions considered in this research.
Table 2. Bandwidth Weights for Different Functions

<table>
<thead>
<tr>
<th>Bandwidth</th>
<th>Function</th>
<th>1/D</th>
<th>1/D²</th>
<th>1/D³</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 0.25</td>
<td></td>
<td>48</td>
<td>70</td>
<td>85</td>
</tr>
<tr>
<td>0.25 – 0.50</td>
<td></td>
<td>24</td>
<td>18</td>
<td>11</td>
</tr>
<tr>
<td>0.50 – 0.75</td>
<td></td>
<td>16</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>0.75 – 1.00</td>
<td></td>
<td>12</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

Spatial data (excluding on-network characteristics) were integrated using these weights to develop databases for different functions. Equation 4 illustrates the integration of spatial data using different weights for a given function.

\[ V = (V_{0-0.25} \times W_{0-0.25}) + (V_{0.25-0.5} \times W_{0.25-0.5}) + (V_{0.5-0.75} \times W_{0.5-0.75}) + (V_{0.75-1} \times W_{0.75-1}) \]  

where, \( V \) is integrated spatial data for a variable; \( V_{0-0.25}, V_{0.25-0.5}, V_{0.5-0.75}, \) and \( V_{0.75-1} \) represent spatial data for the same variable, and \( W_{0-0.25}, W_{0.25-0.5}, W_{0.5-0.75}, \) and \( W_{0.75-1} \) represent spatial weights for buffer bandwidths 0-0.25, 0.25-0.5, 0.5-0.75 and 0.75-1, respectively.

Databases for three different weight functions were developed to determine the best-fit SWM. The weight function with best goodness of fit statistics was considered as the spatial varying pattern to better estimate ridership.

**Statistical Analysis and Model Development**

Multicollinearity occurs when two or more explanatory variables in the model are correlated and provide redundant information about the response variable. High multicollinearity leads to increased standard error of estimates of the coefficients and mislead results. To minimize the effect of multicollinearity, a Pearson correlation matrix was generated using SPSS© software (SPSS 2008) to identify the correlation between the explanatory variables.

In general, variables with a Pearson correlation coefficient greater than 0.3 or less than -0.3 are considered correlated to each other. The generated Pearson correlation matrix was examined to omit one of the two variables that are correlated to each other.

Generalized Estimating Equations (GEE), an extension of the generalized linear models (GLM), was then used to develop bus-stop ridership models in SPSS©. In this research, four GEE (linear, Poisson with log-link, Gamma with log-link, and
Negative Binomial with log-link) models were developed to evaluate the best distribution to estimate ridership at the bus stop. While linear distribution helps examine the presence of a strong linear relation between dependent and independent variables, the log-link (Gamma, Poisson, and Negative Binomial) distributions help examine the presence of a strong non-linear relation between dependent and independent variables.

In each case, a preliminary model was developed using an initial set of explanatory variables that are not correlated to other variables. Significance value was used to examine the strength of each variable. Those with significance value greater than 0.05 (at 95% confidence level) were eliminated one after another. The models were re-run in SPSS© environment until all the variables in the model had a significance value ≤ 0.05. The model when all variables had significance value ≤ 0.05 was considered as the final model for the scenario and was used for assessment.

Quasi-likelihood criterion (QIC) and corrected quasi-likelihood under the independence model criterion (QICC) were used as statistics to assess the goodness of fit. In general, QIC and QICC should be low for a best fit model. The difference between QIC and QICC has to be reasonably low as well.

**Results**

Data for Charlotte (North Carolina) were gathered and used to illustrate the working of methods and development and assessment of models. The bus transit system in the region is operated and maintained by Charlotte Area Transit System (CATS). It serves over 70 routes (with 3,600+ bus stops), of which 56 are local routes and 19 are express routes. The average daily ridership during 2010 was more than 66,000 passengers.

Census estimates with demographic and socio-economic characteristics were obtained from the U.S. Census Bureau website. Land-use data and on-network characteristics were obtained from the City of Charlotte Department of Transportation (CDOT). Bus-stop ridership (boarding only) data were obtained from CATS. All data considered in this research are for 2008.

The bus-stop level ridership data from CATS showed that the number of passengers boarding bus transit system was collected for at least one day at over 2,900 bus-stops during 2008. These data were processed to compute average daily ridership for each of these bus stops.
Of the bus stops for which ridership data were available, 2,857 bus stops were selected to develop ridership models. The average daily ridership for the selected bus stops is ~23. Of the 2,857 selected bus stops, 488 bus stops were observed to have ridership number greater than the average value.

As explained previously, explanatory variables that are not correlated to other variables were selected to minimize redundant explanatory variables and standard errors in the models. This was done separately for databases of each individual buffer width (0.25, 0.5, 0.75, and 1 mile) as well as the integrated databases for different weight functions.

**Selection of Distribution Function that Better Fits the Data**

Models based on different probability distributions were developed, as it is critical to understand the probability distribution that better fits the ridership data. Four GEE models based on different probability distributions (linear, Poisson with log-link, Gamma with log-link, and Negative Binomial with log-link) were developed using data for each buffer width (0.25, 0.5, 0.75, and 1 mile). Overall, 16 models were developed based on SPM to evaluate and select the best proximity distance to capture spatial data.

As an example, Table 3 summarizes results obtained for models based on the four probability distributions using 0.25-mile buffer width data. The information presented in the table can be used to estimate ridership at a bus stop. While substituting data (selected land-use areas, the number of households with no vehicles, mean household income, and speed limit along the corridor) gives a ridership estimate directly in the case of a model based on linear probability distribution, it gives a natural logarithm of ridership in the case of the other three log-link probability distributions. QIC and QICC were compared to identify the distribution that best fits the data for each buffer width. Results obtained show that Negative Binomial with log-link with lowest QIC and QICC (difference between QIC and QICC reasonably low) best fits the data for each selected buffer width.

**Selection of Ideal Proximity Distance to Extract Spatial Data**

Table 4 summarizes parameters of four (Negative Binomial with log-link) models developed using data for different buffer widths (0.25, 0.5, 0.75, and 1 mile). The model developed using the 0.25 buffer width data has the lowest QIC and QICC (difference between QIC and QICC reasonably low) when compared to models developed using data for other buffer widths (0.5, 0.75, and 1 mile). For the data used in this research, this is the best SPM, and 0.25-mile is the best proximity distance that estimates the average daily ridership at the bus-stop.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Linear</th>
<th>Poisson with log-link</th>
<th>Gamma with log-link</th>
<th>Negative Binomial with log-link</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>P Value</td>
<td>Coefficient</td>
<td>P Value</td>
</tr>
<tr>
<td>Intercept</td>
<td>-1.044</td>
<td>.786</td>
<td>1.134</td>
<td>.001</td>
</tr>
<tr>
<td>&lt;0.25 acre residential / apartments</td>
<td>-0.009980</td>
<td>&lt; .001</td>
<td>-0.000262</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>0.25-0.5 acre residential</td>
<td>-0.003185</td>
<td>&lt; .001</td>
<td>-0.000240</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>2 acre residential</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy commercial</td>
<td>0.042656</td>
<td>&lt; .001</td>
<td>0.000527</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Households with no vehicles</td>
<td>0.339156</td>
<td>&lt; .001</td>
<td>0.008756</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Institutional</td>
<td></td>
<td></td>
<td>0.000381</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Light commercial</td>
<td></td>
<td></td>
<td>0.000278</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Light industrial</td>
<td>-0.003799</td>
<td>.003</td>
<td>-0.000242</td>
<td>.008</td>
</tr>
<tr>
<td>Mean household income</td>
<td>0.000083</td>
<td>.003</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed limit</td>
<td>0.034167</td>
<td>&lt; .001</td>
<td>0.027438</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>QIC</td>
<td>17,419,884</td>
<td></td>
<td>107,885</td>
<td></td>
</tr>
<tr>
<td>QICC</td>
<td>17,128,996</td>
<td></td>
<td>105,754</td>
<td></td>
</tr>
</tbody>
</table>
Table 4. Selection of Best Proximity or Buffer Width to Capture Spatial Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>0.25-mile</th>
<th>0.5-mile</th>
<th>0.75-mile</th>
<th>1-mile</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>P Value</td>
<td>Coefficient</td>
<td>P Value</td>
</tr>
<tr>
<td>Intercept</td>
<td>1.570</td>
<td>&lt;.001</td>
<td>3.467</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>&lt;0.25 acre residential/apartments</td>
<td>-0.00012</td>
<td>.007</td>
<td>-0.00012</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>&gt;2 acre residential</td>
<td></td>
<td></td>
<td>-0.00009</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>0.25-0.5 acre residential</td>
<td>-0.00023</td>
<td>&lt;.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 acre residential</td>
<td>-0.00014</td>
<td>.012</td>
<td>-0.00011</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Asian population</td>
<td>0.00123</td>
<td>.003</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy commercial</td>
<td>0.00057</td>
<td>&lt;.001</td>
<td>0.00007</td>
<td>.004</td>
</tr>
<tr>
<td>Heavy industrial</td>
<td></td>
<td></td>
<td>-0.000002</td>
<td>.013</td>
</tr>
<tr>
<td>Households with no vehicles</td>
<td>0.01057</td>
<td>&lt;.001</td>
<td>0.00269</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Institutional</td>
<td>0.00040</td>
<td>&lt;.001</td>
<td>-0.00016</td>
<td>.001</td>
</tr>
<tr>
<td>Light commercial</td>
<td>0.00028</td>
<td>&lt;.001</td>
<td>-0.00010</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Light industrial</td>
<td>-0.00028</td>
<td>&lt;.001</td>
<td>-0.00010</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Mean household income</td>
<td>-0.000003</td>
<td>&lt;.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>One-way street</td>
<td>1.17644</td>
<td>&lt;.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Presence of median</td>
<td>0.30551</td>
<td>.003</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed limit</td>
<td>0.02801</td>
<td>&lt;.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>QIC</td>
<td>4,471</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>QICC</td>
<td>4,431</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The strength of explanatory variables, in general, decreased while goodness-of-fit statistics increased as the distance from the bus stop increased. In other words, results from SPM for different buffer widths tend to show distance decay behavior. This probably indicates that better and more accurate estimates may be obtained by developing models using data integrated from different buffer widths.

**Selection of Best Function to Integrate Data and Develop Model Using SW**

Data from different buffer widths were integrated using different weight functions. Pearson correlation matrix for each weight function was generated to check multicollinearity between explanatory variables. The explanatory variables that are not correlated to other variables were selected based on computed Pearson correlation coefficients. These variables were then used to develop SWM models for different weight functions. Even in this case, models developed using different distribution indicated that Negative Binomial with log-link best fits the data considered in this research. Table 5 summarizes results obtained using integrated data and Negative Binomial with log-link as a probability distribution for different weight functions.

**Table 5. Selection of Best Model Based on Different Weight Functions**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1/D</th>
<th>1/D^2</th>
<th>1/D^3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>P Value</td>
<td>Coefficient</td>
</tr>
<tr>
<td>Intercept</td>
<td>1.750</td>
<td>&lt;.001</td>
<td>2.205</td>
</tr>
<tr>
<td>&lt;0.25 acre residential / apartments</td>
<td>-0.000246</td>
<td>&lt;.001</td>
<td>-0.000217</td>
</tr>
<tr>
<td>&gt;2 acre residential</td>
<td>0.000149</td>
<td>.027</td>
<td></td>
</tr>
<tr>
<td>0.25-0.5 acre residential</td>
<td>-0.000198</td>
<td>&lt;.001</td>
<td>-0.000357</td>
</tr>
<tr>
<td>2 acre residential</td>
<td>-0.000152</td>
<td>.003</td>
<td>-0.000150</td>
</tr>
<tr>
<td>Asian population</td>
<td>0.006860</td>
<td>&lt;.001</td>
<td>0.005906</td>
</tr>
<tr>
<td>Households with no vehicles</td>
<td>0.007594</td>
<td>&lt;.001</td>
<td>0.010010</td>
</tr>
<tr>
<td>Institutional</td>
<td>0.000266</td>
<td>.018</td>
<td>0.000223</td>
</tr>
<tr>
<td>Light commercial</td>
<td>0.000175</td>
<td>.033</td>
<td>0.000291</td>
</tr>
<tr>
<td>Light industrial</td>
<td>-0.000353</td>
<td>&lt;.001</td>
<td>-0.000367</td>
</tr>
<tr>
<td>One-way street</td>
<td>0.698807</td>
<td>&lt;.001</td>
<td>0.552395</td>
</tr>
<tr>
<td>Presence of median</td>
<td>0.236998</td>
<td>.011</td>
<td></td>
</tr>
<tr>
<td>Speed limit</td>
<td>0.027612</td>
<td>&lt;.001</td>
<td>0.023886</td>
</tr>
<tr>
<td>QIC</td>
<td>4,962</td>
<td>4,721</td>
<td>4,801</td>
</tr>
<tr>
<td>QICC</td>
<td>4,964</td>
<td>4,726</td>
<td>4,806</td>
</tr>
</tbody>
</table>

From Table 5, Negative Binomial with log-link model based on 1/D^2 (70, 18, 8, and 4 as relative weight for 0-0.25, 0.25-0.5, 0.5-0.75, and 0.75-1 mile buffer bandwidths, respectively) has the lowest QIC and QICC values (difference between QIC and QICC reasonably low), and is the best fit SWM model for the considered data. In other words, weight function 1/D^2 better explains the spatially-varying relationship
between ridership and independent variables than the other two weight functions considered in this research.

**Comparison of Results from SPM and SWM**

A comparison of results for the model based on integrated data using weight function $1/D^2$ with those for SPM using 0.25-mile buffer width data (shown in Table 6) indicates that the goodness of fit statistics slightly increases when data are integrated for different buffer widths. Therefore, based on statistical parameters, SWM does not yield better estimates than SPM.

**Table 6. Comparison of Best SPM and SWM Models**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SPM - 0.25-mile</th>
<th>SWM - $1/D^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>P Value</td>
</tr>
<tr>
<td>Intercept</td>
<td>1.570</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>&lt;0.25 acre residential / apartments</td>
<td>-0.00012</td>
<td>.007</td>
</tr>
<tr>
<td>0.25-0.5 acre residential</td>
<td>-0.00023</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>2 acre residential</td>
<td>-0.00014</td>
<td>.012</td>
</tr>
<tr>
<td>Asian population</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy commercial</td>
<td>0.00051</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Households with no vehicles</td>
<td>0.01051</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Institutional</td>
<td>0.00040</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Light commercial</td>
<td>0.00028</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Light industrial</td>
<td>-0.00028</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Mean household income</td>
<td>-0.000003</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>One-way street</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed limit</td>
<td>0.02801</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>QIC</td>
<td>4,471</td>
<td></td>
</tr>
<tr>
<td>QICC</td>
<td>4,431</td>
<td></td>
</tr>
</tbody>
</table>

**Validation**

Models developed from SPM and SWM indicate that the SPM model using a 0.25-mile buffer width data and the SWM model based on $1/D^2$ are the best models to estimate bus-stop transit ridership. While statistical parameters indicate that SWM does not yield better estimates, a validation of these models would provide an understanding of how accurate these models are in replicating real-world data.

A total of 128 bus stops that were not used to develop models were selected to validate and assess the two best models (SPM model using 0.25-mile buffer width data and SWM model based on $1/D^2$). Results obtained from validation showed that the SPM model using 0.25-mile buffer width data underestimated ridership for 67 percent of bus stops, while the SWM model based on $1/D^2$ underestimated
ridership for 63 percent of bus stops. The percent difference between actual ridership counts and estimates varied between -44 percent and +40 percent in the case of the SPM model using 0.25-mile buffer width data, while it varied between -58 percent and +49 percent in the case of the SWM model based on $1/D^2$. An overall comparison of absolute value of percent difference between actual ridership counts and estimates from these SPM and SWM models indicates that they do not follow any specific trends to definitely state that one generates better estimates than the other method. As an example, Table 7 shows results obtained from validation for eight (out of 128) randomly-selected bus stops.

**Table 7. Model Validation—Summary**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Actual Ridership Count</th>
<th>SPM - 0.25-mile Estimated</th>
<th>% diff</th>
<th>SWM - $1/D^2$ Estimated</th>
<th>% diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>6.71</td>
<td>-4.2</td>
<td>6.00</td>
<td>-14.2</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>16.85</td>
<td>5.3</td>
<td>18.44</td>
<td>15.2</td>
</tr>
<tr>
<td>3</td>
<td>29</td>
<td>21.33</td>
<td>-26.4</td>
<td>31.86</td>
<td>9.9</td>
</tr>
<tr>
<td>4</td>
<td>45</td>
<td>31.43</td>
<td>-30.2</td>
<td>33.96</td>
<td>-24.5</td>
</tr>
<tr>
<td>5</td>
<td>166</td>
<td>187.95</td>
<td>13.2</td>
<td>122.15</td>
<td>-26.4</td>
</tr>
<tr>
<td>6</td>
<td>241</td>
<td>286.21</td>
<td>18.8</td>
<td>246.37</td>
<td>2.2</td>
</tr>
<tr>
<td>7</td>
<td>376</td>
<td>296.98</td>
<td>-21.0</td>
<td>270.30</td>
<td>-28.1</td>
</tr>
<tr>
<td>8</td>
<td>561</td>
<td>320.46</td>
<td>-42.9</td>
<td>239.21</td>
<td>-57.4</td>
</tr>
</tbody>
</table>

Results from validation reiterates that using SWM (though sounds more meaningful in principle), which requires more data capturing and processing efforts, may not yield better results than SPM using 0.25-mile buffer width data. This primarily could be due to the fact that transit riders are sensitive to walking distance to bus stops. Most riders prefer to walk for less than 5 minutes (0.25-mile distance at 4 feet per second) to access a bus stop. Therefore, demographic, socio-economic, and land-use characteristics within a 0.25-mile distance from a bus stop may be sufficient to statistically explain and estimate transit ridership. It should be noted that these characteristics account for 50 to 85 percent of the data for different weight combinations (functions) used in SWM.

Results for the overall best model (SPM model using 0.25-mile buffer width data) shown in Table 6 can be mathematically represented to estimate daily ridership at a bus stop as
Daily ridership at a bus stop = \( \text{Exp}(1.570 - 0.00012 \times \text{QARA} - 0.00023 \times \text{HAR} - 0.00014 \times \text{TAR} + 0.00051 \times \text{HC} + 0.00040 \times \text{INST} + 0.00028 \times \text{LC} - 0.00028 \times \text{LI} + 0.01051 \times \text{HH0V} - 0.000003 \times \text{MeanHHI} + 0.02801 \times \text{SPLT}) \)

where, QARA is <0.25-acre residential/apartments area, HAR is 0.25–0.5-acre residential area, TAR is 2-acre residential area, HC is heavy commercial area, INST is institutional area, LC is light commercial area, LI is light industrial area, HH0V is households with no vehicles, MeanHHI is mean household income, and SPLT is speed limit (mph). Land-use area characteristics used in this research are expressed in thousand square feet.

From the above equation, it can be seen that the dependent variable (the average daily bus transit ridership at a bus stop) increases with an increase in institutional area, light commercial area, heavy commercial area, the number of households with no vehicles, and the speed limit surrounding the bus stop within a 0.25-mile buffer width. Other explanatory variables (mean household income, <0.25-acre residential/apartments, 0.25–0.5-acre residential area, 2-acre residential, and light industrial) have a negative effect on the average daily bus transit ridership at a bus stop, i.e., average daily bus transit ridership decreases as the value of these variables increases.

**Conclusions**

The objective of this research is to develop and assess models to estimate ridership at the bus-stop level using Spatial Proximity Method (SPM) and Spatial Weight Method (SWM). A GIS tool was used to capture spatial attributes such as demographic, socio-economic, land use, and on-network characteristics surrounding the bus stops. Spatial data surrounding the bus stop was extracted for four different buffer widths (0.25, 0.5, 0.75, and 1 mile). Extracted spatial data along with on-network characteristics were used to develop models to estimate ridership at the bus-stop.

From an assessment of probability distributions to develop models, it can be concluded that Negative Binomial with log-link was found to be a better fit than linear, Poisson with log-link, and Gamma with log-link distributions. This indicates that generalized linear models or count models are more appropriate to model ridership at bus-stop than linear models that were used in the past.
From an assessment of models based on data for different widths, it can be concluded that the model developed using a 0.25-mile buffer width has better goodness-of-fit values than 0.5-, 0.75-, and 1-mile buffer widths. It is, therefore, recommended as the best proximity distance to capture spatial data and estimate ridership at the bus-stop. In general, SPM models exhibited distance decay behavior.

The SWM model with Negative Binomial distribution using weights as a function of 1/D² (relative weights of 70, 18, 8, 4 for buffer bandwidths 0–0.25, 0.25–0.5, 0.5–0.75, and 0.75–1 mile, respectively) was found to be the best model than when compared to function 1/D and 1/D³ to estimate ridership at the bus stop.

A comparison of results (model parameters) obtained from the two spatial modeling methods (SPM and SWM) suggests that SWM models do not yield statistically different outputs than the SPM model using 0.25-mile buffer width data. Results obtained from validation further support that using SWM may not yield better results than SPM using 0.25-mile buffer width data. Therefore, demographic, socio-economic, and land use characteristics within a 0.25-mile distance from a transit stop are sufficient to statistically explain and estimate bus stop transit ridership. This also indicates that riders are sensitive to walking distance to access a bus stop. More than 50 percent of riders prefer to walk ≤ 0.25 miles to access bus stops.

Models developed from the statistical analysis indicate that ridership will be high in areas with households with no vehicles, institutions, and commercial establishments, whereas ridership will be low in areas with residences and high mean household income. Outcomes from this research help the decision makers and planners to better estimate bus transit ridership and identify public transit infrastructure that support sustainability as well as livability and a better quality of life for next generations.

