Cameron E. Gordon  
Bukurije Bajrami  
Nóra Tábori Santiago  
Jonathan Peters

A Bridge Too Far?  
The Staten Island/Hudson-Bergen Light Rail Missed Connection

Junfeng Jiao  
Maxwell Dillivan

Transit Deserts:  
The Gap between Demand and Supply

Arthur C. Nelson  
Bruce Appleyard  
Shyam Kannan  
Reid Ewing  
Matt Miller  
Dejan Eskic

Bus Rapid Transit and Economic Development:  
Case Study of the Eugene-Springfield BRT System

Dr. Michelle Oswald  
Christian Treat

Assessing Public Transportation Vulnerability to Sea Level Rise:  
A Case Study Application

H.-S. Jacob Tsao  
Agus Pratama

Efficient Space Dedication to Bus Rapid Transit  
and Light Rail Systems

Rui Wang  
Chen Liu

Bicycle-Transit Integration in the United States, 2001–2009
Complimentary subscriptions can be obtained by contacting:
Lisa Ravenscroft, Assistant to the Editor
Center for Urban Transportation Research (CUTR)
University of South Florida
Fax: (813) 974-5168
Email: jpt@cutr.usf.edu
Web: www.nctr.usf.edu/jpt/journal.htm

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, JPG, 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 - for 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.

Robert B. Cervero, Ph.D.
University of California, Berkeley

Chester E. Colby
E & J Consulting

Gordon Fielding, Ph.D.
University of California, Irvine

Jose A. Gómez-Ibáñez, Ph.D.
Harvard University

Naomi W. Ledé, Ph.D.
Texas Transportation Institute

William W. Millar
American Public Transportation Association

Steven E. Polzin, Ph.D., P.E.
University of South Florida

Lawrence Schulman
LS Associates

George Smerk, D.B.A.
Indiana University

Vukan R. Vuchic, Ph.D., P.E.
University of Pennsylvania

The contents of this document reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the U.S. Department of Transportation, University Research Institute Program, in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof.
SUBSCRIPTIONS

Complimentary subscriptions can be obtained by contacting:

Lisa Ravenscroft, Assistant to the Editor
Center for Urban Transportation Research (CUTR)
University of South Florida
Fax: (813) 974-5168
Email: jpt@cutrusf.edu
Web: www.cutrusf.edu/jpt/journal.htm

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., TIFF, JPG, 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 - for 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

### A Bridge Too Far? The Staten Island/Hudson-Bergen Light Rail Missed Connection
*Cameron E. Gordon, Bukurije Bajrami, Nóra Tábori Santiago, Jonathan Peters*........... 1

### Transit Deserts: The Gap between Demand and Supply
*Junfeng Jiao, Maxwell Dillivan* ........................................................................................................... 23

### Bus Rapid Transit and Economic Development:
Case Study of the Eugene-Springfield BRT System
*Arthur C. Nelson, Bruce Appleyard, Shyam Kannan, Reid Ewing, Matt Miller, Dejan Eskic* .................................................................................................................................................. 41

### Assessing Public Transportation Vulnerability to Sea Level Rise:
A Case Study Application
*Dr. Michelle Oswald, Christian Treat* .................................................................................................. 59

### Efficient Space Dedication to Bus Rapid Transit and Light Rail Systems
*H.-S. Jacob Tsao, Agus Pratama* .......................................................................................................... 79

### Bicycle-Transit Integration in the United States, 2001–2009
*Rui Wang, Chen Liu*.............................................................................................................................. 95
A Bridge Too Far? The Staten Island/Hudson-Bergen Light Rail Missed Connection

Cameron E. Gordon, Ph.D., University of Canberra (Australia)
Bukurije Bajrami, Nóra Tábori Santiago, Jonathan Peters, Ph.D.
City University of New York/College of Staten Island

Abstract

Few urban areas are as economically and socially integrated as the New York City borough of Staten Island and the New Jersey communities of Bayonne and Jersey City just across the Hudson River. These strong links are illustrated by travel patterns across a north-south corridor from Staten Island up into Bayonne. Yet transit planning and development policy and implementation have been radically different in the two areas, with slow and, right now, stunted development of transit in Staten Island, New York City, as contrasted with the muscular and systematic approach taken in Bayonne and Jersey City, New Jersey. This paper analyzes the links between the two areas, describes the different transit policies taken in each, assesses the outcomes of these different policies, and offers suggestions for ways in which transit and development links could be improved, in particular an extension of the Hudson-Bergen Light Rail (HBLR) into Staten Island. The paper also discusses the interim use of buses as a pre-development phase for light rail (LRT) or bus rapid transit (BRT), focusing on the relatively new S89 route in Staten Island that now links directly to the HBLR and which immediately attracted strong ridership.
Introduction
Economic development of dense urban areas requires effective mass transit planning. Such planning is driven by institutions, and the way these function can make all the difference in the way such plans are developed and implemented. A striking example of this can be seen in two communities that are close geographic, economic, and social neighbors, yet have strikingly different transit configurations with strikingly different results: the borough of Staten Island, New York, and neighboring Bayonne and Jersey City, New Jersey. Staten Island has a transit system almost entirely built around buses, while Bayonne and Jersey City have developed a multimodal system containing integrated light rail (LRT), heavy rail, and buses. Their economic outcomes are also strikingly different. While both are prosperous in terms of income, Bayonne and especially Jersey City have developed a far more diverse and high-quality job base. Staten Island remains primarily a “bedroom” community for people commuting to jobs elsewhere.

This paper analyzes the links between the two areas, describes the different transit policies taken in each, assesses the outcomes of these different policies, and offers suggestions for ways in which transit and development links could be improved, in particular an extension of the Hudson-Bergen Light Rail (HBLR) into Staten Island. The paper also discusses the interim use of buses as a pre-development phase for LRT or bus rapid transit (BRT), focusing on the relatively new S89 route in Staten Island that now directly links to the HBLR and which immediately attracted strong ridership. The overall analysis is grounded on a brief review of the relevant literature on transit planning, policy, and economic development.

Mass Transit Planning in Dense Urban Areas
Large, dense cities must have some sort of transit system. The densities of population and economic activity in such areas are high enough to support a viable patronage, and the costs of not having transit, in terms of congestion, pollution, and other negative externalities provide additional justification and are imperative. There are also clear positive synergies in the form of direct effects on land value and the opening of desirable locations for social and economic activity.

Having transit does not, however, solve the question of what a system should look like, how it should evolve, and what technologies it should use. There are many examples of urban transit that have costs that appear to outweigh the benefits, at least in the short- and medium terms. Moreover, there are significant lags between costs and benefits, and some technologies, especially LRT and heavy-rail
transit (HRT), have substantial capital costs that may take years or even decades to recover. As budgetary resources are always scarce, system design and phasing are critical to ensure that a useful and beneficial system is ultimately built, even if in phases.

A number of clear principles have emerged from the literature on general transit planning for urban areas with sufficient density. Transit multimodality is a foundational principle. In other words, municipalities need to employ a portfolio of transit technologies to meet the diverse needs and conditions presented by a given service area. In transit, these technologies are, generically speaking, bus, BRT, LRT, and heavy rail (HRT), with each category having multiple specific forms (Brown and Thompson 2009).

Following from this is the notion that technology (generally) should fit the need rather than being imposed on an area and hoping for the best. HRT is excellent for some requirements, such as commuter travel between dense nodes, but less desirable for service in more spread out and less dense areas, where buses are often most economical and appropriate. Some systems, like LRT, require dedicated rights-of-way (ROW) that might not be available, or are perhaps inconsistently available. Often, multimodal mixed systems work best—for example, an LRT employing ROW where available and then transitioning to a bus where it is not. BRT is a good example of technology that can be especially flexible, with buses using dedicated busways where possible and then moving on to regular roads where necessary. The Silver Line in Boston is an example of this (Hensher 2007).

Routing and phasing of transit is another key issue. Patterns of residential and commercial activity across an urban space and across a time period will dictate what type of service should be provided, how frequent it is, and where it should go. Urban areas have become increasingly multi-destination, and trips have become increasingly multi-purpose, militating against the traditional peak/off-peak CBD-to-suburb configurations that were the standard 50 years ago and which many systems (including New York City’s) still largely focus on today. Use of a variety of technologies and across a variety of schedules and deployments can be especially effective in adapting existing infrastructure to changing conditions (Schumann 2006).

Transit investment also can yield what Paul Mees calls the “network effect” even in the midst of low density and auto-based development. As Mees puts it, “Public transit (can) imitate the flexibility of the car by knitting different routes into a single multi-modal network. Making transfers between the different routes near
effortless enables the public transit network to mimic the “go anywhere, anytime” flexibility of a road system (Mees 2010, 8).