In this research, the effect of overlapping buffer areas and temporal variation was not considered. Further research on distance decay measure is necessary to determine the effect of overlapping buffer areas to better estimate ridership at the bus-stop level. The function and how sensitive riders are to walking distance varies with the type of public transportation system (bus transit vs. monorail vs. light rail transit vs. commuter rail). It also may vary based on the geographic location of bus stops (downtown/uptown versus urban versus suburban areas) and time of the day. Models for different modes of public transportation by geographic location and time of the day, therefore, need to be developed.
Some of the most influential explanatory variables on bus transit ridership (such as the effect of increases in gasoline price, service quality or level of service, provision of real-time transit information, trip cost, and patron safety) were not considered due to data availability constraints. Examining the effect of these variables in addition to those considered in this research and developing transit ridership models needs further investigation.

References


Zhao, F., L. F. Chow, X. Liu, and M. T. Li. 2005. A Transit ridership model based on Geographically Weighted Regression and service quality variables. Available
at: http://lctr.eng.fiu.edu/re-project-link/finalDO97591_BW.pdf (accessed June 8, 2011).

Acknowledgments
The authors acknowledge the staff of Charlotte Area Transit System (CATS) and the City of Charlotte Department of Transportation (CDOT) for their help with data.

About the Authors
Srinivas S. Pulugurtha (sspulugurtha@uncc.edu) is currently working as an Associate Professor of Civil and Environmental Engineering and an Assistant Director of the Center for Transportation Policy Studies at The University of North Carolina at Charlotte. His areas of interest include traffic safety, GIS applications, transportation planning/modeling, traffic simulation, and development of decision support tools.

Mahesh Agurla (magurla@uncc.edu) is a graduate student in Transportation Engineering at The University of North Carolina at Charlotte.
Transit Coordination in the U.S.: A Survey of Current Practice

Charles Rivasplata, Ph.D., San Jose State University
Hiroyuki Iseki, Ph.D., University of Maryland, College Park
Adam Smith, San Jose State University

Abstract

As cities expand and travel patterns become more complex, transit passengers are becoming increasingly dependent on multiple systems to satisfy their daily travel needs. To facilitate seamless travel, comprehensive service planning, design, and operation are essential. In some cases, regional entities have integrated routes, timetables, and ticketing based on a common set of planning, investment, and marketing principles. The authors administered a nationwide survey of transit operators to explore the following areas of integration: fare policy/media, service scheduling, information coordination, facility and vehicle coordination, and interagency agreements. According to survey results, the nature and extent of integration varied by size of region and type of integration. Respondents identified challenges to coordination, including financial and political commitment. Furthermore, for integration to be successful, regional and local transport entities must work together to ensure that service providers participate in coordinative strategies, balancing the interests and needs of passengers, operators, and residents.
Introduction

In today's world, many people require traveling long distances across multiple cities and towns to reach dispersed locations in order to conduct their various economic and social activities. The provision of transit service that accommodates seamless travel across transit systems in the region is ideal for transit users. In turn, this seamless travel across the region requires appropriate coordination and integration among transit agencies. Over the past few decades, there has been an increasing level of interest in improving the coordination of transit services among many cities and regions around the globe (Tyson 1990; Stokes 1994; White 2002).

The importance of regional coordination and integration has been well recognized by researchers and practitioners (Iseki and Taylor 2009; Rivasplata 2006; Miller et al. 2005; Meyer et al. 2005; Pucher and Kurth 1989). According to NEA, regional coordination/integration is defined as:

The organization process through which elements of the passenger transport system (network and infrastructure, tariffs and ticketing, information and marketing etc) are, across modes and operators, brought into closer and more efficient interaction, resulting in an overall positive enhancement to the overall state and quality of services linked to the individual travel components (NEA Transport 2003, 17).

Transit coordination features the comprehensive planning of services within an urban market for the purposes of facilitating seamless, multi-operator journeys. It entails the organization of modes and services into a system of operational features in terms of routes, frequencies, timetables, fares, and ticketing based on a common set of planning, marketing, and development principles (White 2002; Rivasplata 2006). Nevertheless, there have been relatively few attempts to comprehensively explore transit coordination from the perspective of the transit agency. While numerous studies have explored government and agency perspectives on transit coordination in other countries (Pucher and Kurth 1989; Stokes 1994; NEA Transport 2003), in the U.S., most work on transit coordination has been limited to larger metropolitan areas (MTC 2006) where many of the successful regional strategies have been developed.

The purpose of this study is to identify some of the salient features of transit coordination in the U.S. based on a nationwide survey of transit agencies. This on-line survey asked directors and planners at transit agencies across the nation to answer questions associated with major regional coordination issues for transit service in the following categories: (1) fare coordination, (2) service schedule coordination,
Transit Coordination in the U.S.: A Survey of Current Practice

(3) information coordination, (4) facilities/vehicle coordination, and (5) joint agreements.

The survey was part of a larger study that examined the effects of transit service contracting and the level of regional coordination in the New Orleans Metropolitan Area (Iseki et al. 2011). While the larger study focused on documenting transit service management and operation for improvements of services within individual transit systems as well as regional coordination in relation to privatization, this survey provided valuable information on the present status of transit coordination in the U.S. Based on the analysis of survey data, a number of inferences can be made concerning the impact of specific factors on regional integration in the United States.

In general, the survey questions sought to discern levels of coordination in the U.S., identifying the constraints to inter-operator collaboration as well as the opportunities offered for system improvements. The survey took a unique approach, exploring coordination from the viewpoint of transit operators, as opposed to a regional entity or transit passenger.

Transit Coordination: Background

Regional coordination and integration are essential for transit passengers who depend on more than one transit system for travel (Chisholm 1989; Cook, Lawrie, and Henry 2003; Miller et al. 2005; Pucher and Kurth 1989; NEA Transport 2003). Regional transit systems that are not well-coordinated can impose burdens on transit users, discourage transferring among multiple transit agencies, and decrease ridership. Some of the burdens that riders may face in an uncoordinated transit system are unpredictable travel times, long transfer times, and increased fare payments (Miller et al. 2005).

By coordinating services, some regions have been successful in reducing those burdens, thereby increasing ridership and customer service. The coordination of routes, schedules, and fares can promote the use of transit, especially in large cities where multiple operators provide bus and rail services and, in some cases, more than 10 percent of journeys involve a transfer (White 2002). Past studies have acknowledged that system integration can enhance mobility and access, improving the level of connectivity between systems and prompting transit as a viable mode of transportation for a wider range of trip purposes (Nash 1988; Tyson 1990; Simpson 1994; Stokes 1994; Hensher and Brewer 2001).
While operators often attempt to serve a variety of origins and destinations, it is costly for them to provide direct service between all points, making some interchange inevitable (LTP 1997; White 2002). Passengers transfer when there is either no direct service or when transferring offers a faster alternative (TfL 2001). Transit coordination can effectively deliver more direct service by facilitating vital service connections at strategic locations. For transit to be a viable alternative, experts argue that operators must ensure security and reliability as well as reduce in-vehicle travel and transfer times, provide transfer information, and enhance through-ticketing (Rivasplata 2000; TfL 2001; White 2002).

Where transit systems are integrated in a seamless network of services, commuters spend less time traveling and not only save time and money but also contribute less to urban congestion and pollution. While time-savings is of primary interest to middle- and high-income urban residents, cost savings is critical to the survival of low-income communities, as a higher percentage of their wages is spent on transport (Nash 1988; Wardman 2001). By attracting a higher proportion of travelers to transit, system coordination can help manage transportation demand and reduce traffic congestion and vehicle emissions. Transit can be coordinated so that passengers pay only once, network routing and vehicle headways facilitate transfers, and interchange facilities are kept clean and safe for passengers (TfL 2001, MTC 2006). Collectively, these service features can improve the quality of transit.

It is important to note that there are multiple forms of coordination that require different levels of operator and/or government involvement and depend on the level and nature of transit demand in each urban area. Physical coordination, the most common and least expensive form of coordination, involves establishing points of transfer between and among transit networks (Henry 1990). In addition, information coordination is essential to the distribution of up-to-date route, fare, and timetable data, while institutional coordination ensures public sector participation in the ongoing planning of interoperator schemes.

Under optimal conditions, the more integrated the transit system, the greater the potential for passengers to reap significant cost and time-savings (Nash 1988). For example, interoperator coordination can establish the conditions for two or more operators to develop a discounted, multi-ride ticket/pass. However, political, operational, organizational, and financial barriers often pose challenges to coordinating transit services across jurisdictions within a region. In addition, the specific institutional structure of an urban area can limit coordination (Jemelin and Kaufman 2001; Lee and Rivasplata 2001). For example, in a number of cities with privately-
operated systems (e.g., Britain in the 1990s, Chile in the 1980s), local government has played a very minor role in the planning and regulation of transit systems, leaving it to the operators. In Britain, the Conservative government even discouraged interoperator transit coordination through anti-competitive legislation (OFT 1999; Dodgson 2000; White 2002).

Given the importance of government in the planning and coordination of transit, many argue that a condition necessary for the development of a well-integrated transit system is that an autonomous authority be charged with establishing a set of through-service standards (Nash 1988; Tyson 1990). Based on past experience, when establishing a set of intermodal transport objectives, it is essential that this authority balance the commercial interests of the operators with the needs of passengers (NEA 2003; Rivasplata 2006). It is important that regional coordination policy be transparent to all and designed to preserve operator integrity and competitiveness and respond to a proven demand for transfers.

Despite its importance, relatively little research has been conducted in the U.S. on specific methods and criteria for measuring and evaluating regional coordination and integration using concrete indices and indicators. In contrast, while many studies on the subject tend to define regional coordination broadly, they normally do not offer any specific indicators with which to measure it.

The study of transit integration has provided a number of perspectives from which to evaluate integration. A European Commission study conducted by NEA Transport Research and Training cited a set of theoretical perspectives for approaching coordination (NEA 2003):

1. The engineer’s vision of a well-planned system that promotes a solution but does not account for its eventual impacts.

2. The public management perspective that considers the behavior of public and private entities but often exerts only limited control over service provision.

3. A vision focused on institutions and their evolution that explains influence but does not offer an optimal design.

4. The microeconomics perspective that analyzes certain aspects of coordination (e.g., market failure) but pays little attention to implementation.

This nationwide survey on transit coordination took the second option, largely approaching transit service from a public management perspective. That is to say, in metropolitan regions where multiple transit agencies operate, the survey polled agencies on their perspectives concerning coordination as well as their common
practices and relationships with other transit agencies. We have sought to explore various aspects of transit coordination in transit systems of varying size and geographic location. While some coordinative efforts are well-documented in larger metropolitan regions, such as the San Francisco Bay Area (MTC 2006, Miller et al. 2005), this survey provided information on the magnitude and nature of coordinative efforts throughout the country. The following section describes the scope of the survey, the methodology employed, and descriptive statistics and an analysis of the data.

**Nationwide Survey of Transit Agencies**

The survey was conducted over a two-month period, from April to June 2010. The 2008 National Transit Database (NTD), administered by the Federal Transit Administration, provided a list of 590 transit agencies, all of which provided at least one fixed-route transportation mode. All of these agencies were invited to participate in the survey through email or letter. The invitation explained the purpose of the survey, emphasizing that participation in the survey was voluntary. Respondents to the survey were directed to a computer link from which they could fill out a web-based survey on www.surveymonkey.com. The site provided an overview of the project, the purpose of the survey, survey instructions, and a statement assuring confidentiality.

The survey consisted of two parts. The first part included questions related to agency profile, operating geographic area, and contracting characteristics, such as the number of contractors employed and the functions contracted out. The second part featured questions related to regional coordination. Questions focused on the five following categories of regional coordination:

1. Fare coordination—the coordination of ticketing arrangements and fare structures.
2. Service schedule coordination—the coordination of vehicle schedules to facilitate transfers.
3. Information coordination—the joint distribution of service information by transit operators.
4. Facilities/vehicle—including the collective purchase of equipment, vehicle, and other resources on the part of transit agencies, for the purposes of achieving economies of scale.
5. Joint agreements—formal contracts between agencies for the provision of specific transit services.
A total of 202 responses were received, with an overall response rate of 34 percent, a good result for an agency survey of this nature. The sample represents different-size agencies from 45 states and all major regions of the United States. As Table 1 shows, the survey captured agencies that were closely representative of the fleet sizes of the population of fixed-route transit agencies provided by the NTD. The sample population, however, captured a significantly smaller percentage of agencies with fewer than 25 vehicles and a larger percentage of agencies with 100-249 vehicles.

<table>
<thead>
<tr>
<th>Vehicles Operated at Maximum Service (Total Fleet Size)</th>
<th>Survey Sample</th>
<th>Entire Population of Fixed-Route Agencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 25</td>
<td>28%</td>
<td>43%</td>
</tr>
<tr>
<td>25-49</td>
<td>23%</td>
<td>19%</td>
</tr>
<tr>
<td>50-99</td>
<td>14%</td>
<td>16%</td>
</tr>
<tr>
<td>100-249</td>
<td>19%</td>
<td>11%</td>
</tr>
<tr>
<td>250-499</td>
<td>7%</td>
<td>6%</td>
</tr>
<tr>
<td>500-999</td>
<td>4%</td>
<td>3%</td>
</tr>
<tr>
<td>1,000+</td>
<td>5%</td>
<td>3%</td>
</tr>
</tbody>
</table>

Depending on the presence of other fixed-route transit agencies in the region, respondents were asked a different set of questions. Of the surveys received, 91 respondents (45%) indicated that their agency is the only fixed-route transit agency operating in their region, and thus, were not included in the analysis of multi-operator markets. The remaining 111 respondents reported working for agencies in regions with two or more fixed-route transit agencies and were asked additional questions related to several aspects of regional coordination. Before conducting the statistical analysis, we checked and confirmed that the survey respondents did not overwhelmingly represent multiple transit agencies from the same urban area, i.e., which could have provided duplicate responses.  

**Survey Data Analysis**

**Descriptive Statistics**

**Fare Coordination**

Agencies were polled on a number of questions related to fare coordination (Table 2). Of 111 responses, more than half indicated that their region has a coordinated
fare system. More than half of the agencies sell transit tickets, passes, or tokens that can be used on other transit systems, and a similar number sell tickets through other systems in the region.

Table 2. Questions Related to Fare Coordination

<table>
<thead>
<tr>
<th></th>
<th>Yes</th>
<th>No</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Has a coordinated regional fare system (e.g., the charging of a transfer fare) been established in your region?</td>
<td>58</td>
<td>52</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>48</td>
<td></td>
<td>111</td>
</tr>
<tr>
<td>Does your agency sell transit passes, tickets, or tokens that can be used on other transit systems?</td>
<td>60</td>
<td>54</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>46</td>
<td></td>
<td>111</td>
</tr>
<tr>
<td>Do other transit agencies in your region offer or sell transit passes, tickets, tokens that can be used on your system?</td>
<td>60</td>
<td>55</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td></td>
<td>110</td>
</tr>
<tr>
<td>Does your agency allow transfers from other transit systems for free or with a discounted fare?</td>
<td>70</td>
<td>63</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>37</td>
<td></td>
<td>111</td>
</tr>
</tbody>
</table>

N=number of respondents

While about half of the 111 respondents indicated that a coordinated fare system has been established in their region, the data suggest that the other half operate in regions that do not have a coordinated fare system. Coordinated fare systems generally are considered beneficial to customers, but agencies may have a difficult time implementing a coordinated fare system for a number of reasons, including institutional, financial, or technological hurdles (Miller et al. 2005; Yoh, Iseki, and Taylor 2008). While these difficulties may prevent agencies from providing their customers with a coordinated fare system, agencies may allow customers to transfer for free or with a discount. A discounted or free fare may encourage ridership among riders who use more than one transit system by bringing the entire trip cost down (although reduction in fare revenue could be a financial problem for transit agencies). Among the 68 agencies that allow discounted or free transfers, 49 indicated that their agency allows transfers from other transit systems in the region without an additional fare and 19 reported that their agency allows transfers for an additional fare.

Of the 60 transit agencies that sell fare media for use on other transit systems or whose fare media are sold by other systems, the most popular was a paper pass valid for one week or longer, followed by a one-ride ticket or token. The one-week pass was used by more than half of the responding agencies. These media are inexpensive to implement compared to a smart card system or magnetic swipe card,
which may require installation of new equipment and other ongoing expenses, as well as identification and account information from customers (Giuliano, Moore, and Golob 2000; Yoh et al. 2006). These cost factors may account for the popularity of paper passes as opposed to smart cards and magnetic swipe cards, which only 25 and 12 percent of respondents used, respectively. Many transit agencies are concerned about uncertainty regarding the costs associated with implementing a technologically-sophisticated fare collection system such as a smart card system relative to its potential benefits (Yoh et al. 2006; Iseki, Yoh, and Taylor 2007). Paper passes that are shared among agencies, on the other hand, provide a low-cost way of coordinating fares.

Service Schedule

Agencies were polled on two questions related to service schedule (Table 3). Of the 111 responses, close to 70 percent of these agencies coordinate both their daily and weekly service schedules and timetables with other agencies in their region. While service schedule and time schedule coordination are a very basic level of coordination, they can be very beneficial to transit passengers by reducing passenger wait time, particularly because travelers commonly perceive out-of-vehicle (walking, waiting, and transferring) time more onerous than in-vehicle time (Wardman 2001; Iseki and Taylor 2009). In addition, this type of coordination also may produce benefits to transit operators, as ridership has been shown to increase and customer complaints decrease. A number of other benefits can take place when transit systems are able to coordinate schedules for the convenience of their passengers (Miller et al. 2005).

<table>
<thead>
<tr>
<th>Table 3. Questions Related to Service Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>N</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>Does your agency take into account the service schedule of other transit agencies in the region to determine the daily and weekly service schedules of your agency?</td>
</tr>
<tr>
<td>Does your agency determine time schedules of buses, streetcars, or other fixed-route transit services in coordination with the schedules of other transit systems, taking into account transfer time for users at major transfer points?</td>
</tr>
</tbody>
</table>
Information
The survey asked several questions concerning the joint provision of information. Of the 111 respondents, 83 (75%) provide information jointly with other transit agencies. The most common information provided was route maps and time schedules, which 67 percent of these agencies provided. The provision of integrated information can make it easier for customers to use transit to travel across areas served by multiple agencies (Miller et al. 2005).

The 83 agencies providing joint information indicated the use of a variety of media (Table 4). The most commonly-used media were information pamphlets (65% of the agencies), while less than half of agencies shared websites. A few agencies noted that while they do not share websites, they do provide links to the websites of other agencies. Regional websites, such as 511.org in the San Francisco Bay Area or tripplanner.mta.info in the New York City area, can be very helpful for planning routes across more than one transit system or finding transit information easily and quickly. Nevertheless, information pamphlets may be more popular, as they are accessible to everyone, including transit dependents that are important customers but are less likely to have access to the Internet (e.g., for economic reasons).

Table 4. Media Used in Joint Provision of Information

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information pamphlets</td>
<td>54</td>
<td>65</td>
</tr>
<tr>
<td>Telephone service numbers</td>
<td>49</td>
<td>59</td>
</tr>
<tr>
<td>Transfer centers that provide information</td>
<td>44</td>
<td>53</td>
</tr>
<tr>
<td>Shared websites</td>
<td>37</td>
<td>45</td>
</tr>
<tr>
<td>On-board display</td>
<td>14</td>
<td>17</td>
</tr>
<tr>
<td>Other</td>
<td>15</td>
<td>18</td>
</tr>
</tbody>
</table>

Total number of respondents: 83
Note: Respondents provided multiple answers.

The survey findings indicated that most agencies make use of real-time information. In addition to schedule coordination, the provision of real-time vehicle arrival information has proved effective in reducing waiting time and improving the transit passenger experience (Dzieken and Kottenhoff 2007; Mishalani and McCord 2006). Most of the 111 agencies indicated that they use real-time information such as automatic vehicle location systems, while only about one-third indicated that they do not use it. However, there is little coordination in the use of real-time information among transit agencies. Most agencies use real-time information within their own organization but do not share with other agencies.
Facilities and Signage
Finally, agencies were polled on facility sharing and signage design (Table 5). Approximately 69 percent of the 111 agencies polled shared facilities (e.g., terminals, shelters) with other agencies, although some facilities required more coordination than others. Among agencies that share transfer points and/or facilities, 74 percent indicated that these points are clearly designated, facilitating better operational coordination between agencies and convenient transfers for passengers. Comprehensive planning for and establishment of transfer points can collectively be undertaken by most of the agencies.

Table 5. Questions Related to Facilities and Signage

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does your transit agency share facilities (e.g., terminal, shelter) with other fixed-route transit agencies in the region?</td>
<td>77</td>
<td>34</td>
<td>111</td>
</tr>
<tr>
<td>Are transfer points in your region clearly designated for the convenient transfer between different transit systems?</td>
<td>81</td>
<td>29</td>
<td>110</td>
</tr>
<tr>
<td>Does your agency share the design of system signage with other agencies?</td>
<td>39</td>
<td>71</td>
<td>110</td>
</tr>
</tbody>
</table>

N=number of respondents

The sharing of signage design was not a very common practice. Of those agencies polled, only 35 percent share with other agencies. While shared signage design may not be an essential component of regional coordination, consistency in their use can enhance customer comprehension of information across transit systems and improve their perception that transit agencies are working within a unified transit system (rather than a disjointed system).

Agencies were questioned about the types of facilities shared. Shelters were shared most often between agencies, while 62 percent of agencies shared a terminal with other agencies. Shared facilities for passengers, such as well-designed bus stops or terminals, can reduce walking distance between systems, facilitating transfers for passengers (Parsons Brinckerhoff 2002; Iseki and Taylor 2009). Agencies may have problems with sharing facilities when they cannot reach agreements on maintenance or other responsibilities. While it may be easy to reach interoperator agreements on bus shelters, facility maintenance agreements are more difficult to reach, as evidenced by the fact that only nine percent of agencies polled had such arrangements.
Joint Agreements and Discount Programs

Several questions were asked regarding existing agreements between agencies. A large number of respondents indicated that their agencies currently have agreements with other agencies to expand routes (Table 6). The coordinated expansion of routes can help link locations that do not have service and help prevent the duplication of routes by coordinating service.