It is, of course, very important to meet current needs effectively. But it is also important to guide development through transit investment as well. There is certainly risk in such planning, especially of “white elephants,” but future land uses cannot be simply left to chance with transit following in response. Risk and expense can be minimized in some cases by taking an “incremental” approach, developing or testing demand with buses first, then following with more capital-intensive transit such as BRT and LRT (Hensher 2007).

There are many benefits to getting transit right. By improving the public transportation system through the efficient use of transit technology, emissions are dramatically reduced, traffic congestion is relieved, and riders are provided with a reliable source of commuter service. Here again, the principles above come into play. “LRT stations need to be focal points of multimodalism” (Sungyop et al. 2007, 513), says one author, and this is not just true of LRT but also of BRT and, in some cases such as large transit exchanges, buses as well.

The Tale of Two Cities: Staten Island and Bayonne/Jersey City

An interesting sort of “natural experiment” on the effect on planning and policy on travel and economic development outcomes is occurring in the New York City area where one part of the city—the borough of Staten Island—has radically different transit policies and radically different outcomes than two communities just across the river, Bayonne and Jersey City, New Jersey. Bayonne, in particular, is less than a mile away from Port Richmond, Staten Island, and both communities were in similar places developmentally 40 years ago, but are now in very different places today, the main difference being public transport policy. It is, therefore, interesting to compare these two communities.

New York City has the highest transit usage rate in the United States. Yet many communities within New York City are underserved by public transit, especially for many of the four out of five New Yorkers who live outside the borough of Manhattan. Staten Island, in particular, has had a large increase in population growth, which has resulted in huge increases in travel; however, no major adjustments have been made to deal with that expansion.

Staten Island population reached 444,000 in 2000 and 470,000 in 2005 and is projected to reach a new height of 552,000 in 2030—a 24.4 percent growth rate
increase, the highest in any borough (Fitzsimmons and Birch 2009). However, this estimate is lower than one provided by the U.S. Census indicating that Staten Island’s population will reach 630,000 by 2030 (Cornell university 2008).

Yet there is a lack of general transit service in Staten Island because of the spatial imbalance between activity centers and transit infrastructure. Population growth in Staten Island has been prodigious, but transit planning to either guide or respond to that growth has been almost nonexistent. The system, which is primarily run on local and express buses, has not adapted to growth, nor does it serve a majority of the citizens who have to rely on automobile usage, thus causing traffic congestion.

Across the river from Staten Island in New Jersey are Bayonne and its neighbor, Jersey City. In the 1960s and 1970s, these once booming industrial communities became derelict in an era of post-industrialization. But, unlike Staten Island, Jersey City had a good rail connection to Manhattan via the Port Authority Trans-Hudson (PATH) line (and HRT line), as well as a dense cluster of New Jersey Transit (NJT) commuter trains. As Manhattan’s financial district boomed, Jersey City took advantage of this transit connection to actively lure the financial “back office” to a Gold Coast along the Hudson River that now bristles with high-rise buildings and expensive condominiums. There was also a movement of artists to Jersey City from Manhattan and the other boroughs, taking advantage of cheaper rents on the other side of the Hudson and easy transit access to the cultural amenities of New York City (Fitzsimmons and Birch 2009).

The fact that both Staten Island and Jersey City are roughly equidistant from Wall Street yet Jersey City has all the back-office operations says much about the power of development policy and transit infrastructure. The story becomes even more interesting when considering Bayonne. Bayonne did not initially share in the Jersey City boom. At the time, it had no good transit links to Jersey City and none to Manhattan. Its relative distance and isolation caused it to remain in the economic doldrums, despite offering much cheaper real estate. In this sense, Bayonne’s economic condition closely mirrored the downtrodden Port Richmond neighborhood in Staten Island that was a mere mile away across the Kill Van Kull and which suffered from similar transit neglect. Figure 1 shows the geographic proximity of these two communities along with the rail infrastructure that existed in both places in the 1950s.
Figure 1. Passenger rail service in 1950s Staten Island, NY
The Hudson Bergen Light Rail
New Jersey was proactive about Bayonne in a way that Staten Island has not been about its own transit-isolated communities (or, more properly speaking, New York City was, since Staten Island does not have independent planning authority and must work through city-wide institutions). The State of New Jersey decided to build the Hudson Bergen Light Rail (HBLR) to connect Bayonne with Jersey City and Hoboken and, through those communities, link the city with the wider metropolitan transit system. The HBLR began operation on a former freight rail easement in 2000, and a spur line to the West Side Avenue in Jersey City was added shortly afterwards. By 2002, service was extended to Hoboken Terminal. Service was then extended south to 22nd Street and north to Weehawken and to Union City in North Bergen.

The newest addition to the system is the elevated 8th Street station in Bayonne. Figure 3 shows this network and also shows the proximity of the end of this network to Staten Island. (Fitzsimmons and Birch 2009).

Ridership on this service has shown increasing numbers. The HBLR 20.6-mile light rail system operates with 23 stops and a daily ridership of 38,200 on a normal weekday. To eliminate the need to change between stations, the trains operate on three routes: West Side Avenue (Jersey City)–Tonnelle Avenue (North Bergen), Hoboken Terminal–Tonnelle Avenue (North Bergen), and 22nd Street (Bayonne)–Hoboken Terminal. Trains operate 5:00–1:00 AM daily, running every 5 minutes during the peak period within the core of the system. Off-peak operation during a weekday is every 5–10 minutes (NJT 2010).

The economic development benefits have been pronounced as well. Development has obviously been most pronounced in Jersey City, but Bayonne has gone from no commercial development to 626,270 square feet approved and proposed (by 2003/2004), while other nearby communities of similar size and character in Hudson County (Guttenberg, Harrison, and Kearny) had none (Fitzsimmons and Birch 2009). For Bayonne, these effects can be said to be at least partly driven by the HBLR, which is the primary transit in the area.
Figure 2. Map showing full HBLR system, current SIRT, and proposed connection
Figure 3. Map of proposed connection from Bayonne to Staten Island
Light Rail Transit as a Gap-Filling Mode

LRT is quite often a “gap-filler” for existing transit, filling in holes in bus or rail service or extending the reach of those modes. U.S. statistics show that approximately 53.8 percent of light rail passengers drive and park at an LRT station, while 28.7 percent use bus as their mode of transit (9.1% are picked up/dropped off and 8.4% walk to the station) (Sungyop et al. 2007). A total of 72.5 percent use LRT for a portion of their travel to and from school/work. This fits in with Mees’ “network effect” concept as well, with different modes serving different needs but all being seamlessly linked to deliver trip flexibility.

The boroughs of New York City are an interesting case in this regard. There is a dense subway and commuter rail network, but outside of Manhattan (and even in a few areas in Manhattan), there are significant gaps which are infeasible, economically or practically, to fill with more HRT and yet which would be poorly served in many cases by traditional buses.

Table 1 shows the population distribution around train stations in NYC. The boroughs, Staten Island especially, are not well served by existing HRT infrastructure. Traditional bus service is not filling that gap well either. “Between 1970 and 2000, many of our greatest areas of growth have been underserved NY transit” (NYC 2011). According to U.S. Census 2010 data, only 26 percent of Staten Islanders lived within ½ mile of the subway routes, compared to 94 percent of Manhattan residents (U.S. Census 2010).

Table 1. Population of New York City Boroughs Census Tract Centroids within ½-Mile Radius of Subway Routes

<table>
<thead>
<tr>
<th>NYC Boroughs</th>
<th>½-Mile Buffer Around Subway Routes</th>
<th>2010 Census Total Population</th>
<th>Percentage of Population within ½ Mile of Subway Routes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bronx</td>
<td>998,729</td>
<td>1,385,108</td>
<td>72%</td>
</tr>
<tr>
<td>Brooklyn</td>
<td>2,005,616</td>
<td>2,504,700</td>
<td>80%</td>
</tr>
<tr>
<td>Manhattan</td>
<td>1,489,979</td>
<td>1,585,873</td>
<td>94%</td>
</tr>
<tr>
<td>Queens</td>
<td>1,053,952</td>
<td>2,230,722</td>
<td>47%</td>
</tr>
<tr>
<td>Staten Island</td>
<td>120,753</td>
<td>468,730</td>
<td>26%</td>
</tr>
</tbody>
</table>