Table 6. Existing Agreements between Agencies

<table>
<thead>
<tr>
<th>Agreement</th>
<th>N</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>To expand routes</td>
<td>34</td>
<td>38</td>
</tr>
<tr>
<td>To introduce a regional transit smart card that can be used on multiple systems</td>
<td>26</td>
<td>29</td>
</tr>
<tr>
<td>To jointly market transit services</td>
<td>24</td>
<td>27</td>
</tr>
<tr>
<td>To jointly share data on ridership, accidents, etc.</td>
<td>16</td>
<td>18</td>
</tr>
<tr>
<td>To increase service frequency</td>
<td>15</td>
<td>17</td>
</tr>
<tr>
<td>To jointly train transit workers or share the same training materials</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Other</td>
<td>47</td>
<td>52</td>
</tr>
</tbody>
</table>

Total Number of respondents: 90
Note: Respondents provided multiple answers.

Respondents acknowledged the existence of several types of discount programs. While these programs may not be directly related to regional coordination, they often help agencies increase ridership (Pucher and Kurth 1989). More than half of the respondents indicated that their agencies have a discount program. College-based discounts were the most popular, perhaps because many students do not own a car.

Respondent Comments

In addition to the multiple-choice section of the questionnaire, survey respondents—major stakeholders in the planning process—were asked to provide open-ended comments regarding regional coordination. Experience abroad has shown that stakeholder commitment is important in the improvement of transit coordination. Respondents commented on a variety of issues related to regional coordination, noting the difficulties in implementing regional coordination and also highlighting some of their successes.

Respondents commented on challenges associated with implementing regional coordination, including political barriers such as home rule; institutional barriers, such as a lack of a strong coordinating MPO or RTA; and financial hurdles, such as a lack of funding for regional services. As noted by some of the comments from transit agency executives, agencies face challenges in coordinating transit systems
where longstanding political, institutional, or financial issues persist. Finding ways around these obstacles is likely to be a key step in advancing a region’s level of coordination.

One respondent referred to some of the difficulties of coordinating with other agencies, stating that it is “not the practicalities that create the challenge,” but rather “the political and personal realities.” Where home rule is well established and counties are fiscally responsible for providing transit service, many agencies are unwilling to cooperate (e.g., coordinate timetables) if they do not have to, and it often is difficult to force them to cooperate. Another respondent similarly commented on the difficulties that small agencies have working with larger or more powerful agencies. The respondent noted that smaller agencies often lack the political power to initiate coordination, although they make efforts to do so.

Other respondents pointed to the complexity in achieving coordination efforts when working with other agencies, identifying the difficulty in getting all players to the table to reach an agreement. They pointed out that in order for multiple transit agencies to coordinate effectively, there needs to be strong regional governance, as well as a focus on collective achievements (e.g., incentives for agencies to switch from individual agency fare collection to a regional revenue sharing scheme, based on smart card technology).

In addition, the survey revealed that transit coordination is hampered by local funding requirements. A respondent remarked that when operating funds are secured through countywide sales tax levies, it is difficult for transit agencies to cross county borders to service other counties, even when there are destination points within those counties. The respondent suggested that one way to alleviate the situation might be for federal or state governments to provide additional operating funding.

Several other respondents commented on the success of coordination in their regions, noting the benefits that passengers receive from a coordinated, regional transit system, such as reduced travel costs. Other respondents remarked that at the regional or state level, it is beneficial to promote legislation creating regional transit authorities. These responses indicate that many transit directors believe that regional coordination can benefit the user, but that interagency working relationships require regional governance, regional funding mechanisms, and legislative initiatives that promote regional coordination.
Many transit agencies in the sample operated in regions with one or two other fixed-route agencies. Respondents from small- and mid-size metropolitan regions often reported lower levels of regional coordination, suggesting that as regions grow, many of the agencies in these regions: (1) respond to the increasing demand for regional transit, and/or (2) encounter opportunities to coordinate with other transit agencies. As a result, close working relationships often are established. In this sense, early cooperation between agencies can lay the foundation for successful transit coordination as a region expands.

Analysis of Potential Factors Related to Regional Coordination

Some questions on the survey were designed to test hypotheses based on factors that appeared to be related to regional coordination. Two of the questions, hypotheses, and test results are described below. It should be noted that results are reported for the first and second tests without multiple agencies from the same urban area.

1. **Is regional population size correlated with level of coordination?** It was hypothesized that population size may be correlated with regional coordination because more populous regions tend to have more transit agencies and greater demand for regional transit service and integration. A t-test was run for independent samples on all measures of coordination, testing the mean population size of urbanized areas grouped by their responses to 12 measures of coordination. No significant difference was found in population size between responses for measures of regional coordination in the survey at the 95% confidence level. 4

2. **Is the number of transit agencies in a region correlated with level of coordination?** It was hypothesized that regions with more transit agencies have more opportunities to coordinate with other agencies, improving the chances for these agencies to establish coordinating relationships. In order to test this hypothesis, these agencies were arranged into the three groups, based on the reported number of other transit operators in the region: one to two agencies; three to five agencies, and more than five. 5 The responses were tabulated, and Pearson’s Chi-square tests grouped by responses of “yes” or “no” for all measures of coordination were run. It was found that agencies reporting the existence of 3 or more other transit agencies had higher levels of coordination for 7 of the 12 measures of coordination that we examined at the 95% confidence level. 6
Conclusion

While largely descriptive in nature, the survey results provide some important insights into the activities of transit agencies and the settings within which they are expected to coordinate with other providers. The survey results suggest that regions with four or more transit agencies are likely to have more transit coordination than regions with fewer than four agencies. Perhaps the larger the region, the greater the number of transit agencies there are and the greater the need, demand, and expectation to introduce at least a minimum level of coordination, i.e., most large regions have some form of coordination that allows for transfer (interchange) between transit systems and modes.7

In addition, these results could suggest that if there are only two transit agencies in a region (e.g., one based in the economically-declining inner city and the other in a relatively wealthy suburb), conflicts over such issues as funding may prevent operators from working together. In contrast, if there are four or more operators in a region, there may be less in-fighting among agencies. One of the operators may act as a facilitator and mediator of conflicts, e.g., placing greater focus on regional issues and connections.

While a large number of agencies reported high levels of cooperation, regional coordination is still lacking in many areas of the U.S. Barriers to regional coordination often are political, institutional, or financial in nature, and regional entities lack the ability to integrate transit services due to political and administrative difficulties in coordinating public agencies (e.g., no control of transit agencies within their region or require that standards are met). In some areas, the regional transportation planning organization plays only a limited role in the ongoing planning of transit services in a metropolitan region, many times as the result of political factors. In other cases, the regional government may have very limited resources that can be used to promote coordination. Except for a few cases, dedicated resources for coordination are practically non-existent in many regions—often, MPOs lack either the political power or will to generate funding for ongoing interagency coordination. In addition, there are cases in which inherent conflicts exist between the benefits of regional coordination and the costs to individual transit agencies. For example, while transit users may benefit from regional coordination, for taxpayers in some jurisdictions of the region, the costs may outweigh the benefits.

Overcoming these hurdles and building relationships are important steps to establishing better regional coordination. We argue that for widespread transit coordination to be achieved, it is essential that regional transportation plans propose
policies and financial support for ongoing coordination. In addition, transit service plans can incorporate or balance the needs and desires of all parties—including passengers, operators, communities, and society at large—through a comprehensive planning and outreach process that encourages input from all of these groups and that works through the issues to reach consensus. From an equity point of view, it is important to conduct a careful analysis of costs and benefits for each of these parties as well as society as a whole, not only taking into account direct economic costs and benefits but also indirect social and environmental ones. Once the net benefit of regional coordination is confirmed and adequate compensation for losses is given, this comprehensive planning process will gain greater public acceptance. Clearly, the cost of adopting and implementing specific integration strategies will need to be carefully considered and discussed among all parties involved.

One of the principal strategies warranting consideration in many cities is the granting of greater power to metropolitan planning organizations (MPOs) to promote regional transit policies and generate funding opportunities for the implementation of interagency initiatives. We argue in favor of greater dialogue among transit agencies, contractors, regulators, and planning bodies. There are examples of successful coordination in the U.S., such as in the Washington, D.C. area and in the San Francisco Bay Area, where regional transit agencies and the local MPO regularly meet to discuss issues of regional importance.

In the case of the San Francisco Bay Area, the Metropolitan Transportation Commission (MTC) has played an important role in the planning and funding of mutually agreed-upon programs (e.g., Clipper smartcard, 511 information services). It has facilitated the ongoing coordination of services, often tying available funding to operator participation. In addition, the MTC has begun to work closely with its regional planning counterparts to coordinate transportation with land use, housing, water resources, and air quality.

From the user perspective, as economic and social activities extend across a region, there is a need for seamless regional transit service. A lack of coordination not only places a significant burden on those transit users who have to travel on multiple transit systems, but also reduces the chance of attracting more riders, reducing congestion, and lowering vehicle emission and greenhouse gas levels. Transit agencies and regional transportation agencies need to take a holistic approach to incorporating regional transit coordination in their provision and planning, particularly in response to the need of transit dependents and the threats of environmental degradation associated with widespread automobile dependence. Addressing
these issues is central to promoting livable communities and a sustainable environment. Further research is warranted to measure the net benefits of regional coordination of transit service, to explore successful coordination strategies, and to identify ways of adapting them to local circumstances and conditions.

**Endnotes**

1 A complete list of the survey questions is available upon request.

2 The 111 agencies with at least one other fixed-route transit agency in the same region came from 81 different urban areas. Los Angeles–Long Beach–Santa Ana had 7 agencies, the highest in the survey. Other multi-agency urban areas included NY–Newark, NY, NJ, CT, with four agencies; Chicago, Atlanta, Phoenix–Mesa, Riverside–San Bernardino, and San Francisco–Oakland, with 3; and several others with 2.

3 This is also what was found in the case of one transit agency in the Greater New Orleans Region in the larger research. The transit director stated that the transit agency needs to be very careful about the use of local property tax revenue that funds local transit service, and that it cannot get into extensive regional coordination without making sure that it will benefit the taxpayers within its service area.

4 Values for t-test are available upon request.

5 It should be noted that when referring to the number of transit agencies operating in a region, the agency being surveyed should be added. As such, these 3 groupings correspond to 2–3 agencies, 4–6 agencies, and more than 7 agencies in a single region.

6 Agencies that reported having 3 or more other transit agencies operating in their region had significantly higher levels of transit coordination (than agencies with 1–2 other operators) in the following areas: (a) coordinated fares, (b) interchangeable transit passes, (c) free or discounted transfers, (d) coordinated daily and weekly service schedules, (e) coordinated timetables, (f) joint provision of information, and (g) existing interagency agreements. Values for chi-square tests are available upon request.

7 Survey results indicated that some agencies were particularly well-coordinated. While most respondents requested that their agency name not be disclosed, those that allowed this information to be released reported high levels of coordination. For instance, the San Diego Metropolitan Transit System (CA) and Intercity...
Transit (Olympia, WA) reported high levels of fare coordination, while CityBus (Santa Rosa, CA) and StarMetro (Tallahassee, FL) reported having coordinated service schedules. Similarly, Thousand Oaks Transit (CA) and Glendale Transit (AZ) reported high levels of information coordination, while Petaluma Transit (CA) and Metropolitan Atlanta Rapid Transit Authority (GA) reported high levels of facility coordination. Finally, in the area of joint agreements, Bay Metropolitan Transit (Bay City, MI) and Washington City Transit (PA) reported having several joint agreements with other agencies (e.g., to increase service frequencies, expand routes, jointly market services).

Acknowledgments
The research conducted for this paper was supported by grants from the Mineta Transportation Institute at San Jose State University and the University Transportation Center of the University of New Orleans. This work came from a larger effort conducted by a research team of faculty and students at the University of New Orleans and San Jose State University. We thank the transit officials who participated in the survey and paper reviewers for their comments on the earlier versions of this paper. The views presented are the sole responsibility of the authors and not those of the funding agencies.

References


NEA Transport Research and Training, OGM, Oxford University, Erasmus University, TIS.PT and ISIS. 2003. Integration and regulatory structures in public transport, Final report to DG TREN. Rijswijk, The Netherlands: NEA.


UCB-ITS-PWP-2008-1, California PATH Program, Institute of Transportation Studies, University of California, Berkeley.

About the Authors

**Charles R. Rivasplata** (charles.rivasplata@sfmta.com) is an Adjunct Lecturer in the Urban and Regional Planning Department at San Jose State University, where he teaches courses on transportation planning. He is also a Senior Planner at the San Francisco Municipal Transportation Agency (SFMTA). He completed master’s degrees in Civil Engineering and in City Planning at the University of California, Berkeley (1991) and a Ph.D. at the University of California, Davis (2006). His doctoral dissertation focused on the impacts of Labour Party reforms on transit integration in the U.K. His research interests include transit privatization and deregulation, regional governance, travel demand management (TDM), and transit coordination. He has taught classes on transport planning at the University of California, transportation policy at Cambridge University, and TDM at the Central University of Venezuela.

**Hiroyuki Iseki** (hiseki@umd.edu) is an Assistant Professor of Urban Studies and Planning and a research faculty member at the National Center for Smart Growth at the University of Maryland, College Park. His current research focuses on balancing efficiency, effectiveness, and equity in public policy and planning with special attention to transportation, environment, and land use. His research interest includes transportation economics and finance, public transit planning and management, travel behavior analysis and modeling, regional transportation planning, and geographic information systems (GIS) applications to research and practice in public policy and planning. His work has been published in a range of transportation and planning journals, including *Transportation Research A: Policy and Practice, Transport Reviews, Journal of the Transportation Research Board, Journal of Public Transportation,* and *Journal of Planning Education and Research.*

**Adam L. Smith** (adamleesmith@gmail.com) is a graduate student in the Urban and Regional Planning Department at San Jose State University. His professional interests include transportation and land use planning, transportation finance, urban design, and GIS applications for urban and regional planning.
Bus or Rail: An Approach to Explain the Psychological Rail Factor

Milena Scherer, ETH Zurich
Katrin Dziekan, Berlin Institute of Technology

Abstract

Many public transport studies have found that potential passengers consider rail-based public transport to be superior to bus systems. Why is this? Two studies have been completed in Germany and Switzerland in search of explanations for this so-called psychological rail factor. In this article, these two studies are presented and discussed to introduce the schemata approach and to help identify differences of attributions towards rail- and bus-based public transport.

The research found a psychological rail factor (i.e., a preference for using rail assuming equal service conditions) of 63 percent for regional train and 75 percent for trams compared to bus services. The rail factor is highly loaded with emotional and social attributions. They account for 20–50 percent of the share in the different schemata for bus, rail, and tram.

Introduction

It is recognized that hard factors such as travel time, cost, availability of public transport services, and car ownership have a major impact when people consider the choice between using an automobile or public transport. Nevertheless, there is evidence from the literature that rail-based public transport often is considered superior to bus systems, even in cases where quantitative hard factors are equal. This attraction of passengers is known as a psychological rail factor, and it is used to express a higher attraction in terms of higher ridership of rail-based public
transport in contrast to bus services (Axhausen et al. 2001; Megel 2001b; Ben-Akiva and Morikawa 2002; Vuchic 2005; Scherer 2010a). The existence of this rail factor is widely accepted among experts, but little evidence exists about the reasons for this phenomena.

The idea of a rail factor is consistent with statements that the image of a transport system has an impact on demand. Furthermore, research shows that transport characteristics often are misperceived (or misbelieved) and that costs are ranked less important by users making mode choice decisions than planners expect. This raises the question of how public transport characteristics are perceived and valued and which attributions are made towards different transport modes (Beale and Bonsall 2007; Guiver 2007). While many efforts have been undertaken to analyze customer attributions towards car and public transport in general, only a few studies distinguish between different public transport modes (e.g., Megel 2001a; Cain et al. 2009).

It is expected that the images of different public transport systems vary between regions since customer attributions derive from perceptions and beliefs, which are influenced by local conditions and different cultures (Scherer 2010a). Thus, in addition to investigating attributions toward public transport modes in general, it is of interest to explore these attributions against the background of different spatial areas. The two case studies presented in this article explore differences in attributions towards train, tram, and bus in Germany and Switzerland to enhance the knowledge about different images of public transport systems.

**Attributions to Public Transport Systems**

*Function of Attributions and Schemata*

In cognitive psychology, attributions are defined as ways in which people perceive and value a product or service. A combined set of attributions forms an image of the product or service. Attributions can be organized into categories to develop a schema. Schemata are organized packets of information about the world, events, or people, and they are stored in the long-term memory. Schemata describe more generally a cognitive structure of types of background knowledge that a person brings to any given context (Eysenck and Keane 2005).

These schemata are abbreviations and save cognitive resources. Since human beings need to save cognitive effort, they build up behavior routines based on schemata, stereotypes, and scripts. This makes life easier, because one does not have to
think in depth about everyday things. Hence, analyzing cognitive structures such as schemata is important for understanding human behavior.

Understanding schemata about specific issues provide useful information how people perceive specific concepts. For further research, the question of how these schemata influence behavior becomes prominent. The next section outlines how attributions and schemata have been considered in public transport research.

**Literature Review of Public Transport Attributions**

Attributions to public transport are important; they form the perception of a public transport mode and, thus, the image of different public transport modes. Perception of public transport service quality and attributions of public transport have been prominent issues in transportation research, especially research that targets shifting automobile drivers towards public transport. Investigation of perception and attributions usually is based on qualitative research such as focus group discussions and semi-structured interviews.

Negative attributions towards a transit mode usually result in a poor image of this mode. This can be shown with the psychological model of barriers to train use developed by Dziekan et al. (2004). They found that barriers to train use are higher when this mode is loaded with negative attributions. It is of interest to enhance the knowledge about the quality of the attribution in order to investigate their influence on intended behavior on barriers towards behavior.

A key problem with using attributions to investigate mode choice decisions is that many studies do not distinguish between public transport modes (e.g., Wirthlin Worldwide and FJCandN 2000). However, several recent studies have made a differentiation between various bus and light rail modes. Cain et al. (2009) found that full bus rapid transit (BRT) is perceived by everyone as superior to regular bus services in the Los Angeles region. In contrast, although other high-quality bus services (non-BRT) also were highly regarded by their users, the general public's view was influenced by the same negative perceptions as regular buses. Hence, modal familiarity led to a higher acceptance of the respective transport mode.

Widell and Olsson (2002) found in their research on Stockholm's subway system that the subway had more negative attributions than other public transport systems in Stockholm. Two main reasons were found for the negative perception. First, the old subway trains were rated as too noisy since they had the worst rating of all public transport vehicles investigated. Second, the Swedish prefer daylight to underground situations for cultural reasons.
Guiver (2007) found in a discourse analysis of focus group discussions on bus and car travel that the local buses often were seen as sub-standard when compared with bus services in other cities. Both the activated scenario and the selective attributions towards bus travel support the assumption that mode choices are being made partly on personal experiences and common cultural representations of modes. This means that planners need to consider different pre-conceived beliefs as well as ways of thinking and processing information when they design public transport systems (Beale and Bonsall 2007).

Megel (2001a) has shown that the schemata approach is an appropriate method for investigating and describing different attributions to trams/trains and buses. She developed a prototype for “rural public transport” and its subcategories “train ride” and “bus ride” based on corresponding attributions.

With regard to different attributions to bus and light rail, light rail generally is perceived as more reliable, more comfortable, faster, and more spacious than buses. Furthermore, light rail is more often rated higher concerning intangible factors, a finding that emerges from positive attributions such as “new, enjoyable, and attractive” (Beirão and Cabral 2007).

Existing studies have shown that public transport modes are attributed with different aspects; respectively, they are rated differently by different stakeholders. These attributions are not constant over locations and times and depend on existing public transport services. Furthermore, negative or weak attributions have been found to act as barriers to a specific travel behavior. The case studies presented in this article aim to present differences in public transport modes based on the psychological concept of schemata. These schemata serve as basis for the discussion of positive and negative attributions that may stimulate or hinder certain travel behavior.

**Description of Case Studies**

**Method**

Both case studies presented here explore public transport attributions by applying a content analysis (Mayring 1993) and coding of the attributions. The starting point was the German study that comprises a psychological investigation of preferences and attributions of different regional public transport systems, bus and train, to investigate the rail factor. This work was based on structured face-to-face interviews with inhabitants in two mid-size cities in Germany. The public transport service was, in one case, bus-based and, in the other, mainly based on regional trains.
The Swiss study developed the approach from the German study further to investigate the two common urban public transport systems bus and light rail (tram) on a nationwide basis. Therefore, data were collected with a web-based questionnaire and sent to a random sample of Swiss residents. The allocation of the participants into areas served by bus or tram was based on residential postal codes.

The German Study: Face-to-Face Interviews on Regional Public Transport

The first study to investigate the psychological rail factor was conducted in 2000 by Megel (2001a; 2001b). The research focused on the underlying reasons for preferring rail-based public transport over bus-based public transport. Why do people choose one or the other? The respondents were asked to answer the following hypothetical question:

Imagine the following hypothetical situation: To go from A to B, you may choose between a bus ride and a train ride. The travel time of 60 minutes is the same for each mode. The route, your way to the stop, the ticket price, and the service frequency would be the same. What would you choose—bus or train?

The respondents subsequently were asked why they chose one or the other public transport option to reveal the attributes in the train schemata and bus schemata. Face-to-face interviews were conducted using a semi-standardized questionnaire. Talking directly to people ensured that they really understood the question and were motivated to give as many reasons as possible for their decision on the hypothetical question. Information about gender, age, frequency of public transport use, last bus or train ride occurrence, educational background, ownership of half-fare card for train travel (Bahncard 50), car availability, and income also was collected.

The face-to-face survey was conducted in the city centers and inner-city market places in two medium-size cities in Eastern Germany (Annaberg-Buchholz and Bischofswerda) by trained interviewers on normal weekdays. The locations were not close to the train station or bus stops to avoid priming effects or biases in the answers. Inhabitants older than 18 years were asked to participate in the survey. The representative sample consisted of 422 people.