As Table 2 shows, the rate of automobile ownership on Staten Island is much higher than in the rest of the city. A total of 15.7 percent of Staten Island households do not own a vehicle, 37 percent own one vehicle, and the remaining 47 percent of households have two or more vehicles (U.S. Census 2006–2010 American Community Survey 5-Year Estimates). This situation, a result of poor transit availability, is replicated, if not as severely, in the other boroughs.
Table 2. Vehicles per Household

| Selected Housing Characteristics Based on 2006-2010 American Community Survey 5-Year Estimates |
|---------------------------------|-------------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
|                                 | No cars    | % With No Cars | 1 car        | % With 1 car | 2 cars        | % With 2 cars | 3 or more cars | % 3 or more cars |
| Bronx                           | 277,959    | 58.8           | 144,073      | 30.5          | 40,560        | 8.5            | 9,872           | 2.1                           |
| Brooklyn                        | 510,338    | 56.5           | 297,887      | 33.0          | 78,588        | 8.7            | 17,178          | 1.9                           |
| Manhattan                       | 568,824    | 77.7           | 145,120      | 19.8          | 15,825        | 2.2            | 2,435           | 0.3                           |
| Queens                          | 281,418    | 36.3           | 311,536      | 40.2          | 140,231       | 18.1           | 41,126          | 5.3                           |
| Staten Island                  | 25,837     | 15.7           | 60,704       | 37.0          | 56,489        | 34.4           | 21,249          | 12.9                          |
| Total                           | 1,664,376  | 54.6           | 959,320      | 31.5          | 331,693       | 10.9           | 91,860          | 3.0                           |

Number of Vehicles per household in New York State and the United States

|                                 | No cars    | % With No Cars | 1 car        | % With 1 car | 2 cars        | % With 2 cars | 3 or more cars | % 3 or more cars |
| New York State                 | 2,053,740  | 28.5           | 2,335,931    | 32.4          | 1,964,874     | 27.3          | 851,195        | 11.8                          |
| United States                  | 10,113,266 | 8.9            | 38,014,177   | 33.3          | 43,264,978    | 37.9          | 22,843,575     | 20.0                          |
A Mere Mile: The Case for a Staten Island/HBLR Link

Bayonne was in a similar, perhaps worse, position than Staten Island back in the 1970s. NJ Transit planned and then built the HBLR, significantly ameliorating the transit gap within New Jersey and increasing connectivity with the dense and, before the LRT, inaccessible State transit system nearby. Staten Island is less than two miles of road and bridge away from being connected to the HBLR. If such a connection were built, it would provide Staten Island with access to a regional national transportation infrastructure. Measurement from the proposed terminus station in Staten Island to the currently-under-construction 8th Street station of the HBLR is about 3 km (1.88 mi). LRT “gives medium-sized urban centers the chance to create direct links between inner city, the outlying districts and surrounding population centres” (De Bruijn and Veeneman 2009, 351). Staten Island residents currently have the longest commute (by any mode) in the nation and the most extreme commuters (i.e., those with work trips above 90 minutes long in either direction), and an LRT link would ameliorate this situation.

Based upon a discussion with NJ Transit, the estimated cost of construction is $150 million dollars. New federal infrastructure is typically funded with 80 percent federal money and 20 percent local funding. This extension would include approximately 1.6 miles of track and could be expected to yield a probable ridership of 15,000 per weekday, which is actually the recommended HRT threshold for U.S. federal funding (the LRT threshold is 7,500). Still, these are forward estimates. Would actual ridership be that high if an LRT link between Staten Island and Bayonne was built? Fortunately, there is a good evidence to indicate a high probability of “yes.”

Hudson Bergen Light Rail and Buses as a Market Test

Staten Island is linked to Bayonne by the Bayonne Bridge. When the Bayonne Bridge was built in 1931, sections of the roadway deck were reserved to accommodate heavy rail tracks (PANYNJ 2012). Some sort of rail transit was contemplated but, like many infrastructure projects of the era, the Great Depression literally derailed it.

Decades later, New Jersey’s building of the HBLR on its side of the Bayonne Bridge has fulfilled a part of the original plan. The 8th Avenue station of that line is already built as an elevated station, so the infrastructure will mostly be in place for the extension of the service through the Bayonne Bridge should that be decided.

The market potential of more robust transit linkage between Staten Island and Bayonne has been effectively “empirically” tested through initial bus service along
a potential LRT corridor in Staten Island that could form the basic spine of a connecting service to the HBLR. In 2007, the Metropolitan Transit Authority (MTA) established a bus route, S89, to link Staten Island with the HBLR. The S89 route begins at Richmond Avenue and Hylan Boulevard and completes its route at the 34th Street HBLR Station. However, this bus line only currently operates in peak AM and PM hours on weekdays and has no weekend service. In spite of these limitations, this bus route has shown that there are a promising number of commuters who depend on this daily service and also what an approximate viable alignment for a Staten Island LRT line could be.

Figure 4 shows the S89 boardings in both directions. These loading counts show that the S89 has generated a strong and immediate ridership on a daily basis that is relatively broadly distributed, particularly along the northern half of the route. The “0” at the Northbound HBLR station indicates that everyone exits the bus at this stop; the “0” in the Southbound S89 bus station indicates the last S89 service stop.

What is generating this ridership? In a few words: the connection to the HBLR. The MTA reports that in 2009 S89 annual ridership was 233,067, with a daily average weekday ridership of 918 (Schumann 2006). According to a NJ Transit report conducted by Rutgers University, this service provides 800–900 NY riders per weekday that ride the HBLR (Robins and Jans 2008). These riders are almost entirely heading to and from the LRT in Bayonne. As of 2011, annual ridership was 224,071, a 1.2 percent increase from 2010’s annual ridership of 221,507.

This is confirmed by other data. A license plate survey was conducted on June 14, 2010, at the HBLR 34th Street Station parking lot by researchers from the College of Staten Island. A total of 424 cars were parked at this facility, and all of the vehicles were recorded and counted by the authors. This vehicle count showed that 70 percent of the vehicles outside the LRT station belonged to residents of New York, 28 percent were from New Jersey, and the remaining 3 percent were from other states. Based upon a cross-reference from the NYC Department of Motor Vehicles database, 207 of the license plates were from NY State, with 198 of these from Staten Island.
Figure 4. Map showing ridership on S89 bus in both northbound and southbound directions (numbers indicate how many riders are on bus at each stop)

Figure 5 shows in detail the distribution of these license plates by ZIP code. This broadly confirms results of the HBLR study by Marchwinski et al. (1999), the results of which are depicted in Figure 6). Based on the survey data conducted by both the College of Staten Island/NYS DMV and the NJ Transit HBLR report, 90 percent of the license plates belonged to Staten Islanders. The annual usage rates for Staten...
Island riders were expected to be at 281,060 riders, based on 353 Northbound and 322 Southbound riders on the S89 during a standard 260 business day year and the 198 recorded parked vehicles belonging to Staten Islanders driving both to and from the station.
Figure 6. Map illustrating 2005 Ridership Survey conducted by NJ Transit
There is strong reason to believe that ridership on an LRT would be much greater than that of the current S89. The S89 is limited to people who live within walking distance of the route or those who transfer from a local bus to the S89 or park on the street. These riders are forced to take a minimum of two to three modes (walk, bus) of transport prior to arriving at the HBLR station. Even so, ridership has been strong. The creation of an LRT integrated with the HBLR would certainly increase both ridership and connectivity.

Another limit currently is that the S89 service provides access only to residents in close proximity of Richmond Avenue, with the rest of Staten Island underserved by any public transportation going to or from the HBLR. Frequency of service is also limited: this is a peak-only period service, running inbound (to NJ) from 5:25–8:22 AM and outbound (to SI) 3:55–7:25 PM. Increasing service frequency and connectivity through an LRT would deliver significant advantages to riders and likely significantly increase transit usage.

According to NY Transit’s report from April 2008, the “HBLR has been successful in reducing peak period auto trips from Bayonne and Staten Island to downtown Jersey City employment centers” (PANYNJ 2012).

**Rail Transit Access and Non-Auto Households**

One of the more interesting questions in transportation is the impact of transit services on auto ownership and the frequency of non-car-owning households. The authors examined the five counties of New York City to observe the relationship between household proximity to the New York heavy rail system and non-car-owning households using Geographic Information System (GIS) mapping of the 2010 Census data on automobile ownership and overlaying that with the New York City Heavy Rail Network (New York City Subway and Staten Island Railroad). Figure 7 provides an overview of that data.