Preferences

The results showed that 63 percent of the people chose the regional train in the hypothetical situation. This confirms the existence of a rail factor. Against the expectations that good bus service or bad train service have an influence on preference, no significant differences concerning the decision in favor for train were
found between the structurally comparable regions of Annaberg-Buchholz (bus region) and Bischofswerda (train region).

A detailed analysis of the data showed that neither gender nor income had an influence on the preference for rail. However, the frequency of public transport use did have a positive influence on the rail preference: almost all heavy users (use public transport nearly every day) of the regional train service preferred train and almost all owners of a half-fare card preferred train travel. Furthermore, increasing education level showed correlations to the train preference.

The data also showed that younger people (18–24 years) have a significantly higher preference for train travel than older people (>65 years) (Megel 2002). Almost 80 percent of the younger people in the sample preferred train, while only 46 percent of the older people chose the train. A detailed analysis showed that older women are more likely to prefer the bus than older men (67% vs. 41%). In the bus region, significantly more non-captives (car available in the household and ownership of driver license) preferred the train over the bus (captives train preference 51% vs. non-captives train preference 68%).

**Attributions**

The interviewers collected detailed information on the reasons for choosing the train or the bus option. Each person gave, on average, three explanations for their choice. Using the method of content analysis (Mayring 1993), all answers were analyzed and categorized into pre-defined subcategories of the schemata framework (see Table 1 for first attributions). Since first attributions are directly related to the “picture in mind” that one has when thinking about the preferred public transport system, they contribute best to the schemata of bus and train.

The majority of the attributes for the train choice were:

- Emotional attributions (38%)
- Activity space (12%)
- Contra bus arguments (7%)
- Seats (5%)
- Attributions to guideway (5%)

The most important subcategories for first attributions for the bus decision were:

- Routing (23%)
- Emotional attributions (19%)
- Experience (13%)
- Attributions to guideway (9%)
### Table 1. Comparison of First Attributes to Riding Regional Train (N=261) and Riding Regional Bus (N=146) in the Different Subcategories

<table>
<thead>
<tr>
<th>Category/Subcategory</th>
<th>Examples</th>
<th>% Bus</th>
<th>% Tram</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Emotional factors</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emotional attributions</td>
<td>Convenient, attractive, nostalgic</td>
<td>43.1</td>
<td>51.7</td>
</tr>
<tr>
<td>Usability</td>
<td>Less complicated, easy to use</td>
<td>18.5</td>
<td>37.5</td>
</tr>
<tr>
<td>Train ride in itself</td>
<td>Enjoy the ride</td>
<td>0.7</td>
<td>0.4</td>
</tr>
<tr>
<td>Emotion</td>
<td>Like train/bus ride</td>
<td>3.4</td>
<td>4.2</td>
</tr>
<tr>
<td>Stress/relax</td>
<td>More relaxed, less stressful</td>
<td>0.0</td>
<td>1.1</td>
</tr>
<tr>
<td>Experience</td>
<td>Habit, familiarity, memories</td>
<td>13.0</td>
<td>4.2</td>
</tr>
<tr>
<td>Staff</td>
<td>Friendly staff</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Security</td>
<td>Better security feelings</td>
<td>4.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Social factors</td>
<td>Less crowded, communicate, socializing</td>
<td>2.0</td>
<td>0.4</td>
</tr>
<tr>
<td>Others</td>
<td>Ambience, flair</td>
<td>1.4</td>
<td>2.3</td>
</tr>
<tr>
<td><strong>Interior and design</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity space</td>
<td>More space, ability to move around</td>
<td>-</td>
<td>11.9</td>
</tr>
<tr>
<td>Seats</td>
<td>Higher seat comfort, more leg space</td>
<td>2.7</td>
<td>5.0</td>
</tr>
<tr>
<td>Seat selection</td>
<td>Higher seat availability</td>
<td>-</td>
<td>0.0</td>
</tr>
<tr>
<td>Design</td>
<td>Better boarding</td>
<td>4.8</td>
<td>0.4</td>
</tr>
<tr>
<td>Others</td>
<td>Climate/air conditioning in vehicle</td>
<td>2.1</td>
<td>1.5</td>
</tr>
<tr>
<td><strong>Guideway and route</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Routing</td>
<td>Density and distribution of stops</td>
<td>22.6</td>
<td>2.3</td>
</tr>
<tr>
<td>Advantages of tracks</td>
<td>Dedicated right-of-way</td>
<td>-</td>
<td>0.8</td>
</tr>
<tr>
<td>Attributions to guideway</td>
<td>Faster, on time, more reliable</td>
<td>8.9</td>
<td>4.6</td>
</tr>
<tr>
<td>Others</td>
<td>Environmental reasons</td>
<td>-</td>
<td>3.8</td>
</tr>
<tr>
<td><strong>Activities and possibilities</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activities</td>
<td>Reading, smoking, studying</td>
<td>-</td>
<td>2.3</td>
</tr>
<tr>
<td>Luggage</td>
<td>Possibility to carry bicycle</td>
<td>1.4</td>
<td>0.8</td>
</tr>
<tr>
<td>Children/family</td>
<td>Ability to take stroller, better for children</td>
<td>0.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Toilet</td>
<td>Toilet available</td>
<td>-</td>
<td>1.1</td>
</tr>
<tr>
<td>Services</td>
<td>Restaurant/minibar</td>
<td>-</td>
<td>0.0</td>
</tr>
<tr>
<td>Others</td>
<td>Attractive stations, openable windows</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Contra reasons</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contra bus</td>
<td>Travel sickness, density of bus stops</td>
<td>-</td>
<td>6.5</td>
</tr>
<tr>
<td>Contra system rail</td>
<td>Remote train stations.</td>
<td>4.1</td>
<td>-</td>
</tr>
<tr>
<td>Contra train--probably not system-dependent</td>
<td>Bad experiences with train rides, anonymity in the train</td>
<td>4.1</td>
<td>-</td>
</tr>
<tr>
<td>Contra train--not system-dependent</td>
<td>Dirty stations, dirty vehicle interiors</td>
<td>1.4</td>
<td>-</td>
</tr>
<tr>
<td><strong>Other reasons</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cheap prices</td>
<td>4.8</td>
<td>2.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>
All attributes for train and for bus were categorized into subcategories that derived from the schemata frames as presented in Table 1 with according percentages. In both schemata, the majority of attributions were concerned with aspects of the category emotional factors (52% for train and 43% for bus). For the train schema, the attributions regarding design/interior and activities/possibilities were more important than in the bus schema. Aspects of the route/line such as flexibility and availability were the major positive attributes in the bus schema.

About 7-10 percent of the first attributions account for contra reasons that are expected to strengthen ones barrier for the choice of this mode and also enforce the current preference. Interestingly, differences between contra reasons on bus and train are small. Considering the literature review where buses where found to be more often related with negative scenarios, this was not expected.

Since the respondents were asked to list all reasons for their preference, it is interesting to compare the overall picture they construct with all reasons given to that of the first attributions (see Scherer et al. 2011 for the review of all attributions).

- There is a remarkably higher share of emotional attributions for trains in first attributions (38%) compared to the comprehensive list (18%).
- The share of emotional attributions is also high for buses, but not to the same extent as for trains (19% and 14%).
- Contra bus arguments have the third-highest share of first attributions in the train schema (7%). When considering all arguments, the share decreases to less than 5 percent.
- The ranking of bus attributions remains similar regarding first attributions and all attributions towards bus preferences. Attributions for tram preferences show a higher variation between first-mentions and all attributions.

As the first argument that one has in mind intuitively has a higher weight in the schemata concept, we conclude that the rail factor established in this study is mainly driven by emotional factors and contra reasons that form a barrier towards bus modes.

**The Swiss Study: Web Questionnaire to Bus and Tram**

The second case study is a Swiss survey conducted in autumn 2009 by Scherer (2010b). The study's two main objectives were first, to collect reasons and attributions for the preferences of bus and tram to be used in the subsequent investigations of perception of urban public transport, and second, to explore the situations and preferences of residents of different areas in Switzerland, including rural areas,
conurbations, and urban areas with and without tram presence, to provide first indications of different attributions made by respondents.

Almost every municipality in Switzerland is served by public transport. In remote mountainous areas, service is mostly bus-based, but regional rail service also is possible, depending on the geographical location. Urban areas and conurbations are served by high-quality bus service and commuter rail. The four biggest conurbations—Geneva, Berne, Basle, and Zurich—also provide tram services, and Lausanne has one subway line on tires due to topographical conditions. Public transport is integrated in a tariff system, with no distinction between transport modes. This allows passengers to transfer without any obstacles between rail, bus, and tram.

The small size of the country and the high availability of public transport services allow the assumption that most of the residents have some experience with public transport in general and also with tram service in particular. According to the Swiss Federal Statistical Office (2007, p. 38), on average, every resident boards a public transport vehicle 218 times per year.

Data were collected by means of a web survey. Similar to the German study, the survey contained questions in a hypothetical setting, which required a high cognitive effort by the participants. This imagination is mainly influenced by cognitive structures (schema, prototypes, and memory representations) that are built up from the experiences, habits, attitudes, etc., of the participants. The respondents were asked to imagine two urban public transport modes (bus and tram) under exactly the same service conditions regarding timetables and availability, and then to state which mode they would prefer in the given situation. Next, they were asked to provide up to three reasons for their decision.

The questionnaire contained a combination of stated preference questions in an open and closed form. It was attached to a web-based omnibus survey provided by a market research institute (an omnibus survey is a survey where several different customers can include their questions on the same survey). This is especially convenient for a small amount of questions and has the advantage of sharing the costs for collection of socio-demographical data between customers. Due to its characteristics, an omnibus covers respondents that are online at least once a week and are between the ages of 15 and 75 years.

The universe of the study was all residents living in the German- or French-speaking areas of Switzerland. The Italian area was neglected because, in contrast to the
other two regions, there is no tram service in this region. Finally, 515 questionnaires were included in analysis.

Preferences
The answers to the hypothetical question about the preference for bus or tram operating under same service conditions showed a clear preference for trams. A total of 385 (75%) of all respondents preferred the tram, and 130 (25%) chose the bus (see Figure 1).

![Figure 1. Spatial distribution of preferences](image)

Attributions
The stated reasons for the preference were classified according to the key presented in Table 2. A total of 999 reasons for tram preference and 281 reasons for bus preference were collected and classified. Based on the assumption that the first answer is highly related to the “picture in mind” that one has when thinking about the preferred public transport system and to not overrate the second and third answers, only the first reasons were selected for this analysis. This means that, in total, 372 reasons for a tram preference and 132 reasons for a bus preference were analyzed (see Table 2).
### Table 2. Categorization Key and First Attributions in Swiss Study

<table>
<thead>
<tr>
<th>Categories/Subcategory</th>
<th>Examples</th>
<th>% Bus</th>
<th>% Tram</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vehicle characteristics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seat/space</td>
<td>Spacious interior, availability of seat, more space, less full, comfortable (to sit)</td>
<td>30.3</td>
<td>15.1</td>
</tr>
<tr>
<td>Boarding</td>
<td>Low-floor, wider doors, easier to board</td>
<td>0.8</td>
<td>2.2</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>Modern, new, air-conditioned, better ambience, cleanliness, more comfort, quiet</td>
<td>6.0</td>
<td>2.2</td>
</tr>
<tr>
<td>Sight</td>
<td>Overview in vehicle, better sight/windows</td>
<td>-</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>Attributions of guideway</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reliability</td>
<td>Right-of-way, dedicated lane, on time, reliable</td>
<td>6.1</td>
<td>29.3</td>
</tr>
<tr>
<td>Flexibility</td>
<td>No tracks/wires, flexible routing</td>
<td>1.5</td>
<td>-</td>
</tr>
<tr>
<td>Ride comfort</td>
<td>Comfortable to ride, less shaking</td>
<td>5.3</td>
<td>11.6</td>
</tr>
<tr>
<td>Orientation</td>
<td>Visibility of guideway</td>
<td>3.8</td>
<td>0.5</td>
</tr>
<tr>
<td>Safety</td>
<td>Safety, fewer accidents</td>
<td>-</td>
<td>4.6</td>
</tr>
<tr>
<td><strong>Availability factors</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Service</td>
<td>Distribution of stops, timetable/frequency, operation hours, connections, routing, service information</td>
<td>11.4</td>
<td>4.8</td>
</tr>
<tr>
<td><strong>Environmental issues</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental aspects</td>
<td>Environmentally friendly, no exhaust, less noisy, energy consumption</td>
<td>3.0</td>
<td>16.9</td>
</tr>
<tr>
<td><strong>Activities during ride</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activities during ride</td>
<td>Ability to read or work during ride, bring luggage</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Emotional and social factors</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive feelings</td>
<td>Convenient, better, something special, easier to use, ride pleasure, attractive, relaxed</td>
<td>15.1</td>
<td>7.5</td>
</tr>
<tr>
<td>Habit/ knowledge</td>
<td>Habit, practice, nostalgic reasons, familiarity</td>
<td>9.1</td>
<td>2.1</td>
</tr>
<tr>
<td>Special connection</td>
<td>Rail fan, Job at railway company</td>
<td>-</td>
<td>1.3</td>
</tr>
<tr>
<td>Socialising</td>
<td>Meet other people</td>
<td>2.3</td>
<td>-</td>
</tr>
<tr>
<td>Connection to area</td>
<td>More rural, urban feelings</td>
<td>0.8</td>
<td>0.3</td>
</tr>
<tr>
<td>Security</td>
<td>Aggressive riders</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Other reasons</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contra reasons</td>
<td>I don't like the other mode</td>
<td>4.5</td>
<td>1.1</td>
</tr>
<tr>
<td>Sickness</td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Other reasons</td>
<td>Costs, etc.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>
From those who preferred using a bus, the first attributions in subcategories towards a bus were:

- Seat/space in vehicle (30%)
- Positive feelings (15%)
- Availability of service (11%)
- Habit/knowledge (9%)

The overall data then were analyzed compared to socio-economic variables to identify patterns for bus preferences. In contrast to the attributions towards a tram, as presented below, no significant impact of socio-demographic variables was detected for the bus schema.

From those who preferred using trams, the first attributions in subcategories towards a tram were:

- Reliability (29%)
- Environmental aspects (17%)
- Seat/space in the vehicle (15%)
- Ride comfort (12%)

Two variables were found to have a significant association with the attributions to tram: ownership of a public transport pass (PT-pass) and place of residence. Both PT-pass owners and non-owners ranked guideway attributions as most important, but PT-pass owners ranked vehicle attributions as well as emotional and social attributions higher than environmental benefits, while non-PT-pass owners ranked environmental benefits second to guideway situation.

In terms of place of residence, the ranking of most important attributions for inhabitants of rural areas are guideway, environmental issues, and emotional factors, in contrast to people living in tram cities where vehicle attributions were mentioned far more often. The rank order of attributions of inhabitants of the three spatial classes (rural, conurbation without trams, conurbation with trams) follows assumed traffic concerns or traffic problems usually encountered in these locations.

Emotional and social factors play a less prominent role in attributions than expected from the German study. One third of the arguments for a bus preference concerned the seat/space situation in vehicles, and one third of the arguments for a tram preference are based on guideway characteristics related to higher reliability. Overall, a tram gets a higher share of rational reasons for its preference mentioned as first attribution than a bus. One third of the first attributions to a bus are based on emotional and social factors and contra reasons to a tram. Preferences in this
study show more rational reasons compared to those in the German study. One explanation might be that people had time to reflect their attributions since they had to write them down. In contrast, in the German study, the participants were asked to explain their choice in personal interviews. This methodological difference may lead to a higher share of rational reasons.

**Schemata of Bus, Tram and Train**

**Recoding of Answers**

Two persons recoded the attributions for bus and regional train from the German study independently according to the categorization key in Table 2. The recoded dataset serves as a basis for comparison of attributions towards urban and regional bus and tram and regional train. The results from the recoded dataset differ marginally from the original studies due to exclusion of attributions that contradict the hypothetical situation of equal public transport services.

General caution has to be exercised when comparing the results of both case studies, because these studies were completed in different times (2000 and 2009) and different geographical areas with variances in public transport service levels. Since public transport service has changed only marginally in the German study areas over the last 10 years, the effect of different time horizons on level of service aspects can be neglected.

The main socio-demographic difference between the two datasets is ownership of a public transport pass (German study = 7.5%, Swiss study = 43%). Distributions of other variables such as gender, age, household size, and number of cars per household are similar across both datasets.

**Schemata**

Figure 2 shows the resulting schemata for regional bus, regional train, urban bus, and tram based on recoded first attributions mentioned in the surveys. It can be seen that each schema is loaded differently with the defined categories from the classification key in Table 2—in other words, the schema for each mode contains different numbers of categories of attributions, e.g., regional trains include the category “activities during ride” but none of the other modes do.
Considering the resulting schemata, regional bus and regional train are highly loaded with emotional attributions. Almost 50 percent of the first attributions towards these transport modes fall within this category. The share of emotional and social factors is also high in the schema of urban buses (36%). Compared to that, the tram schema is less loaded with emotional factors (17%).

Regarding regional transportation, it can be seen that reasons for people preferring a bus include a higher availability of bus service compared to train service. In contrast, a train is more suitable for conducting activities during a ride. This reflects the local situation in the case study areas.

In urban areas, a tram is heavily linked to positive guideway attributions and has strong environmental-friendly attributions. These attributions correspond with congested situations and emerging environmental discussions in cities.
Since schemata support cognitive shortcuts and finally influence people’s behavior, it is interesting to establish that about 20–50 percent of the schemata for public transport modes are emotionally driven. According to the schema theory, the influence of positive feelings towards a mode, habit and knowledge, and barriers towards other modes are expected to have a significant effect on travel behavior.

**Discussion**

In both studies, a high preference for rail-based systems was found. In the underlying hypothetical situations where public transport opportunities are equal, a rail factor definitely exists for the case study areas. However, since the questionnaires did not allow for undecided respondents, their role should be mentioned as well. These respondents could have a higher tendency for choosing tram/rail due to an unconscious rail preference (which, of course, further supports the existence of a rail factor). Assuming that undecided respondents may tend to favor tram/rail when asked in a survey, an even higher rail preference would be the result.

The schemata approach is based on the first (intuitive) response mentioned for the respective preference. An answer is expected to be more intuitive when a less cognitive effort is needed to give a reason for preference. Hence, the personal interviews conducted in Germany meet this condition better than the web-based questionnaire in the Swiss study, because filling out a questionnaire requires more time and allows reflecting on the answer. Thus, it is expected that the schemata built up from reasons mentioned in the German study correspond higher with the real picture in mind than the schemata constructed with reasons from the Swiss study. As a consequence, emotional and social factors tend to be underestimated in the schemata for urban bus and tram.

As first attributions show a higher share of emotional and social factors than the comprehensive set of attributions, we conclude that they have a higher weight in a schemata and also a higher weight for certain behavior. Furthermore, emotional and social aspects also include attributions from people who were unable to define their reason for preference in words. Hence, the inability to express what someone likes about a public transport mode is expected to have a high share in this category since the respondents in this situation tend to give general answers such as “better,” “I like,” etc., although they might really be affected by other attributions (e.g., they might have meant that one mode is more reliable).
In congested areas with high demand, the main travel concerns are reliability (attributions of guideway) and space in the vehicle. Reliability is attributed to trams with their dedicated rights-of-way and far less to buses. On the other hand, buses are expected to have higher seat availability than trams. This category (vehicle characteristics) encompasses, on the one hand, aspects such as vehicle size and capacity (which favor trams) but, on the other hand, expected crowding conditions and, hence, buses are seen as less crowded and thus providing more space. This is especially interesting since the people choosing bus seem to expect that more public transport customers are riding trams. This also reflects a hidden rail factor in urban areas.

The category availability factors tend to have a higher impact in regional areas where public transport service is less dense. In these cases, a bus is expected to be more effective to meet availability needs. This reflects differences in routing and stop-distributions between regional train and regional bus services. This category especially can be influenced by cultural differences, since availability of regional public transport service is higher in Switzerland than in Germany.

In the category of environmental issues, the higher share attributed to urban public transport can be influenced by the time when the study was conducted. The climate debate was far less prominent in 2000 (when the German study was completed) than in 2009 (when the Swiss study was completed). Nevertheless, the data show the unsurprising tendency that rail-based public transport is considered to be more environmentally-friendly than buses.

**Conclusions**

The results support the assumption of a hypothetical psychological rail factor. Derived from the psychological approach of schemata, 20–50 percent of the explanation for the psychological rail factor is based on emotional and social aspects such as positive feelings and habits. Schemata are influenced by local conditions and, as a consequence, they cannot be generalized and applied to different regions properly without considering different cultural backgrounds.

Our findings underline the conclusion in Cain et al. (2009) that specific locations influence the image of a public transport system. Furthermore, similar to Cain et al. (2009), the results show that familiarity with a certain mode tends to influence the preference. The ratio of preferences for trams is lower in rural regions compared to tram cities in the Swiss study. Additionally, the German study found a higher
preference for train by owners of specific travel cards. With regard to the findings of Beirão and Cabral (2007), the same attributions have been found as relevant except for the space in the vehicle.

In contrast to common mode choice models that are mostly based on hard factors, this research was based on the concept that attributions towards a public transport system form the basis for system perception and image. Attributions can be combined into categories that form schemata for different modes. Since schemata and similar routines are used as cognitive shortcuts, they affect human behavior. However, further research is needed to investigate the specific relationship between public transport schemata and travel behavior, e.g., to contribute to mode choice models. Schemata give a valuable insight in irrational reasons for mode choice that are mostly excluded in common mode choice models.

The presented studies support the conclusion that how people think and talk about public transport modes reflects the schemata of public transport modes. Schemata are a useful background for helping design public transport systems. For example, thinking of barriers toward public transport use in general or buses in particular, the schema shows that implementing small individual measures to improve bus service are not likely to be effective since the bus schema is highly loaded with emotional factors, based on experiences and habits. Considering the findings of Guiver (2007) concerning negative scenarios and the importance of contra arguments combined with the psychological model by Dziekan et al. (2004), we find it questionable whether single improvements targeting only one attribution can lead to higher demand. Overcoming one negative attribution is not simply a matter of creating a more positive image for a public transport mode.

Our findings give an overview of the relevance of rather irrational reasons related to the decision making of public transport customers. For practitioners, it is important to know more about the image and schemata of the different PT modes. This allows for specific improvements of public transport services by appropriate consideration of these aspects, which account for 20-50 percent of the schemata.

References


About the Authors

**MILENA SCHERER** *(scherer@ivt.baug.ethz.ch)* is a doctoral student and research assistant at the Institute for Transport Planning and Systems (IVT) at the Swiss Federal Institute of Technology (ETH) in Zurich. She has a master’s degree in civil engineering with specialization in transport engineering and transport planning. Her doctoral thesis focuses on behavioral differences caused by various public transport modes.

**KATRIN DZIEKAN (born MEGEL)** *(katrin.dziekan@tu-berlin.de)* is a senior researcher at the Berlin Institute of Technology, at the chair of Integrated Transport Planning. She received her Ph.D. from the Department of Transport and Logistics at Royal Institute of Technology in Stockholm/Sweden. Her main research fields are user perspective in public transport and evaluation of transit and transport-related measures.
The Impact of Weather on Bus Ridership in Pierce County, Washington

Victor W. Stover, Nelson\Nygaard Consulting Associates, Seattle
Edward D. McCormack, University of Washington

Abstract

A factor that influences transit ridership but has not received much attention from researchers is weather. This paper examines the effects of weather on bus ridership in Pierce County, Washington, for the years 2006–2008. Separate ordinary least squares regression models were estimated for each season, as weather conditions may have different effects depending on the time of year. Four weather variables were considered: wind, temperature, rain, and snow. High winds negatively affected ridership in winter, spring, and autumn. Cold temperatures led to decreases in ridership in winter. Rain negatively affected ridership in all four seasons, and snow was associated with lower ridership in autumn and winter. These results suggest that adverse weather conditions can have a negative effect on transit ridership.

Introduction

Many factors influence transit ridership, including the quantity and quality of transit service provided, spatial factors, gasoline prices, the economy, and others. One factor that may affect ridership significantly on a day-to-day basis, but that has not received much attention from researchers, is weather. Adverse weather conditions such as rain, snow, fog, wind, or extreme temperatures may cause people to shift transportation modes or avoid traveling at all. The issue is important to transit
agencies. If weather was shown to have a significant impact on ridership, agencies could take steps to mitigate the effects of weather, such as installing more shelters at transit stations, in order to maximize passenger comfort and ridership.

This paper examines the impacts of weather on transit ridership in Pierce County, Washington. Three years of ridership data from Pierce Transit and weather data from Seattle-Tacoma International Airport were used to model the relationship with ordinary least squares (OLS) regression. The paper begins with an examination of the theoretical relationship between weather and transit and a review of the literature. Next, the study area, methodology, and data are described. A presentation of the results, the sensitivity analysis, and a discussion of the findings follow.

Theoretical Framework

The numerous factors that influence transit can be categorized into two general groups: internal and external (Taylor et al. 2009). Internal factors are those that the transit agency can control, including the quality and quantity of service provided and the cost of a ride. External factors are influences beyond the control of transit agencies, including spatial factors (land use, density, urban form design), socioeconomic factors (population, employment, rate of auto ownership, average income), pricing factors (price of gasoline, road cost, parking costs), and environmental factors (weather). Most of the factors tend to be constant or change gradually over time, but weather is an external factor that can change drastically from one day to the next and be measured on a daily basis. A city could be hit with major rain one day and have clear skies and no precipitation the next. Both conditions could have an effect on transit ridership.

Weather can affect transit use and other forms of travel in two ways (Guo et al. 2007). First, weather can affect the activities that cause people to travel. Weather is not likely to affect indoor activities, but it may affect outdoor activities. A person is more likely to participate in outdoor activities in pleasant weather, leading to more travel on nice days. Second, weather affects the travel experience. People may be less likely to ride transit if waiting for the bus in the rain makes them uncomfortable. In addition, inclement weather may slow down transit vehicles and reduce quality of service, making transit a less appealing option to travelers. Numerous studies have found that adverse weather conditions such as rain and snow affect traffic speeds (Lamm et al. 1990; Ibrahim and Hall 1994; Rakha et al. 2008), and it is likely that those conditions affect bus operating speeds, making transit service slower. Hofmann and O’Mahony
(2005) found bus travel times to be longer on rainy days than on non-rainy days, although they did not state whether the results were significant.

The extent to which weather affects travel decisions may be influenced by the sources that travelers use to receive weather information. Information can be obtained from secondary sources, such as weather forecasts provided by the media, or from direct observations. People who receive weather information from secondary sources may be more likely to change their travel modes because they have more time to plan alternate trips, although research on this issue has been inconclusive. Khattak and de Palma (1997) found that drivers were slightly more likely to change their travel modes if they received their weather information from secondary sources, but the result was not statistically significant. A survey of Geneva commuters found that 55 percent of respondents who changed their travel patterns because of weather received weather information from secondary sources (de Palma and Rochat 1998).

**Previous Research**

Little research has been conducted on the impacts of weather on transit ridership, although interest in the topic appears to have increased in recent years. In general, studies that have examined the impacts of weather on aggregate ridership data have found that ridership decreases in adverse weather conditions.

Kalstein et al. (2009) studied the extent to which different types of air masses affected ridership on rail systems in Chicago, the San Francisco Bay Area, and northern New Jersey. Air masses are parcels of air that affect entire regions and can be categorized on the basis of variables such as temperature, humidity, and cloud cover. The researchers found that ridership was significantly higher on dry, comfortable days and significantly lower on moist, cool ones.

A study in Chicago used OLS regression to explore the relationship between ridership on Chicago Transit Authority buses and trains and five weather variables (temperature, rain, snow, wind, and fog). All of the variables had significant impacts on ridership, although they affected bus and rail modes differently. In general, ridership was higher in good weather and lower in bad weather. The weather affected bus ridership more than rail ridership and weekend days more than weekdays (Guo et al. 2007).

Cravo and Cohen (2009) used OLS regression to assess the impacts of temperature, rain, and snow on transit ridership/revenue in New York City. Most of the variables were found to have a statistically significant impact on revenue. Cooler-than-nor-
mal temperatures increased subway revenue in the spring/fall and increased bus revenue in all seasons. Warmer-than-normal temperatures decreased subway revenue in the summer. Snow decreased revenue for both bus and subway, as did rain.

Changnon (1996) examined the effects of summer precipitation on transit systems in the Chicago area. The study found that ridership was significantly lower at the five percent level on rainy days when compared with non-rainy days. Rain that occurred during the midday hours had a stronger effect than rain that occurred in the morning or evening periods, which suggests that discretionary passengers were more affected by rain than commuters, who tend to ride in the mornings and evenings.

Related studies have used surveys to determine how weather influences travel behavior. Khattak and de Palma (1997) conducted a survey in Brussels to determine how weather caused commuters to change travel decisions. Fifty-four percent of automobile users stated that they changed their mode, departure time, and/or route choice because of weather conditions. Twenty-seven percent of those respondents stated that the influence of weather on travel mode change was either “very important” or “important.” This result suggests that some drivers will shift modes to carpools or public transit in response to weather, although it is unclear whether this deviation would lead to an overall increase in transit ridership. In a survey of commuters in Geneva, 53 percent of respondents stated that the influence of weather conditions on mode choice was “very important” or “important” (de Palma and Rochat 1998).

### Study Area

Pierce County is located in the Puget Sound region of Washington and is the state’s second most populous county, with approximately 786,000 residents in 2008. Its county seat and largest city is Tacoma, with an approximate population of 197,000 in 2006, according to the U.S. Census Bureau. The county is considered to be a part of the Seattle metropolitan area, as it is directly south of King County, where Seattle is located. Public transit in the county is provided by Pierce Transit, which serves all of the county’s major jurisdictions and some unincorporated areas, but not the entire county. The agency operated 58 local, express, and dial-a-ride routes as of December 2008. For the years 2006 to 2008, the average weekday ridership was approximately 44,000. Including weekends, the average ridership was about 37,000.

The weather data for this study were observed at Seattle-Tacoma (Sea-Tac) International Airport, which is located in King County approximately 15 miles (24 km) northeast of Tacoma. The airport is close to Pierce County and is a station in the
Automated Surface Observing Systems (ASOS) program, which is intended to be the “nation's primary surface weather observation network” (National Weather Service 2009). The station provides quality-controlled data for the variables analyzed in this study. Pierce County does have an ASOS station at Tacoma Narrows Airport, but that particular station does not provide a 30-year historical average temperature. The Sea-Tac Airport station was chosen because it provides the necessary data and has weather that is similar to Pierce County because of its close proximity.

The Seattle area’s climate is classified as warm temperate with a dry warm summer (type Csb) on the Köppen-Geiger climate classification map (Kottek et al. 2006). Summer tends to be warm and dry, while winter is typically cold and wet. Temperatures seldom dip below freezing, and snow is rare. Figures 1 and 2 present the average monthly temperature and precipitation for Sea-Tac Airport.

![Figure 1. Sea-Tac Airport average monthly temperature](source)

![Figure 2. Sea-Tac Airport average monthly precipitation](source)
Methods and Data
The primary intent of this study was to measure the impacts of weather factors (the independent variables) on transit ridership (the dependent variable). Two general methods to measure these impacts have been identified in the literature: absolute level and relative change (Guo et al. 2007). The absolute method compares the absolute levels of weather and transit ridership to identify relationships between the two. For example, higher temperatures may lead to higher ridership and greater rainfall may lead to lower ridership. With the relative change method, weather is compared to a benchmark. The benchmark could be the weather conditions from the previous day or the historical average weather for the day. The rationale for the relative change method is that travelers may make decisions about which mode they will take on the basis of how the weather forecast compares to the previous day or the normal weather for that day.

For the temperature variable, this study took a departure from the normal (historical average) approach, and for the rainfall, wind speed, and snow variables, it used an absolute level approach. Daily temperatures were compared to the historical averages for each day, and a departure from the normal value was calculated to quantify the change. If, for example, on a given day the temperature was 60°F (16°C) and the normal temperature was 69°F (21°C), then the departure from normal was designated as -9 °F (-5°C). The hypothesis was that temperature would affect ridership only if it significantly departed from the historical average. An analysis of average ridership data determined that an 8°F departure in either direction might be the threshold at which temperature begins to impact ridership. Two dummy variables were created to test this: a variable for days when the departure temperature was 8°F above normal or higher, and a variable for days when it was 8°F below normal or lower.

The absolute level method was used for the rainfall and wind speed variables to determine what effects absolute changes in the variables have on ridership. A dummy variable for snow was included in the model rather than the actual amount of snowfall because the weather station at Sea-Tac Airport does not record the magnitude of snowfall, only total precipitation and a remark that snow occurred. Additionally, the amount of snowfall is often highly localized in the Puget Sound region, so a snowstorm might accumulate 4 inches (10 cm) of snow at Sea-Tac Airport but only 1 inch (2.5 cm) in downtown Tacoma. By using a dummy variable for snow, the model measured the impact that any amount of snow would have on ridership. To obtain an accurate measure for rain by itself, precipitation from all days with measured snow...
was assumed to be snow, and precipitation was assumed to be rain when snow did not occur. Weather data were obtained from the National Climatic Data Center.

Although this study is concerned primarily with the effects of the weather variables, omitting other independent variables that affect the dependent variable would bias the estimated value of the regression coefficients. Additional independent variables were added to the models to account for non-weather factors that influence transit ridership and to help avoid omitted variable bias. Vehicle revenue hours and the adult fare price were obtained directly from Pierce Transit. The price of gasoline was defined as the price of a gallon of unleaded regular gasoline in dollars for the Seattle-Tacoma-Bremerton area. Unemployment rate was included to control for the state of the local economy, as the economy has an impact on how much people travel. The size of the labor force was used as a proxy for population. Data for all three variables were obtained from the Bureau of Labor Statistics.

The study period for the analysis was January 2006 to December 2008. Because the temperature variables could have different effects on ridership depending on the season, a separate model was estimated for each of the four seasons: winter (December, January, February), spring (March, April, May), summer (June, July, August), and autumn (September, October, November). Ordinary least squares was used to estimate the parameters of the multiple regression models. Each model took the following form at the outset:

\[
\text{riders} = \beta_0 + \beta_1 \text{windspeed} + \beta_2 \text{departure warm} + \beta_3 \text{departure cold} + \beta_4 \text{raintotal} + \beta_5 \text{snow} + \beta_6 \text{gasprice} + \beta_7 \text{labforce} + \beta_8 \text{revenue hours} + \beta_9 \text{unemployment} + \beta_{10} \text{fare} + \beta_{11} \text{Monday} + \beta_{12} \text{Tuesday} + \beta_{13} \text{Wednesday} + \beta_{14} \text{Thursday} + \beta_{15} \text{Friday} + \beta_{16} \text{Saturday} + \beta_{17} \text{Holiday Saturday} + \beta_{18} \text{Holiday Sunday} + u
\]

where,

- **riders** = unlinked passenger trips on local routes
- **windspeed** = daily average measured wind speed (miles per hour)
- **departure warm** = departure from normal temperature higher than 7°F
- **departure cold** = departure from normal temperature lower than -7°F
- **raintotal** = total rainfall (inches)
- **snow** = dummy variable for snow
- **gasprice** = price of gasoline (in dollars)
- **labforce** = size of the labor force
- **revenue hours** = revenue hours of service provided on local routes
- **unemployment** = unemployment rate
fare = price of basic adult fare (in dollars)

Monday = dummy variable for Monday
Tuesday = dummy variable for Tuesday
Wednesday = dummy variable for Wednesday
Thursday = dummy variable for Thursday
Friday = dummy variable for Friday
Saturday = dummy variable for Saturday
HolidaySaturday = dummy variable for holidays when a Saturday schedule was used
HolidaySunday = dummy variable for holidays when a Sunday schedule was used
u = unobserved factors
β_0 = intercept parameter
β_{1-18} = independent variable parameters

Estimation of each regression model was a multi-step process. Initially, an unrestricted model was estimated to include all possible relevant variables. Variables with p-values of 0.10 or greater were deemed insignificant and were removed from the model, except in some close cases. A Wald test was performed for the day-of-week dummy variables to determine whether they were jointly significant. If together they were significant, they remained in the model, even if some were insignificant individually. Finally, a restricted model was estimated by using all significant variables. After each step, a White test was used to detect heteroscedasticity, and an LM test was used to test for serial correlation. If necessary, heteroscedasticity-robust standard errors and autoregressive terms (which appear as AR(n) in the results tables) were used to correct for the conditions.

Results

Table 1 presents the unrestricted results from the four seasonal models. Restricted models were estimated after insignificant variables had been removed, and those results are displayed in Table 2. The coefficient for each independent variable represents the change in ridership given a 1-unit change in the independent variable, holding other variables constant. The results for the weather variables are given in absolute change (number of riders) and percentage change (compared to the mean daily ridership for the season in question). The daily ridership averages were 35,167 for winter, 37,497 for spring, 37,045 for summer, and 38,566 for autumn. Variables in the restricted model were significant at the 10 percent level or lower, or very close. P-values are included in Tables 1 and 2.
### Table 1. Unrestricted Model Results

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
</tr>
</thead>
<tbody>
<tr>
<td>windspeed</td>
<td>-163.72 (0.0032)</td>
<td>-121.36 (0.0037)</td>
<td>-65.02 (0.2928)</td>
<td>-181.13 (0.0083)</td>
</tr>
<tr>
<td>departurewarm</td>
<td>2,361.29 (0.0786)</td>
<td>449.55 (0.2699)</td>
<td>161.46 (0.7407)</td>
<td>1,345.79 (0.1401)</td>
</tr>
<tr>
<td>departurecold</td>
<td>-4,076.37 (0.0016)</td>
<td>-1,374.58 (0.2606)</td>
<td>89.54 (0.8540)</td>
<td>-903.66 (0.5321)</td>
</tr>
<tr>
<td>raintotal</td>
<td>-1,832.24 (0.0569)</td>
<td>-3,473.40 (0.0000)</td>
<td>-2,655.13 (0.0857)</td>
<td>-2,467.43 (0.0001)</td>
</tr>
<tr>
<td>snow</td>
<td>-4,069.00 (0.0003)</td>
<td>932.72 (0.3870)</td>
<td>N/A</td>
<td>-4,316.57 (0.0553)</td>
</tr>
<tr>
<td>gasprice</td>
<td>41.33 (0.0018)</td>
<td>28.66 (0.0001)</td>
<td>22.03 (0.0232)</td>
<td>23.40 (0.0022)</td>
</tr>
<tr>
<td>laborforce</td>
<td>0.03 (0.7268)</td>
<td>-0.05 (0.1869)</td>
<td>-0.03 (0.3647)</td>
<td>-0.09 (0.0959)</td>
</tr>
<tr>
<td>revenuehours</td>
<td>4.96 (0.4533)</td>
<td>32.75 (0.0000)</td>
<td>48.00 (0.0000)</td>
<td>48.84 (0.0000)</td>
</tr>
<tr>
<td>unemployment</td>
<td>2,845.15 (0.0053)</td>
<td>-1,977.10 (0.0045)</td>
<td>-19.70 (0.9083)</td>
<td>2,424.04 (0.0001)</td>
</tr>
<tr>
<td>fare</td>
<td>1,933.27 (0.7716)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Monday</td>
<td>20,311.26 (0.0040)</td>
<td>-6,523.85 (0.1624)</td>
<td>-24,145.8 (0.0000)</td>
<td>23,309.60 (0.0104)</td>
</tr>
<tr>
<td>Tuesday</td>
<td>21,227.88 (0.0024)</td>
<td>-5,802.63 (0.2000)</td>
<td>-23,720.98 (0.0000)</td>
<td>-23,207.99 (0.0106)</td>
</tr>
<tr>
<td>Wednesday</td>
<td>21,080.47 (0.0025)</td>
<td>-6,113.30 (0.1776)</td>
<td>-24,255.02 (0.0000)</td>
<td>-22,645.37 (0.0125)</td>
</tr>
<tr>
<td>Thursday</td>
<td>20,817.44 (0.0029)</td>
<td>-6,344.06 (0.1623)</td>
<td>-24,461.67 (0.0000)</td>
<td>-23,613.83 (0.0092)</td>
</tr>
<tr>
<td>Friday</td>
<td>21,253.83 (0.0024)</td>
<td>-6,578.40 (0.1477)</td>
<td>-24,681.17 (0.0000)</td>
<td>-24,741.93 (0.0064)</td>
</tr>
<tr>
<td>Saturday</td>
<td>6,683.02 (0.0000)</td>
<td>1,594.52 (0.1089)</td>
<td>-2,221.18 (0.0295)</td>
<td>-2,828.48 (0.1548)</td>
</tr>
<tr>
<td>HolidaySaturday</td>
<td>-14,578.69 (0.0106)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>HolidaySunday</td>
<td>-20,571.16 (0.0047)</td>
<td>6,214.94 (0.1792)</td>
<td>28,607.42 (0.0000)</td>
<td>25,491.72 (0.0053)</td>
</tr>
<tr>
<td>AR(1)</td>
<td>0.22 (0.0014)</td>
<td>0.38 (0.0000)</td>
<td>0.39 (0.0000)</td>
<td>0.35 (0.0000)</td>
</tr>
<tr>
<td>AR(2)</td>
<td>0.16 (0.0004)</td>
<td>0.15 (0.0179)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Intercept</td>
<td>-24,092.31 (0.1183)</td>
<td>12,622.35 (0.3293)</td>
<td>-14,964.75 (0.2854)</td>
<td>-2,902.04 (0.8545)</td>
</tr>
<tr>
<td>Observations</td>
<td>269</td>
<td>276</td>
<td>276</td>
<td>273</td>
</tr>
<tr>
<td>Adj R-squared</td>
<td>0.9237</td>
<td>0.9774</td>
<td>0.9726</td>
<td>0.9455</td>
</tr>
</tbody>
</table>

(): p-value

N/A: variable was omitted because there were no changes or occurrences of that variable during the study period, or AR(n) was unnecessary.
Table 2. Restricted Model Results

<table>
<thead>
<tr>
<th>Dependent Variable: riders</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Independent Variable</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>windspeed</strong></td>
<td>-170.42 (0.0013)</td>
<td>-109.00 (0.0070)</td>
<td>---</td>
<td>-186.46 (0.0303)</td>
</tr>
<tr>
<td><strong>departurewarm</strong></td>
<td>1,988.95 (0.1130)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>departurecold</strong></td>
<td>-3,949.38 (0.0023)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>raintotal</strong></td>
<td>-1,776.88 (0.0724)</td>
<td>-3,649.76 (0.0000)</td>
<td>-2,726.26 (0.0066)</td>
<td>-2,304.98 (0.0000)</td>
</tr>
<tr>
<td><strong>snow</strong></td>
<td>-3,910.39 (0.0002)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>gasprice</strong></td>
<td>55.83 (0.0000)</td>
<td>24.11 (0.0000)</td>
<td>19.78 (0.0001)</td>
<td>22.51 (0.0061)</td>
</tr>
<tr>
<td><strong>laborforce</strong></td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>-0.10 (0.0233)</td>
</tr>
<tr>
<td><strong>revenuehours</strong></td>
<td>---</td>
<td>26.82 (0.0000)</td>
<td>44.92 (0.0000)</td>
<td>48.93 (0.0000)</td>
</tr>
<tr>
<td><strong>unemployment</strong></td>
<td>3,594.10 (0.0000)</td>
<td>-2,017.17 (0.0035)</td>
<td>---</td>
<td>2,521.91 (0.0001)</td>
</tr>
<tr>
<td><strong>fare</strong></td>
<td>---</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Monday</strong></td>
<td>25,569.48 (0.0000)</td>
<td>---</td>
<td>-20,924.29 (0.0000)</td>
<td>-23,430.56 (0.0055)</td>
</tr>
<tr>
<td><strong>Tuesday</strong></td>
<td>26,443.65 (0.0000)</td>
<td>---</td>
<td>-20,519.80 (0.0000)</td>
<td>-23,337.41 (0.0060)</td>
</tr>
<tr>
<td><strong>Wednesday</strong></td>
<td>26,310.86 (0.0000)</td>
<td>---</td>
<td>-21,051.90 (0.0000)</td>
<td>-22,776.70 (0.0078)</td>
</tr>
<tr>
<td><strong>Thursday</strong></td>
<td>26,022.19 (0.0000)</td>
<td>---</td>
<td>-21,224.20 (0.0000)</td>
<td>-23,776.21 (0.0054)</td>
</tr>
<tr>
<td><strong>Friday</strong></td>
<td>26,495.89 (0.0000)</td>
<td>---</td>
<td>-21,468.33 (0.0000)</td>
<td>-24,850.88 (0.0038)</td>
</tr>
<tr>
<td><strong>Saturday</strong></td>
<td>7,805.53 (0.0000)</td>
<td>2,977.91 (0.0000)</td>
<td>-1,529.34 (0.1213)</td>
<td>-2,792.50 (0.1320)</td>
</tr>
<tr>
<td><strong>HolidaySaturday</strong></td>
<td>-18,866.12 (0.0000)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>HolidaySunday</strong></td>
<td>-25,642.01 (0.0000)</td>
<td>---</td>
<td>25,430.75 (0.0000)</td>
<td>25,419.08 (0.0026)</td>
</tr>
<tr>
<td><strong>AR(1)</strong></td>
<td>0.25 (0.0000)</td>
<td>0.38 (0.0000)</td>
<td>0.39 (0.0000)</td>
<td>0.33 (0.0003)</td>
</tr>
<tr>
<td><strong>AR(2)</strong></td>
<td>0.16 (0.0000)</td>
<td>0.15 (0.0133)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Intercept</strong></td>
<td>-15,346.55 (0.0066)</td>
<td>-2,302.33 (0.5298)</td>
<td>-25,399.08 (0.0000)</td>
<td>-2,166.29 (0.8564)</td>
</tr>
<tr>
<td><strong>Observations</strong></td>
<td>269</td>
<td>276</td>
<td>276</td>
<td>273</td>
</tr>
<tr>
<td><strong>Adj R-squared</strong></td>
<td>0.9236</td>
<td>0.9775</td>
<td>0.9729</td>
<td>0.9454</td>
</tr>
</tbody>
</table>

(): p-value
N/A: Variable was omitted because there were no changes or occurrences of that variable during the study period, or AR(n) was unnecessary.
---: Variable was omitted because it was insignificant in the unrestricted model.