The authors then selected the Census tracts that were within ½ mile of the heavy rail network and then calculated the number of households without cars and divided it by total households within that zone. We also calculated the share of no-car households in the areas outside of the heavy rail network. Based on this, we were able to calculate the conditional probability of a household living within ½ mile of the rail network given that they are zero-car households.
Figure 7. Map showing percentage of households without any cars in New York City
Table 2. NYC Actual Rates and Relative Rates of Zero-Car Households

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Rate</th>
<th>Relative Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within ½ mile of subway line</td>
<td>42.73%</td>
<td>85.83%</td>
</tr>
<tr>
<td>Outside ½ mile of subway line</td>
<td>7.05%</td>
<td>14.17%</td>
</tr>
<tr>
<td>Total</td>
<td>49.78%</td>
<td></td>
</tr>
</tbody>
</table>

It was found that 85 percent of households that did not own a car were within ½ mile of a heavy rail line. In New York City, while the overall percentage of households within ½ mile of the subway and rail system is very high (74.7%), the zero-car households tended to be even more concentrated. We found the exact opposite in terms of households with automobiles—they tended to be more likely to live outside of the ½-mile range of the heavy rail system. These results confirm the potential benefit of rail transit as a density magnet as well as supporting non-automobile households in a dense urban setting.

We estimate that the combination of a lower-density of transit network in regions outside of Manhattan creates the potential need for an additional 266,082 vehicles in New York City. In addition, the lack of a heavy rail network in many areas creates a need for an additional 339,464 vehicles. In total, the weaker rail systems in the Outer Boroughs of New York City create the need for more than 605,000 vehicles for city households, or roughly 30–34 percent of the private vehicles registered in New York City. This is based on the assumption that a household adds only one vehicle if outside the rail network. The potential exists to add two and three cars in some areas. Clearly, the location and development of further rail transit networks will have significant impacts on car ownership, even in a dense city like New York City.

Conclusions
Figure 7 shows the potential that LRT, both the one discussed here and other possible corridors, such as the aforementioned North Shore Light Rail, could have in terms of transit connectivity. The status quo is shown here—i.e., Staten Island as almost completely cut off from the region’s rail network. A relatively simple investment would change that picture radically. Through the development of a light rail over the Bayonne Bridge, an integrated transit network would be created, joining Bayonne to Staten Island. This merger would stimulate development through the region, reduce traffic congestion and emissions, and provide ample service to both communities. This extension could be a catalyst for additional mergers or the
completion of track plans that had been abandoned. Through minor modification or redesign, facilities can provide services interlinking communities that were once only viable to travel by private vehicles.

Based upon the data in this paper, the implied Staten Island ridership via the S89 service is 91,780 annually and via automobile is 51,480 annually, bringing a total of 143,260 annual riders to HBLR service.

This case shows that robust transit linkages have a two-way relationship with economic development. Of course, it is well known that appropriately sited and planned linkages can lead to significant economic renewal. Based on the experience of Bayonne and the HBLR, a Staten Island LRT link will likely increase commercial development and revitalize development on the North Shore of Staten Island, spurring economic development and creating access to jobs that are currently limited because of inefficient transportation options. The introduction of transit-oriented development also will improve land values in the vicinity. New York City Mayor Michael Bloomberg supports the expansion of transit access to underserved areas, as Transportation Initiative 3 of PlanNYC 2030 indicates (NYC 2011). This initiative lists the possibility of reopening the Staten Island North Shore Alignment, the abandoned rail line that runs from Arlington to the Ferry Terminal. PlanNYC also contains Initiative 4, which asks to “improve and expand bus service” (NYC 2011).

At the same time, economic development and the public/private institutions responsible for planning that development can be a key factor in determining whether useful transit investments are made or not. A mere mile separates Staten Island from Bayonne. And yet, the development and associated transport policies in the two jurisdictions are many miles apart. This institutional separation has led to an obvious, and economically wasteful, disparity in a region that is otherwise closely integrated. In that sense, the HBLR serves as a cautionary tale for other urban/suburban regions where there are close actual potential links that robust transit could serve well but that might be stymied by the artifices of political and administrative borders.

Acknowledgments

This research was supported, in part, by a grant of computer time from the City University of New York High Performance Computing Center under NSF Grants
CNS-0855217 and CNS-0958379. Also, we thank research assistants Hyoung Suk Shim, Jacquelyn Cannizzo, and Afrona Kaziu.