Average wind speed was significant in the winter, spring, and autumn models, but not summer. A 1-mph (1.6 kph) increase in average wind speed resulted in decreases in ridership of 170 in winter, or a 0.48 percent drop from the average ridership in that season. The decrease was 109 (0.29%), and 186 (0.48%) for spring and autumn, respectively. Assuming a linear relationship, a 10-mph (16 kph) increase
in wind speed would lead to a decrease of 1,865 riders in autumn, a drop of 4.84 percent. Although the model assumed a linear relationship between ridership and wind speed, this may not be true in reality, as wind speed may have a greater effect during strong wind events.

Temperature was found to affect ridership in the winter months only. The colder-than-normal variable was statistically significant, and the warmer-than-normal variable was on the border of being statistically significant. A temperature that was more than 7°F cooler than normal resulted in 3,949 (11.23%) fewer riders, while a temperature that was more than 7°F warmer than normal resulted in 1,989 (5.66%) more riders. This suggests that ridership decreases in cooler than normal temperatures and increases in warmer than normal temperatures during the winter months. This is logical, as cold temperatures make waiting for the bus outside more uncomfortable. The variables may be insignificant in the spring, summer, and autumn months because temperatures in those seasons are more comfortable than in winter, and departures from the normal temperature are still generally comfortable.

Rain was the only variable that was significant in all four seasons. One inch (2.5 cm) of rain resulted in decreases in ridership of 1,777 (5.05%) for winter, 3,650 (9.73%) for spring, 2,726 (7.36%) for summer, and 2,304 (5.97%) for autumn. These results are logical, as rainy weather makes waiting for a bus in the rain unpleasant if no shelter is provided. When it rains, many people likely switch to automobiles for transportation if that mode provides a more comfortable experience. Rain may also affect travel in general, reducing travel on all modes. In addition, rain may decrease bus operating speeds, making the mode less attractive to travelers.

The final weather variable, snow, was significant in winter and on the border of being significant in autumn. The occurrence of snowfall led to a decrease of 3,910 (11.12%) riders in winter and 5,052 (13.10%) riders in autumn. Snow may cause travelers to choose a different mode or to not travel at all. In addition, some Pierce Transit route alignments are modified when it snows, which likely reduces ridership.

**Sensitivity Analysis**

Sensitivity analysis was used to test the sensitivity of the regression models to modifications. The first sensitivity test dropped Saturdays and Sundays from the models and estimated them using weekdays only. Table 3 presents the results for the weather variables from the restricted models. In general, the coefficients are larger than in the original models due to higher average ridership on weekdays.
than on all days, but the significant variables are largely the same. Rain became insignificant in the summer model, but warmer than normal temperatures became significant in the autumn model and had a positive impact on ridership.

**Table 3. Weekday Model Results**

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
</tr>
</thead>
<tbody>
<tr>
<td>windspeed</td>
<td>-190.88 (0.0045)</td>
<td>-108.93 (0.0562)</td>
<td>---</td>
<td>-188.97 (0.0905)</td>
</tr>
<tr>
<td>departurewarm</td>
<td>3,060.64 (0.0128)</td>
<td>---</td>
<td>---</td>
<td>1,925.41 (0.0668)</td>
</tr>
<tr>
<td>departurecold</td>
<td>-5,778.00 (0.0006)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>raintotal</td>
<td>-2,308.68 (0.0186)</td>
<td>-4,733.23 (0.0002)</td>
<td>---</td>
<td>-3,114.87 (0.0001)</td>
</tr>
<tr>
<td>snow</td>
<td>-5,915.16 (0.0000)</td>
<td>---</td>
<td>---</td>
<td>-8,374.21 (0.0880)</td>
</tr>
</tbody>
</table>

(): p-value
---: Variable was omitted because it was insignificant in the unrestricted model.

In the second sensitivity test, outlying observations with at least 1 inch of daily rainfall (14 observations) and/or an average wind speed of 15 mph (32 observations) were excluded. Table 4 presents the results for the weather variables from the restricted models. The results are slightly different but mostly similar to the original results. Wind speed became insignificant in the winter and autumn models, snow became insignificant in the autumn model, and warmer-than-normal temperatures became significant in the autumn model. This suggests that wind may only have a significant impact in autumn and winter on very windy days. The significance of rain was not affected by removing outliers.

**Table 4. Outliers-Removed Model Results**

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
</tr>
</thead>
<tbody>
<tr>
<td>windspeed</td>
<td>---</td>
<td>-105.41 (0.0122)</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>departurewarm</td>
<td>2,885.43 (0.0300)</td>
<td>---</td>
<td>---</td>
<td>1,651.14 (0.0226)</td>
</tr>
<tr>
<td>departurecold</td>
<td>-4,767.64 (0.0005)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>raintotal</td>
<td>-3,964.41 (0.0044)</td>
<td>-3,783.70 (0.0000)</td>
<td>-2,726.26 (0.0066)</td>
<td>-3,979.32 (0.0024)</td>
</tr>
<tr>
<td>snow</td>
<td>-4,195.79 (0.0009)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

(): p-value
---: Variable was omitted because it was insignificant in the unrestricted model.
The sensitivity analysis yielded interesting findings. Wind speed may not have as strong an impact as the original results suggest, except when winds are very strong. In addition, warmer-than-normal temperatures may lead to increased ridership in autumn, which the original model did not show. The changes in results caused by modifying the models indicate that they are somewhat sensitive to removing weekend days and outliers. The choice of which data are included in the analysis can affect the results, but the overall conclusions of the analysis remain the same. Each weather variable had an effect on ridership in at least one season, and rain was the most significant variable throughout the year.

**Discussion**

The results of this study are consistent with others in suggesting that adverse weather conditions lead to lower transit ridership. Each of the four weather variables had a significant effect on ridership in at least one season. Winter was the season most affected by weather, while summer was the least affected. Puget Sound weather during the summer is generally less severe than in other seasons, so it is logical that weather affects transit less in that season than in others.

This study adds to the small body of research on the effects of weather on transit ridership by using different analysis methods as well as a new study area. The use of absolute level and relative change methods for different variables and the inclusion of independent variables other than weather distinguish this study from others on the topic. Examining the relationship between weather and transit ridership for different agencies in various geographic areas is important because the weather-transit relationship may vary in different locations.

The results are significant for Pierce Transit and other transit agencies. Some of the effects that weather has on ridership could be mitigated by making the transit experience more comfortable. A common belief in the transit industry is that people are more likely to ride transit when they are comfortable while waiting for transit and while on transit vehicles. One way to improve the comfort of waiting passengers is by placing shelters at stops, which provide weather protection and a place to sit (Law and Taylor 2001). Pierce Transit provides shelters at 21 percent of its stops (Sandy Johnson, Pierce Transit, unpublished data), and adding more shelters to highly-used stops could improve ridership, although there has been limited empirical study of the issue. A study on transit amenities found that a bus shelter with walls, a roof, and seating is an amenity that induces trips and that passengers
notice when weather protection is sufficient (Projects for Public Spaces, Inc. and Multisystems, Inc. 1999). In addition, providing a climate-controlled environment on buses can help mitigate the effects of weather.

This study had some limitations. The most significant was the combination of weather data from Sea-Tac Airport in King County with transit data from Pierce County. A more precise analysis would have used weather data from within the transit agency’s service area. Although the airport is close to Pierce County, slightly different weather conditions in the two locations could have occurred, leading to less accurate results. In general, however, Sea-Tac Airport and the Pierce Transit service area have similar weather conditions during the same day, so the results can be used to make general observations about the weather-transit ridership relationship, such as rainfall leading to lower ridership. A second limitation was that the weather data were aggregated for 24-hour periods, but Pierce Transit buses only run during a portion of those hours. So, for example, rain included in the daily rainfall total may have occurred at night, when transit service was not running. It would likely have been more accurate to exclude weather data from the hours when buses were not running. Last, weather conditions such as snow and icy roads adversely affect transit operations and quality of service, which affects ridership. However, it is unknown which component affects ridership more on snowy days: the reduction in passenger comfort or the reductions in quality of service.

Additional research on the weather-transit relationship is necessary and should examine three issues. First, the specifics of the relationship may differ in other climates. Recent studies examined the issue in northern cities, but weather may have a different effect on ridership in cities with hotter climates, such as Phoenix or Houston. Second, further research should determine whether different types of bus routes are affected differently. For instance, routes that serve primarily park-and-ride lots with shelters may be affected differently than routes that serve areas where people walk to the closest bus stop. Last, a similar analysis could use forecast data for the weather variables as opposed to observed data because people may base their travel decisions on the forecast from the previous night rather than on actual conditions.

Acknowledgments

The authors thank Sandy Johnson of Pierce Transit for providing data and information about the system.
References


**About the Authors**

**Victor W. Stover** (vstover@nelsonnygaard.com) is a recent graduate of the University of Washington, where he earned master’s degrees in urban planning and civil engineering. He is currently a transportation planner with Nelson\Nygaard Consulting Associates in Seattle.

**Edward D. McCormack** (edm@uw.edu) is a Research Assistant Professor in Civil and Environmental Engineering at the University of Washington.
The Potential Role of Flexible Transport Services in Enhancing Rural Public Transport Provision

Nagendra R. Velaga, John D. Nelson, Steve D. Wright, John H. Farrington
University of Aberdeen, UK

Abstract

This paper explores the existing context of public transport provision in rural and remote areas illustrated with experience from Scotland. A critical review of existing Flexible Transport Services (FTS) in rural areas is provided and illustrated with selected case studies, with the objective of identifying the extent to which FTS can enhance the public transport offer. Findings confirm that FTS offers considerable potential to contribute to and support the public transport system in rural areas; however, the paper also identifies the many challenges in successful development or enhancement of FTS in rural areas.

Introduction

It is widely accepted that a basic problem with rural transport is the lack of opportunities available to access a necessary range of basic service outlets and amenities located in distant centers (Nutley 2003; Kamruzzaman and Hine 2011). Traditionally, for most trips in urban areas, users seeking an alternative to private car use will generally have a choice of several alternative transport modes ranging from a (relatively) low-cost fixed route and fixed schedule public transport service to a high-cost and comfortable private taxi providing door-to-door service. This range of transport supply may not be available for remote and sparsely populated rural
areas, where population density is low. Often, these remote areas are provided with inadequate public transport options for most of the day. The definition and classification of urban and rural areas varies across the world and even within the UK. In this paper, we have considered a six-stage urban-rural classification by the Scottish Government that is based on settlement size and proximity to other bigger settlements (National Statistics 2010).

The need for transport services for socially disadvantaged groups (e.g., older adults, young, and disabled) in rural and remotely located areas is undeniable (Currie 2010). To a great extent, a well-organized public transport system in rural areas can enhance economic growth by improving social inclusion, accessibility, and mobility (Farrington and Farrington 2005). However, the characteristics of rural areas present some barriers to improving and developing public transportation. Examples of such characteristics are (1) rural dwellings are distributed over large areas, (2) population density is low and so potential passenger numbers are limited, and (3) level of demand is unpredictable. As a result, public transport systems in rural areas generally suffer from low and uncertain demand, and service coverage is very limited since the provision of frequent and widespread commercial public transport services is financially unjustifiable for the passenger numbers attainable.

A flexible and demand-responsive transport system has been identified as one of the promising solutions for widespread public transport in rural areas at times that are desired (Mulley and Nelson 2009). Over the last 20 years, many flexible transport services have been established; examples include shared taxicabs, shuttle vans, dial-a-ride services, paratransit services, ring-and-ride services, dial-up buses, lift shares, and car-clubs (Li and Quadrifoglio 2010). However, these are introduced largely as stand-alone services often to cater to a specific group of the population or to fill a specific need. There is little or no integration between services and so they may not offer a comprehensive network solution that could fill the gaps in conventional public transport in rural areas. More recent interest has centered on the extent to which collective or shared taxi services could be used to meet rural accessibility needs; the institutional, regulatory, and financial barriers to the introduction of such a scheme nationwide are explored by Mulley (2010).

FTS have been introduced both as part of the public transport mix and also to meet certain accessibility gaps. It is recognized that accessibility is a multi-dimensional concept relating to the ease with which individuals can reach destinations. Daniels et al. (2011) suggest that a number of different accessibility gaps can, therefore, exist, including a lack of service (spatial gap), inaccessible vehicles (physical gap), no
service at the required time or the journey takes too long (time gap), passengers do not have the required information (information gap), services are too expensive (economic gap), and cultural/attitudinal issues around the use of public transport (cultural/attitudinal gap).

Evidence (Nelson and Phonphitakchai 2011) suggests that a well-designed flexible transport system can integrate different modes of transport to provide more user-centric, comfortable, and cost effective transport options by offering desired flexibility in choosing route, time, mode of transport, service provider, payment system, etc. Therefore, the main objective of this paper is to examine to what extent flexible and demand-responsive transport could be used to enhance public transport provision in rural areas and identify various challenges in implementing and enhancing FTS in rural and remote areas.

Public Transport in Rural Areas: Case Study of Scotland

Public transport in rural areas generally suffers from lack of service availability and infrastructure; services are infrequent, not easily accessible, and not connected to other modes of transport (Halden et al. 2002; Currie 2010). Recently, to enhance accessibility and connectivity for socially-disadvantaged groups the provision of enhanced public transport in remote areas is seen as one of several major rural development rationales (Currie 2010). Despite the efforts by the government, public transport provision in rural areas is still associated with poor service levels (Hurni 2006). This leads to problems of social exclusion particularly for the young, old, low-income, and disabled (Farrington and Farrington 2005; Shergold and Parkhurst 2010).

A study by Farrington et al. (1998) showed that in rural Scotland 89 percent of households had access to a car; moreover, cars were the main mode of transport for 77 percent of journeys, most rural areas were not connected by trains, and buses were used for 2 percent of journeys. Further, output from a survey of commuters who did not use public transport and used a personal car to access their work, study, and other basic amenities (such as hospitals and shopping centers) is shown in Figure 1 (Scottish Executive, 2003). This survey was conducted with the age group of 16 and above, and the sample size was 31,031 randomly-selected households across Scotland. It was identified that in rural areas the most common reason for not using public transport is lack of service availability, followed by no direct route and inconvenience.
In rural areas, if both a public transport service and access to a car are available for a journey, most passengers use a personal car; the main reason is lack of convenient public transport (Scottish Executive 2006a). In Figure 2, passenger views on the convenience of public transport in Scotland are shown. In rural Scotland, about 25 percent of passengers stated that public transport is very inconvenient. Conversely, about 50 percent of urban dwellers regarded public transport as being very convenient. According to the Scottish Household Survey conducted in 2009, only 2 percent of the rural population agreed that they have good public transport (National Statistics 2010).

The geographical classification of Scotland shows that remote rural areas occupy 69 percent of the total land and contain only 6 percent of the total Scottish population (National Statistics 2010). (Here, remote rural areas are defined as settlements of less than 3,000 people not within a 30-minute drive of a settlement of 10,000+ people.)

The road travel time by car to basic amenities (such as hospitals, and shopping centers) by postcode sector in Scotland is shown in Figure 3. From Figure 4, it is revealed that 73, 61, and 85 percent of remote rural population are located more than a 15-minutes drive time by public transport to reach the nearest GP, post office, and shopping facilities, respectively. Further, National Statistics (2010) revealed that about 29 percent of remote rural dwellers are more than 13 minutes and 20 percent are more than 26 minutes from their nearest bus stop.

Access to basic amenities through public transport is an essential requirement for rural dwellers, and the Scottish Government has recognized inadequate public transport as a major cause of social exclusion in remote rural areas (Scottish Executive 2001). Considering the conditions of public transport in remote areas of Scotland, in order to enhance social inclusion, accessibility, and mobility, there is a clear imperative to further improve transport provision. In the following section, the potential for demand-responsive and flexible transport services in rural and remote areas is reviewed.
The Potential Role of Flexible Transport Services in Enhancing Rural Public Transport Provision

Figure 1. Reasons for not using public transport

Source: Scottish Executive, 2003

Figure 2. Views on the convenience of public transport in Scotland

Source: Scottish Executive, 2006a
Figure 3. Road travel time to basic amenities by postcode sector in Scotland

Source: Modified from Halden et al. (2002) and TACTRAN (2008)
Review of Flexible Transport Services in Rural Areas

It seems unlikely that traditional fixed-route public transport in rural areas can be expected to provide a greater contribution than at present; the main barriers to this are identified as effective deployment in terms of both financial and carbon efficiency (Shergold and Parkhurst 2010). Recent studies suggest that one set of solutions for rural transport problems could be demand-led approaches such as demand-responsive flexible transport services, more formalized lift-giving, and community transport schemes (Mulley 2010). However, implementation of these demand-led approaches in rural areas has associated problems or limitations such as with technology, integration, and cost (Shergold and Parkhurst 2010).

A feasibility evaluation of FTS by Takeuchi et al. (2003) showed that FTS is one of the better solutions for transport problems in remote areas with low demand where conventional public transport systems are not appropriate. It was identified that FTS can improve mobility for special users (such as older adults and persons with disabilities) in rural areas because users are specific and demand density is small. Scott (2010) reviewed a specific FTS (Treintaxi services in Netherlands) that connects train stations and surrounding suburban and rural areas and found that Treintaxi services improve connectivity. In an international review, Enoch et al. (2004) found that fixed-route, fixed-schedule public buses are not ideally suited to serving dispersed rural areas with correspondingly low demand for public transport; and substitution of FTS can substantially replace conventional public transport.
transport services. However, there can be problems with lack of operators willing or able to participate in rural areas and in smaller settlements, leading to shortage of vehicles (Grosso et al. 2002). One possibility is to establish a service based on taxis in remote areas, although this may require considerable effort by local authorities (Enoch et al. 2004).

Brake and Nelson (2007) identified that in a deregulated public transport environment (such as the UK), more integrated flexible transport solutions (e.g., permitting the general public on education contract services, the use of taxis for shared public transport, and the provision of vehicles enabling access to work) based on people’s real needs are required. Their research has examined the conditions that shape the provision of rural transport (such as demand pattern, rural accessibility) and analyzed the role of FTS in rural public transport using a case study of rural flexible transport schemes (Phone and Go services) in Northumberland, UK. Their study revealed that full integration of fixed-route public transport with FTS and links between stakeholders working in partnership would lead to enhancement of the rural transport system; similar findings have been demonstrated in urban and peri-urban locations (Nelson and Phonphitakchai 2011).

In 2008, the UK Commission for Integrated Transport (CfIT) examined the role of taxi-based demand-responsive transport services alongside conventional public transport in meeting rural accessibility needs (CfIT 2008). Its project conducted primary desktop research of publicly-available data, case studies, and stakeholder consultation of existing rural FTS across the UK and mainland Europe (see Figure 5). Their analysis concluded that demand-responsive FTS could be a promising solution to connect remote rural areas—with low population density and individuals with different requirements—and conventional public transport on main corridors. It was also found that integrated large-scale (regional) rural FTS with public transport can offer several benefits (for example, cost efficiencies, better services). From case studies, it was also noted that significant amounts of public subsidy/funding are generally provided to improve and maintain public transport services in rural areas, though this has not generally been applied to rural FTS (CfIT 2008).

A recent review of 48 FTS schemes in England and Wales (Laws et al, 2009) found that in rural areas, 16 out of 25 FTS require more than £5 subsidy per passenger trip, 8 out of 25 FTS require £2–£5 subsidy per passenger trip, and one service is breaking even. Funding remains a key barrier to the introduction of FTS in rural areas.
Within the UK, Mulley (2010) has analyzed the barriers to a nationwide shared taxi service to improve rural accessibility. Mulley concluded that while no institutional barriers have been identified within the deregulated framework for the introduction of collective taxi-based services, there is a complex regulatory system and an environment, through subsidy policy, that militates against the provision of a good quality taxi-based service, as observed in mainland Europe.

FTS has also been identified as attractive not only because it can potentially be integrated with, and complementary to, conventional public transport services but it is also considered as an option for reducing vehicle pollutants (such as CO, NOx and Particulate Matter) by optimal use of vehicles (Dessouky et al. 2003; Tuomisto and Tainio 2005; Diana et al. 2007). It should be noted, however, that such studies have not explicitly considered the rural context.

Hensher (2007) compared fixed-route public transport and informal flexible transport systems in some developing countries (e.g., the taxi van industry in South Africa). It was identified that FTS services offer the best transport service to con-
nect main public transport corridors in low-density areas (suburban and rural); however, a greater focus should be placed on making these informal FTS safer and more reliable.

With this evidence, it can be inferred that FTS is widely seen as very effective in extending and augmenting public transport in rural areas and can become an accepted form of public transport. However, there are some issues (e.g., technological, financial, integration, shortage of vehicles, safety, and reliability) in developing and enhancing FTS in rural areas. The following section explores the experiences with FTS in rural Scotland and identifies various challenges and opportunities for the enhancement of existing FTS.

Existing Experience with FTS in Rural Scotland
Scotland has wide experience with FTS services, many of which operate in rural areas. In 2006, there were about 140 schemes in operation, and their spread—categorized by user type and operator type—is illustrated in Figure 6.

Source: Modified from Scottish Executive, 2006b

Figure 6. FTS schemes in Scotland
From Figure 6, it can be observed that more than 50 percent of FTS are dedicated to mobility-impaired clients, with about 12 percent for general healthcare. None of the general healthcare FTS are established in the Scottish Highlands, where most of the land is rural and remote rural. There are five FTS schemes specifically for older adults and only one specifically for young passengers. It can be inferred from this that these groups could be perceived as potentially likely to be excluded. FTS schemes are operated/managed/commissioned by a range of different groups; it was also identified that most of the FTS in Scotland are community/volunteer and commercial type operation, and only about 7 percent are operated by local authorities.

Some examples of current and previous FTS schemes for the general public in rural Scotland are listed in Table 1.

Characteristics of the above FTS schemes in Scotland are further discussed here.

- The Gaberlunzie bus service in East Lothian was one of the earliest DRT services in rural Scotland. This service aimed to connect rural areas to the local towns of Haddington and Dunbar. Due to the high cost per passenger trip (£12), in 2001, this service was redesigned as a fixed route Monday–Saturday service (Scottish Executive 2006b).

- Flexible Transport Agency Services in Angus, which started in March 2002, were part of a European project funded by the EU-IST Programme (Eloranta and Masson 2004). The Angus FTS was not able to expand as a local agency for two principal reasons: (1) a variable pricing structure through the different operators (i.e., users did not necessarily have a constant price for a trip) due to the service being provided by different operators; and (2) users choosing to directly communicate with the operator for subsequent trips rather than through the Travel Dispatch Center (Scottish Executive 2006b).

- Midlothian Council’s Dial a Journey service was established in 2003 to replace the conventional bus services withdrawn due to increasing costs and declining demand. The Dial a Journey service was run by local taxi operators (under taxi legislation), with conventional bus fares charged to passengers. The difference between taxi and bus fares was topped up by the council (Scottish Executive, 2006b). This service was stopped in March 2007 due to lack of funding.

- The Aberdeenshire A2B dial-a-bus is a demand-responsive door-to-door transport service introduced by Aberdeenshire Council in 2004 with assis-
<table>
<thead>
<tr>
<th>Area or Council</th>
<th>Scheme</th>
<th>Level of Flexibility</th>
<th>Operators</th>
<th>Start Date</th>
<th>End Date</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midlothian</td>
<td>Dial a Journey</td>
<td>Flexible</td>
<td>Local taxi operators</td>
<td>March 2003</td>
<td>March 2007</td>
<td>Scottish Executive (2006b)</td>
</tr>
<tr>
<td>Aberdeenshire</td>
<td>A2B Dial-a-Bus: Alford; Central Buchan; Fraserburgh; Huntly; Inverurie; Oldmeldrum; Peterhead; Strathdon; Turriff and Westhill</td>
<td>Fully-flexible</td>
<td>Stagecoach Bluebird, local taxi firms and Aberdeenshire Council</td>
<td>2004</td>
<td>Still operating</td>
<td><a href="http://www.aberdeenshire.gov.uk/publictransport/a2bdialabus/index.asp">http://www.aberdeenshire.gov.uk/publictransport/a2bdialabus/index.asp</a></td>
</tr>
<tr>
<td>Fife</td>
<td>Ring &amp; Ride Kirkcaldy; Levenmouth - (Leven/Buckhaven/Methil/Methilhill, Kennoway, Windygates); Dunfermline (inc Rosyth); Glenrothes</td>
<td>Destination specific and flexible route</td>
<td>Stagecoach</td>
<td>2004</td>
<td>Still operating</td>
<td><a href="http://www.fifedirect.org.uk">http://www.fifedirect.org.uk</a></td>
</tr>
<tr>
<td>Highland</td>
<td>Dial-a-Bus Aird; Ardross; Black Isle; Dornoch; Gairloch; Nairnshire</td>
<td>Fully-flexible</td>
<td>Local bus and taxi firms</td>
<td>From 1998</td>
<td>Still operating</td>
<td><a href="http://www.highland.gov.uk/">http://www.highland.gov.uk/</a></td>
</tr>
<tr>
<td>West Lothian Council area</td>
<td>Taxibus services</td>
<td>Semi-flexible area-wide services</td>
<td>Local taxi firm</td>
<td>May 2011</td>
<td>Still operating</td>
<td><a href="http://www.travelnescotland.com/cms/content%5C://WL_Taxibus.xmthtlang=en">http://www.travelnescotland.com/cms/content\://WL_Taxibus.xmthtlang=en</a></td>
</tr>
<tr>
<td>Strathclyde (Strathclyde Passenger Transport)</td>
<td>My Bus</td>
<td>Semi-flexible area-wide services</td>
<td>Local bus and community transport groups</td>
<td>1996</td>
<td>Still operating</td>
<td><a href="http://www.spt.co.uk/mybus/">http://www.spt.co.uk/mybus/</a></td>
</tr>
</tbody>
</table>
The Potential Role of Flexible Transport Services in Enhancing Rural Public Transport Provision

tance from the Scottish Executive. The services are fully flexible within defined areas and offer pick-up from the user’s door, home road-end, or a recognized bus stop. Bookings are made through the Council-run booking office and can be made on the day of travel subject to availability.

• Fife Ring & Ride is a door-to-door service that will take users anywhere within the local operating area. Bookings are made through the Council-run booking office the day before travel.

• Highland Dial-a-Bus provides an on-demand service within a defined area and time period and is available to all members of the public. Several of the services have replaced fixed-route buses. Bookings are made with the relevant provider the day before travel.

• The Stirling Council DRT Scheme is provided in rural areas where commercial or conventional bus operators are unable to provide bus services. Bookings are made with the provider the day before travel, but every effort is made to accommodate passengers making bookings at shorter notice.

• West Lothian Taxibus provides public transport to areas at times when no bus service is available. Bookings are made direct to the taxi operator the day before travel.

• MyBus is another of the earlier demand-responsive flexible transport services in Scotland designed to help all people living in rural areas with limited or no public transport. Additionally, it operates throughout metropolitan areas of Strathclyde. The services originally established as Dial-A-Ride are now offered on an open-access basis and booked via a common dispatch center.

The majority of the above services allow advanced booking only on the day before travel and use very little or no intelligent transport systems and advanced information and communication technology support. The Aberdeenshire A2B Dial-a-Bus and Strathclyde MyBus services are the exception and allow on-the-day booking supported by booking, scheduling, and dispatching software provided by Trapeze software. The Aberdeenshire service is also designed to provide interchange at selected points to the main public transport network, enabling travel outside the A2B areas.

The examples above show that often FTS for the public are introduced either where no other public transport is available or to replace fixed-route bus services where demand is especially low or distant from the fixed route. There is an increasing trend towards using taxi operators to provide the services; this offers an already existing vehicle resource as well as a booking capability and, hence, offers significant reductions in operating costs.
It is clear from the evidence that most of the rural FTS services in Scotland are on a small scale, isolated from each other as well as from other modes of transport (e.g., rail) and lacking strategic or regional planning. The recent study by CfIT (2008) on “A New Approach to Rural Public Transport” suggests there are likely benefits in terms of economies of scale to be gained from more coordinated services implemented across a wider area at the regional scale.

Other recent studies have identified that FTS plays an important and growing role in the spectrum of transport provision in rural Scotland (Juffs 2010). Juffs reports that local authorities have begun to seriously consider the role that FTS could have within local transport infrastructure provision. That realization has not generally emerged as a response to a specific local initiative or policy directive, but more so as bus services, previously regarded as stable and commercially viable, have been withdrawn, leaving local communities more isolated. Due to funding constraints, local authorities are now rarely able to provide support to replace withdrawn fixed-route services but may be able to support a lower-cost FTS, which may actually fill the gap left by more than one withdrawn fixed-route service. Considering the conditions of public transport in remote areas of Scotland and geographical conditions (e.g., rurality and widely spread population), further development and improvement of demand-responsive FTS is one of the promising solutions to enhance social inclusion, accessibility, and mobility. The following section provides various research challenges and opportunities.

Challenges and Opportunities for the Development and Enhancement of FTS in Rural Areas

There are certain problems involved in implementing/enhancing flexible transport in rural areas. This paper has considered evidence drawn from a review of various pilot FTS projects in rural Scotland, consultation with rural FTS scheme operators (e.g., Aberdeenshire Council), and presentation and targeted group discussion with FTS routing and scheduling software providers (e.g., Trapeze software) to identify various challenges and opportunities to develop and enhance FTS in rural areas. The following eight research challenges are identified.

1. Adopt a holistic approach (user, operator, and transport authority perspectives): There are three major players involved in a typical FTS: users, operators, and transport authorities. So far, researchers have generally concentrated either on user (passenger) perspectives or operator perspectives. For example, Finn (1999) and INVETE (2000) concentrated on passenger user requirements; Chen and Tsai (2008) and Garaix et al. (2010) developed
optimization methods or techniques to maximize benefits to FTS operators. Often, the perspective of the transport authority is neglected. Moreover, considering requirements from all three components together can lead to a better outcome, such as the development of an intelligent decision making method that can fulfill user requirements, minimize cost, maximize operator benefits, and consider the regulations made by transport authorities.

2. **A clear national level plan:** It can be seen in Figure 6 that flexible transport services are generally planned and offered for limited areas by particular local authorities by targeting specific categories of people in the community. Developing a national-level plan for FTS, as advocated by Juffs (2010), may encourage better integration and coordination of services, leading to improved economic growth and increased social inclusion. However, development of a national FTS plan requires cooperation and coordination among different public authorities; it might be more difficult to achieve this, as different levels of government are often responsible for different aspects of public service delivery.

3. **Integration of multiple modes:** Integration of other modes of transport (e.g., rail) with flexible transport systems can improve the overall system performance (e.g., combined ticketing and payment system) and enable complete journey times and connections to be planned. Further research could develop a framework to support the integration of other modes of transport with FTS.

4. **Service availability:** Unlike urban areas, in rural areas it is very difficult to find transport service providers willing to cooperate to provide FTS. Due to the lack of service providers, often the service will be very costly or ineffective. Consider, as an example, an older adult passenger who wants to travel to an airport from a remote area that is far from the destination point; due to the lack of availability of transport service providers, the passenger may be recommended either to travel by taxi, which is very costly, or to travel on the previous day, which is inconvenient. Research could investigate further the mechanisms required to make better use of the available transport resource in remote rural areas (e.g., supported area-wide shared taxis schemes or building Community Transport capacity and capability).

5. **Accessibility to remote areas:** Rural dwellings are normally distributed over a large area. For example, about 20 percent of the UK’s population live in rural areas distributed across about 80 percent of the land (House of Commons 2000; National Statistics 2010). It is very difficult to develop flexible
transport systems that can pick-up and drop-off according to the individual user’s desire. Some remote areas are not easily accessible. In some cases, these remote areas are not appropriately connected to a necessary range of basic service outlets and amenities (e.g., hospitals, schools) located in distant centers; this particularly affects socially-disadvantaged groups (e.g., older adults). Another research opportunity could be to look into the accessibility requirements of older adults, patients, and physically-challenged passengers in remote areas and the effect this has on FTS design and operation.

6. **Understanding uncertainties and estimating transport demand in rural areas:** Travel demand in rural areas is not easy to forecast. In the context of rural FTS, if transport demand models could be used to predict the potential transport requirements, then this would provide a very useful tool to aid the planning and scheduling of FTS vehicles.

7. **Define appropriate evaluation methods and tools:** There appears to be no fully accepted or implemented approach to the ex-ante or ex-post evaluation of FTS; this is a significant challenge, both for the planning and implementation of specific programs and schemes and for the understanding of benefits and costs. The method of Social Return on Investment (SROI) promises the ability to capture the wider, non-market benefits that FTS are designed to realize (see, e.g., Wright et al. 2009). While this speaks to a broader social agenda, transport policy makers and practitioners are also likely to require benefit-cost analysis of proposed FTS schemes.

8. **Real-time communication to and from users:** Communicating with passengers in real-time is also a major issue in remote areas. The principal mode of communication is telephone and rarely Internet. A more sophisticated passenger information “ecosystem” enabling all users to share information could enhance the benefits of integrated flexible transport services.

**Conclusions**

Public transport conditions in rural Scotland demonstrate that the main reasons for rural passengers using their personal car are lack of service availability, lack of direct route, and inconvenience. There is clearly a need to provide good quality transport services that are responsive to people’s real needs, flexible, well-marketed, well-integrated, and provide stable and reliable transport services for socially-disadvantaged groups that are not able to access conventional public transport and personal cars. This is especially pertinent in more rural areas. From
this study, it was identified that Flexible Transport Services (FTS) can be a promising solution for developing transport solutions, particularly in rural and remote areas where public transport is not active.

In rural Scotland, FTS has been shown to be a good option for filling gaps in public transport through replacing withdrawn fixed-route bus services at a lower cost or by offering public transport in areas where commercial or conventional bus operators are unable to provide bus services. However, most of the existing Scottish rural flexible transport has limitations, such as small-scale operations, isolation from other modes of transport, targeting only specific categories of people in the community, not allowing booking on day of travel, and use of very little or no intelligent transport systems and advanced information and communication technology support. Removing these limitations could improve the transport conditions in rural areas and enhance mobility and connectivity and, thereby, social inclusion.

In this paper, associated problems involved in implementing/enhancing flexible transport in rural areas are discussed. Through the evidence drawn from a review of rural FTS projects, consultation with rural FTS scheme operators, and presentation and targeted group discussion with FTS routing and scheduling software providers (e.g., Trapeze software) various research challenges and opportunities are identified to develop and enhance FTS in rural areas. These key research challenges include (1) considering user, operator, and transport authority perspectives concurrently; (2) developing a national level FTS plan for rural areas; (3) integrating with different transport modes; (4) addressing some issues related to service provider availability; (5) better appreciation of accessibility and connectivity needs of socially-disadvantaged groups in remote areas; (6) better understanding of uncertainties with transport supply and demand in rural areas; (7) defining appropriate evaluation methods and tools; and (8) enhancing real-time communication with FTS users in rural areas.

Acknowledgments

This research is supported in part by an award made by the RCUK Digital Economy programme to the dot.rural Digital Economy Hub; award reference: EP/G066051/1.
References


INVETE project. 2000. User needs and requirements for the in vehicle terminal, Deliverable D2.


The Potential Role of Flexible Transport Services in Enhancing Rural Public Transport Provision


About the Authors

**DR. NAGENDRA VELAGA** (n.r.velaga@abdn.ac.uk) is Research Fellow in Intelligent Transport Systems at the dot.rural Digital Economy Hub, University of Aberdeen, UK.

**PROFESSOR JOHN NELSON** (j.d.nelson@abdn.ac.uk) holds the Sixth Century Chair of Transport Studies and is Director of the Center for Transport Research, University of Aberdeen, UK.

**DR. STEVE WRIGHT** (s.d.wright@abdn.ac.uk) is a Research Fellow in the Center for Transport Research, University of Aberdeen, UK.

**PROFESSOR JOHN FARRINGTON** (j.farrington@abdn.ac.uk) is Chair of Transport and Environment and Director of the dot.rural Digital Economy Hub, University of Aberdeen, UK.
Are Smart Card Ticketing Systems Profitable? Evidence from the City of Trondheim

Morten Welde
Norwegian University of Science and Technology

Abstract

Electronic ticketing in public transportation based on smart cards is gaining momentum worldwide. It is widely recognized that a smart card system can deliver benefits to both passengers and operators, but due to its complexity, implementation can come at a considerable cost. Therefore, it is likely that a commercial appraisal from the perspective of the public transportation operator alone would reveal that costs are higher than benefits and, hence, economic non-viability. This paper presents the experiences of the Norwegian city of Trondheim, which recently implemented a fully-interoperable electronic smart card system. A social cost-benefit analysis of the scheme is presented, focusing on net overall benefits for the passengers, the bus company, the local transportation authority, and the rest of society. The main conclusion of the paper is that the smart card ticketing system in Trondheim delivers a positive net present value. The paper demonstrates that economic evaluation of smart card ticketing schemes using the principles of social cost-benefit analysis is desirable and possible. Because commercial non-viability may represent constraints to the implementation of such schemes, the findings presented in this paper provide valuable information to those currently working on smart card ticketing strategies.
Background

Electronic ticketing in public transportation based on smart cards is gaining momentum worldwide. It is widely recognized that smart cards can deliver benefits to passengers and public transportation operators through time savings, increased travel convenience, more flexible ticketing, lower administrative costs, and better marketing information. The implementation of smart card systems is, however, a complex process that includes legal, economic, and technological issues. Implementation can thus come at a considerable cost. Therefore, it is likely that a commercial appraisal from the perspective of the public transportation operator alone would reveal costs higher than benefits and, hence, economic non-viability. Authorities and public transportation operators, therefore, often are reluctant to sanction large investments in such systems.

A striking example of transportation investments that may not generate sufficient revenues to justify private investment alone is public transportation investments. Public transportation often is subsidized to ensure that important services are provided even if they do not generate sufficient ticket revenues to justify their operations. Even in countries where the public transportation industry is completely deregulated, there is usually some kind of operator reimbursement for services such as certain rural routes, school travel, or free travel for older adults. Other arguments for subsidizing public transportation include the positive externalities generated by the service, the potential for user-scale economics (often referred to as the Mohring effect), and alleged public or merit good characteristics. This implies that, in reality, very few, if any, investments in public transportation are profitable from a purely commercial perspective. When deciding whether to implement smart card ticketing systems, the investment should be evaluated from a social perspective, following the principles of social cost-benefit analysis. Cost-benefit analysis (CBA) is a methodology based on the valuation of all relevant effects accruing from an investment or policy. Harberger (1971; cited in Winston 2006) described the principles of applied welfare economics through CBA as follows: benefits and costs to consumers should be calculated using consumer surplus; benefits and costs to producers should be calculated using producer surplus; and benefits and costs to each group should be added without regard to the individual(s) to whom they accrue. Thus, it is the change in consumer and/or producer surplus that determines the change in social surplus in a CBA. (For a comprehensive review of cost-benefit theory and methodology, see Boardman et al. 2006.) In other words, CBA is concerned with the welfare of society as a whole and not just a smaller part of it. That will be illustrated in this paper.
This paper presents the experiences of the Norwegian city of Trondheim, which recently implemented a fully-interoperable electronic smart card system. A social cost-benefit analysis of the scheme is presented, focusing on net overall benefits for the passengers, the bus company, the local transportation authority, and the rest of society.

**Smart Card Ticketing in Trondheim**

The city of Trondheim (pop. 175,000), which is the third largest city in Norway, implemented electronic smart cards (the t:card) for its public transportation system in June 2008. It is a region-wide scheme in which customers can use one smart card based on one contract for buses, trams, and regional coaches operated by 10 public transportation operators in Trondheim and the 2 counties surrounding the city. The total population in the two counties, including Trondheim, is approximately 425,000. Prior to this implementation, payment was based on a wide array of paper-based ticketing schemes. Customers still can pay with cash, but soon after implementation, smart card use accounted for approximately 70 percent of all payments; after more than three years of operation, approximately 90 percent of all trips currently are paid for using the t:card. This means that accommodating those customers who still pay their fares by cash is becoming more expensive, which raises the issue of transferring to full-scale electronic ticketing with no option to pay by cash. Customers using the t:card are offered discounts from 5–25 percent, depending on whether a pre-paid amount is deposited on the card or if it is linked to a bank account. In addition, monthly passes are offered, which gives frequent travelers significantly lowers fares than they would pay if purchasing single tickets. The single ticket cash fare in Trondheim is $5.30, while the price of a monthly pass for the greater Trondheim area is $105. (For more information, see the transit authority AtB’s website: www.atb.no.)

In 2009, two thirds of the operating costs of public transportation in Trondheim were paid for by ticket revenues (approximately $35 million). The remaining one third was covered by local authority subsidies. Ten years ago, the share of subsidies to costs was close to zero, but that share has increased due to fare reductions, increased operating costs and increased bus frequencies.

The public transportation system in Trondheim is based on 42 bus routes and 1 tram line. Trains, which are not currently part of the smart card system, carry pas-
sengers to and from neighboring towns. Currently, the total number of bus trips per year is 21 million.

Until recently, bus services in Trondheim were provided by a direct contract with a publicly-owned local bus company, but now are based on gross subsidy tendering, where services are planned and managed by the transit authority AtB, a subsidiary of Sør-Trøndelag County, where Trondheim is located. With services now tendered, the quality of operations is expected to increase due to increased requirements to vehicles and services in the call for tenders. Beginning in fall 2011, all services are now provided by low-floor buses, which, fulfill the Euro 5 guidelines for emissions. New buses also have a rear access option for t:card holders. Although this option increases the risk of fraud, it is expected that it will contribute to reduced dwell times.

Literature Review

Smart cards are used for a number of different transportation applications, among which ticketing is the most widespread. However, despite being invented more than 30 years ago, the history of smart cards is littered with a number of spectacular and costly failures. Regardless, the last 15 years have seen a growing number of smart card schemes being launched, many of which are a result of the success of large-scale electronic ticketing schemes in Asia (Blythe 2004). This has led to an increased interest in investigations into the benefits and costs of smart card ticketing for public transportation.

In a report by the UK Department for Transport (DfT) and Detica (2009), the net present value (NPV) of a national smart ticketing infrastructure over a 10-year period was estimated at $36.8 billion with full take-up. Even with a minimal rollout of smart cards, the NPV was estimated at $2.8 billion, equivalent to a Benefit-Cost Ratio (BCR) of 1.8, which is close to the level considered as a high value for money (2.0). The DfT concluded that the installation of smart card infrastructure in UK public transportation has large one-off costs but relatively low operating costs. The benefits are large and come from factors such as modal shifts, cost savings, increased revenue, fraud reduction, better service, and improved access to and integration with other services. It is worth noting that the DfT report identified real scale economies in the implementation of smart card technology. Although some benefits could be gained from partial implementation, real payback is expected once a full national interoperable scheme is in place.
The view of large potential benefits, however, was not supported by the Confederation of Passenger Transport. In a *Local Transport Today* article published on November 19, 2009, it was argued that the lack of smart card schemes in operation was not a result of market failure, but due to an unviable business case for public transportation operators and uncertain benefits for all parties involved. Fearnley and Johansen (2009) reached the same conclusion in a commercial appraisal of the Flexus system for public transportation in Oslo, which is struggling to implement an interoperable smart card system for buses, trams, and metro lines in Oslo and the neighboring county. The new system provided a negative NPV for the operator, and initial assumptions, so far, have turned out to be overly optimistic.

This is similar to the views of Iseki et al. (2008), who claimed that the benefits of smart card systems often are vague and that it is still unclear whether the benefits of smart cards outweigh the costs. The authors reviewed three case studies (and, according to the authors, the best studies available) of smart card systems in the U.S. and concluded that none of the three studies was based on complete and consistent applications of accepted cost/benefit methodologies. Their conclusions were that smart card systems hold great potential for providing extensive benefits in terms of speed, flexibility, and information, but at substantial time, effort, and monetary costs. The limitations of previous studies and the lack of general methodologies implied, however, that any study of current smart card schemes in operation would require substantial data collection and analysis. In this, Iseki et al. identified one of the most serious shortcomings of intelligent transport systems (ITS) and perhaps of smart card systems in particular: the consistent lack of comprehensive economic evaluations to properly appraise the costs and benefits of such schemes. As argued by Odeck and Welde (2010), when ITS projects are not evaluated according to the same methodologies as traditional transportation investments, many potential ITS projects may lose terrain relative to alternative solutions. In addition, ITS often represents new applications that are still in their early stages in many countries. Ascertaining their expected effects, therefore, often is difficult. This might make traditional evaluation methods such as cost-benefit analysis (CBA) inappropriate. Although frameworks for CBA exist in most countries, these are not necessarily suitable for ITS evaluation. In particular, the limitations of traditional CBA for ITS evaluation are related to data issues, the time horizon, and the valuation of user benefits. Odeck and Welde nevertheless concluded that evaluating ITS projects using the principles of cost-benefit analysis is desirable and possible. Although there are costs and benefits associated with ITS that are difficult to monetize, most of the benefits and costs of ITS schemes, such
as electronic payment systems, are measurable in monetary terms and, therefore, are suitable for CBA.

One of the very few economic appraisals of smart card technologies was presented by Cheung (2006), who analyzed the effects of the Dutch national smart card system. Although not necessarily providing benefits to each of the individual operators involved, the analysis indicated that the project has resulted in large cumulative benefits, with a BCR on the order of 0.2-0.5. The most important direct benefit for passengers was the amount of time spent purchasing tickets, while operators have benefited from reduced fraud and increased opportunities for more sophisticated price differentiation.

More recently, the ability of smart cards to generate new public transportation trips has been highlighted by research by Transport for London and consultant MIT. In a *Local Transport Today* article published on February 25, 2011, TfL’s director of fares and ticketing said that, “Research suggested that 9% of all Oyster ‘pay-as-you-go’ journeys on the Underground were generated by the ease of using the Oystercard.” The increased use of public transportation in London due to the Oyster card was estimated to generate some $83 million per year. This has lead to calls for Oyster card systems to be implemented in neighboring Scotland to encourage bus and rail travel (Wilcox 2011).

**Framework for Evaluation**

In this paper, the evaluation of the smart card system in Trondheim is based on social cost-benefit analysis. Social CBA differs from commercial appraisal in that all costs and benefits associated with a particular scheme are included, regardless of to whom they accrue. This means that a scheme that involves direct revenues and turns out to be non-viable from a commercial perspective still may be desirable from a social perspective when all external benefits and costs are included.

The implementation of an interoperable smart card system in Trondheim was motivated by potential benefits for all parties involved and affected by public transportation in Trondheim: passengers, operators, local authorities, and the wider community. Table 1 outlines the expected impacts for all of the affected groups.
Table 1. Benefits and Costs—Affected Groups

<table>
<thead>
<tr>
<th>Passengers</th>
<th>PT Operators</th>
<th>Local Authorities</th>
<th>Wider Community</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time savings</td>
<td>Time savings</td>
<td>Improved statistics</td>
<td>Cost of taxation</td>
</tr>
<tr>
<td>Reduced delays</td>
<td>Increased reliability</td>
<td>Project costs</td>
<td>Reduced emissions</td>
</tr>
<tr>
<td>Less need to carry cash</td>
<td>Project and investment costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Operating costs</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| + | +/- | -/+ | -/+ |

The introduction of smart cards in public transportation reduces the time spent boarding and paying, provided that payment is done when boarding. This constitutes a time saving for each passenger. Although this may be a small and potentially negligible time saving for the individual—normally not more than a few seconds—it is important to note that the individual passenger will save time at every stop and for every foregoing passenger who previously would have paid by cash. Over the course of an average bus or tram journey, this could constitute a significant time saving for both the passengers and the operator(s). This is similar to the user-scale economies identified by Mohring (1972), where the presence of an additional user increases the likelihood of additional services being provided due to time savings and the resulting increased demand. This also is similar to benefits arising from measures to improve accessibility to passengers with special needs, often referred to as “universal design” (UD). The conventional thinking is that UD is for the few, i.e., the impaired, and given that they are few in numbers, UD projects generally will be unprofitable from a socioeconomic point of view because benefits will be low while investment costs will be high. However, a recent study has shown that UD projects may benefit all users of the facility, whether impaired or not, as the additional costs of implementation often are low; hence, their NPVs often are high and positive (Odeck et al. 2010).

Smart cards often also increase bus route reliability and reduce delays for passengers. Payment by cash can be a complex process, where the average time per passenger varies from a few seconds to more than a minute. This makes scheduling difficult. The introduction of smart cards normally reduces this pay time variability and, hence, contributes to both reduced delays and increased reliability.

Another benefit for passengers and operators is a reduced need for cash. Today, people are increasingly carrying no cash at all, and the percentage of transactions made by credit and debit cards is increasing annually. In 2009, there were 1.2 billion card transactions in Norway (up 10% from 2008). This is equivalent to 246 transac-
tions per person (Norges Bank 2010). Norges Bank, Norway’s central bank, has estimated that cash settles only about 23 percent of transactions at the point of sale, representing 14–38 percent of the value of all sales. The ratio of the cash stock to GDP in Norway has fallen over the past decades and has fallen considerably faster in Norway than in the other Nordic countries (Gresvik and Haare 2008).

It is expected that smart cards, at least initially, increase operating costs for the operators involved. These, along with project and investment costs, which are shared with local authorities, represent the direct costs of implementing the smart card system. In addition, costs financed by the public sector through taxation should be multiplied by 1.20, which is the standard marginal cost of public funds in Norway, reflecting the fact that distortive taxes lower welfare by more than they collect in revenue.

Finally, smart card systems normally provide local authorities with better public transportation statistics and ease the planning and scheduling of services. In addition, operators may benefit from additional information on customer trips, paving the way for loyalty schemes and a better understanding of customer needs and journey patterns (Davis 2002, in Blythe 2004). It is also not unreasonable to believe that, as smart cards reduce dwell time, local emissions could be reduced. This will benefit the wider community.

From the above, we notice that most of the envisaged effects can be measured in monetary terms, and an economic assessment can be done. In CBA, the relevant investment criteria are the net present value (NPV) and the benefit cost ratio (BCR).

The NPV can be expressed as follows:

\[
NPV = I_0 + \sum_{t=0}^{n} \frac{B_t - C_t}{(1 + r)^t}
\]  

Here, \( B \) and \( C \) represent benefits and costs, \( r \) represents the discount rate, and \( t \) represents the time period. The NPV determines the absolute economic merit of a project. If its value is greater than zero, it means that the project generates benefits that are greater than its cost and is therefore profitable from an economic point of view.

The BCR is a value for money measurement and is different from the NPV. It is defined as the ratio of the net benefits of a project to its costs. Formally, the BCR is written as:
The BCR has a simple interpretation, making it useful for policy makers to judge the worthiness of projects in terms of returns per euro invested. If the ratio of NPV to the total costs of carrying out the project ($C$) is, for example, 0.2, it means that the returns are 20 percent, or a 20-cent profit for every dollar invested in the project.

In practice, we use the NPV to determine whether a project is profitable from an economic point of view. If the aim is to rank ITS projects among themselves or against other projects, then the BCR should be used, because it shows which projects give the greatest returns per dollar invested.

**Data and Methodology**

**Data**

The data for the analysis were collected in cooperation with AtB, the body responsible for Trondheim’s public transportation system. Stensrud and Kuipers (2008) provided a comprehensive overview of all costs associated with the smart card system. Although it was implemented in 2008, the process leading up to implementation was arduous and prolonged. The planning started in the early 1990s, but because implementation turned out to be more complex than was first assumed, it was postponed several times. The process even resulted in a court case with the equipment supplier, which ended in a settlement in 2007. After the settlement, the project was restarted and reorganized. Therefore, as the project contents and organization have been so different, the project can be split into two phases: before and after the court settlement in 2007. In this paper, we use the costs after 2007 as the basis for the analysis. The analysis covers only the city of Trondheim and not those neighboring regions where the t:card also can be used.

Time savings usually constitute the largest share of estimated benefits of transportation projects, and the estimation of time saved per passenger, therefore, requires careful calculation. The estimated time saving of 6.8 seconds, as shown in Table 2, for each boarding passenger using a smart card is based on registrations performed by students at the Norwegian University of Science and Technology during the spring of 2009. The means are based on a sample of 900 observations. Unfortunately, this was done almost a year after implementation, and we cannot rule out the possibility that those still opting for cash payment at this stage represent the slower payers. The time savings, thus, may be underestimated. As Table 2
shows, even smart card transactions take time, but cash is more time-consuming and, above all, involves more variability in time spent per passenger, which makes scheduling more difficult.

Table 2. Time in Seconds Spent on Cash Payment vs. Smart Card Payment

<table>
<thead>
<tr>
<th></th>
<th>Cash Transactions</th>
<th>Smart Card Transactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of cases</td>
<td>436</td>
<td>466</td>
</tr>
<tr>
<td>Mean</td>
<td>8.3</td>
<td>1.5</td>
</tr>
<tr>
<td>St. dev.</td>
<td>6.5</td>
<td>1.8</td>
</tr>
<tr>
<td>Minimum</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Maximum</td>
<td>47</td>
<td>18</td>
</tr>
</tbody>
</table>

The analysis is based on measured data after 12–24 months of operation. In addition to time savings, the data are composed of investment and operating costs, reinvestment costs, project costs, bus trips, t:card shares, load factors, and standard national values for the value of time and discount rates. The appraisal period is 10 years. This is considerably shorter than what is used for traditional transportation expenditures, which are appraised over a 25-year period. A 10-year appraisal period reflects the uncertainty associated with technology investment and ensures a conservative approach to the analysis. The main parameters used in the estimation are listed in Table 3.

Table 3. Parameters Used in the Estimation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment costs</td>
<td>$2,400,000</td>
</tr>
<tr>
<td>Operating costs per year</td>
<td>$900,000</td>
</tr>
<tr>
<td>Annual service and maintenance costs</td>
<td>$200,000</td>
</tr>
<tr>
<td>Reinvestment costs (every three years)</td>
<td>$1,400,000</td>
</tr>
<tr>
<td>Project costs (before implementation)</td>
<td>$1,400,000</td>
</tr>
<tr>
<td>Total number of bus trips per year</td>
<td>17,300,000</td>
</tr>
<tr>
<td>Share of trips performed with the t:card</td>
<td>70% in 2008, 80% in 2009, 90% thereafter</td>
</tr>
<tr>
<td>Annual increase in the number of bus trips</td>
<td>2.5%</td>
</tr>
<tr>
<td>Average time saving per t:card transaction</td>
<td>6.8 seconds</td>
</tr>
<tr>
<td>Average load factor</td>
<td>20</td>
</tr>
<tr>
<td>Time value for bus passengers</td>
<td>12.5/hour</td>
</tr>
<tr>
<td>Time value for bus company</td>
<td>65.9/hour</td>
</tr>
<tr>
<td>Discount rate</td>
<td>4.5%</td>
</tr>
<tr>
<td>Appraisal period</td>
<td>10 years</td>
</tr>
<tr>
<td>Marginal cost of public funds</td>
<td>20%</td>
</tr>
</tbody>
</table>

*U.S dollars—values based on exchange rate of August 15, 2011
The Norwegian framework for CBA of transport investment provides guidelines for project appraisal, including standard values of time, marginal cost of public funds, and the discount rate.

**Methodology**

The average time saving per passenger is estimated to be 6.8 seconds for each time a boarding passenger uses a smart card instead of paying by cash. Notice that this does not mean that each smart card transaction represents a time saving. The previous paper-based ticketing arrangements also included monthly passes, which holders would simply display to the bus driver. This proportion of users would not generate time savings when switching to the t:card.

This means that the total gross time savings $t$ per year, measured in hours for passengers using smart cards, can be expressed as follows:

$$T_{\text{t:card},t} = \frac{P_{\text{t:card}} \times tk_{sec}}{3600}$$  \hspace{1cm} (3)

where $P_{\text{t:card}}$ is the total number of passengers using smart cards per year, and $tk_{sec}$ denotes the average time savings per smart card transaction.

The net annual time savings for all passengers is expressed as:

$$T_{\text{tot},t} = (T_{\text{t:card},t} + (T_{\text{t:card},t} \times BP) \times (1 - m))$$  \hspace{1cm} (4)

Here, the time saving for smart card users is adjusted for $m$, the proportion of users with monthly passes in the last year before smart card implementation. In addition, the equation includes time savings for passengers already on the bus (the average load factor), $BP$. These passengers also will save time at each bus stop whenever a boarding passenger uses a smart card.

The annual value of time savings can then easily expressed as:

$$B_t = (T_{\text{tot},t} \times w_p) + (T_{\text{t:card},t} \times w_b)$$  \hspace{1cm} (5)

Here, $w_p$ and $w_b$ express the value of travel time savings for bus passengers and the bus company, respectively.

By including investment costs and operating costs and inserting $B_t$ into Equation (1), we are able to calculate the NPV of the smart card ticketing system in Trondheim.
Results
Based on the data and methodology presented above, a cost-benefit analysis was performed. The results are presented in Table 4.

Table 4. Cost-Benefit Analysis of the Smart Card System in Trondheim

<table>
<thead>
<tr>
<th></th>
<th>NPV Costs*</th>
<th>NPV Benefits</th>
<th>NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment costs</td>
<td>($2,400,000)</td>
<td>32,800,000</td>
<td>16,600,000</td>
</tr>
<tr>
<td>Project costs</td>
<td>($1,400,000)</td>
<td>16,300,000</td>
<td>49,100,000</td>
</tr>
<tr>
<td>Operating and reinvestment costs</td>
<td>($12,000,000)</td>
<td>16,300,000</td>
<td>32,500,000</td>
</tr>
<tr>
<td>Marginal cost of public funds</td>
<td>($800,000)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time savings of bus passengers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time savings of bus company</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>NPV</strong></td>
<td><strong>(16,600,000)</strong></td>
<td><strong>49,100,000</strong></td>
<td><strong>32,500,000</strong></td>
</tr>
<tr>
<td><strong>BCR</strong></td>
<td></td>
<td></td>
<td><strong>1.96</strong></td>
</tr>
</tbody>
</table>

The smart card ticketing system in Trondheim is profitable from a socioeconomic point of view, with an NPV of $32.5 million. This equals a BCR of 1.96, meaning that $1 spent on the t:card system generates benefits of $2.96. This is also substantially more than what is usually provided through traditional transportation expenditure, which, in the Norwegian case, may struggle to deliver a positive NPV at all. This analysis differs from one that a transit agency or a public transportation operator typically might carry out in two respects, in that it includes the costs of funds financed by taxation and, most importantly, it includes the values of travel time savings for both bus passengers and the bus company.

The implementation of smart card ticketing is a complex process, involving a number of actors and requiring readjustments for both operators and passengers. It often takes time before all challenges are overcome and before all benefits can be realized. In our opinion, the long-term objective should be to abolish cash payment completely. This will increase the social surplus further through the elimination of the need to handle cash—an expensive operation. In some countries, abolishing cash payment is said to be unrealistic, as certain income groups do not qualify for credit card payments or pre-paid card payments. That may be true for activities such as grocery shopping, but public transportation ticketing systems, which are based on small amounts, usually do not rely fully on customers qualifying for credit or who have their travel card accounts linked to a bank account. Both the t:card in Trondheim and the Oyster card in London allow users to store a pre-paid cash amount on the card regardless of creditworthiness.
In time, it should also be a realistic objective to reduce the costs of operating the system. The first years of a new ticketing system often have a high number of customer inquiries, but as users become familiar with the system and take advantage of more efficient ways to manage their contracts, savings could be realized. It is also worth noting that conservative estimates were used throughout the analysis. It is likely that the NPV of Trondheim’s smart card system is higher than that estimated above.

There are a number of benefits that are not monetized and included in the analysis. One such benefit is the above-mentioned reduced need for cash. For bus drivers, large amounts of cash pose a security risk. During the last five years, there have been several robberies and attempted robberies on buses in Trondheim, and the union representing the drivers has suggested a complete removal of all cash on board the buses. In Sweden, work to remove cash from buses is in progress in several cities (Rathe 2008), and the t:card could therefore be a step in the direction of cashless public transportation in Trondheim.

Another non-monetized benefit is the improved quality of public transportation statistics. Accurate travel information is important for transportation research, policy analysis, and planning. Previous paper-based systems failed to provide planners with necessary information. Statistics were incomplete and consisted of a limited set of information needed for analysis and planning. Previously, the bus company in Trondheim, which was responsible for collecting the data, even failed to provide information on the development in the number of bus passengers from one year to the next. The introduction of smart cards has improved this situation, and now detailed statistics on the number of trips per bus service, including time of day and day of week, are available. It is expected that this information could be used to improve the quality of public transportation in Trondheim.

Trondheim’s smart card system generates substantial time savings for both passengers and operators. Take a 5-kilometer bus service with 10 stops as an example. At an average speed of 15 kilometers per hour, the trip will take 19 minutes, 48 seconds. If, at each stop, two of the passengers boarding are previous cash payers, this will generate a total time savings of two minutes. Depending on where passengers board along the route, this could constitute a time savings of up to 10 percent. It is not unreasonable to expect that this time savings could increase the demand for public transportation. Rødseth and Bang (2006) used a travel time elasticity of −0.26, whereas Balcombe et al. (2004) reported long-run travel time elasticities between −0.38 and −0.69. This means that a 10 percent reduction in travel time along a bus route could generate passenger growth on the order of 3–7 percent.
Introducing smart cards and increasing the efficiency of ticketing, hence, could be efficient tools in increasing the demand for public transportation and promoting a modal shift away from private cars.

**Conclusions**

In this paper, we have demonstrated that the smart card ticketing system in Trondheim delivers a positive net present value. For bus passengers, the main benefit lies in time savings during boarding and reduced dwell time. Although these represent only a small time saving for the individual, all passengers already on the bus will save time at every stop when passengers pay using smart cards, so the total time savings due to the t:card could be considerable over the course of a bus trip. This is an example of user-scale economics. Further passenger benefits include increased timetable reliability and a reduced need for cash. The bus company benefits from reduced delays and increased reliability because of the shorter time spent at bus stops. This could allow the bus company to reduce the number of buses needed or increase the service level to passengers.

This paper has demonstrated that economic evaluation of smart card ticketing schemes using the principles of social cost-benefit analysis is desirable and possible. Even if all effects are not monetized and included in the analysis, the main costs and benefits are, and because the non-included non-monetized effects mostly would have increased the net benefits of the scheme, we consider the analysis to be robust and, if anything, erring on the pessimistic side. Because commercial non-viability often constrains the implementation of smart card schemes, these findings provide valuable information to those currently working on smart card ticketing strategies.

**References**


About the Author

MORTEN WELDE (morton.welde@vegvesen.no) is with the Norwegian Public Roads Administration in Oslo and the Norwegian University of Science and Technology in Trondheim.