References


**About the Authors**

**Dr. Cameron Gordon** (cameron.gordon@canberra.edu.au) is an Associate Professor of Economics at the University of Canberra in Australia. He also has an ongoing research appointment with the University Transportation Research Center Region 2 in New York. He has had visiting appointments with the Centre for Transport Studies at the Imperial College (London) and the Institute for Transport and Logistics Studies with the University of Sydney.

**Bukurije Bajrami** (bbegai@gmail.com) is an Administrator at the CUNY High Performance Computing Center and a Research Associate and visualization specialist at the Social Policy Simulation Center. She specializes in geospatial analysis and traffic flow modeling and is currently enrolled in the Urban Affairs Graduate Program at Hunter College, CUNY. She has recently presented her work at the Transportation Research Board of the National Academies of Science.

**Nóra Tábori Santiago** (Nora.Santiago@csi.cuny.edu) is a Geographic Information Systems Specialist at The City University of New York High Performance Computing Center, located at The College of Staten Island. In addition, she serves as a technical consultant to the Center for the Study of Staten Island and is enrolled in the Urban Affairs Graduate Program at Hunter College, CUNY. She received her B.A. in Geography from Hunter College, the City University of New York, and specializes in the spatial analysis of social and demographic measures of equity, the spatial burden of taxation, and geospatial analysis of transportation system performance.

**Jonathan R. Peters** (Jonathan.Peters@csi.cuny.edu) is a professor of finance in the Business Department at The College of Staten Island, CUNY and a Research Fellow at the University Transportation Research Center at The City College of New York. He is also a member of the doctoral faculty in the Ph.D. Program in Earth and Environmental Sciences at the CUNY Graduate School. He received his Ph.D. in Economics from CUNY and his master’s degree in Economics from Hunter College.
Transit Deserts: The Gap between Demand and Supply

Junfeng Jiao, University of Texas at Austin
Maxwell Dillivan, Ball State University

Abstract

The term “transit desert” is a new concept that looks at the gap between level of transit service (supply) and needs of a particular population (demand). These populations are often referred to as “transit dependent,” people that are too young, too old, or too poor or who are physically unable to drive. “Transit deserts” in this case are defined as areas that lack adequate public transit service given areas containing populations that are deemed transit-dependent. This study aims to analyze and establish a clear method for calculating and quantifying gaps between transit demand and supply using Geographic Information Systems (GIS). The study looks at four major U.S. cities: Charlotte, North Carolina; Chicago, Illinois; Cincinnati, Ohio; and Portland, Oregon. Transit deserts often occur in neighborhoods surrounding historic downtowns; however, exceptions occur in very isolated rural areas.

Introduction

The concept of “transit deserts” introduced in this study is similar to the increasingly popular concept of “food deserts” (Clark et al. 2002; Whelan et al. 2002; Wrigley 1993; Wrigley et al. 2002; Jiao et al. 2012). Enormous attention has been paid to improving food systems and food environments through planning efforts to achieve equitable access to high-quality, affordable food for everyone. Food desert analyses identify geographic locations where concentrations of people who lack access to healthy food exist in the urban landscape. Similar analysis can be applied to mass transportation systems as well. While access to healthy, affordable foods
has been compromised due to suburban sprawl (Morland et al. 2002; Jiao et al. 2012), choice of modes of transportation have as well. Taking the concept of food deserts and applying it to public transportation enables spatial patterns to emerge regarding service provision and service need. Locations of vulnerable populations can be determined and analyzed. There has been almost no research done using this approach to evaluating transit systems based on gaps between demand and supply in a spatial context.

Transit deserts are generally defined as areas containing a large constituent of transit-dependent populations with limited automobile access where the level of mass transit service (supply) does not adequately service these populations (demand). Areas of high concentrations of people who rely on public transportation for daily activities are in the greatest need of the provision of transit services. Transit-dependent populations typically are those who are too young, too old, or too poor or who are physically handicapped and unable to drive (Grengs 2001). “Transit deserts” in this case are defined as areas that lack adequate public transit service given areas containing populations that are deemed “transit dependent.” Various indicators such as age, income, and access to a private vehicle are used to determine dependency. Since transit-dependent populations comprise individuals who rely on transit systems for access and mobility, this population will benefit most from investments made in high-quality, reliable, and frequent transit service (CATA 2011). Currently, a significant portion of mass transit riders are completely dependent upon the various forms of urban mass transportation in a time when dependency is likely to increase with car-ownership rates slowing and worldwide oil reserves dwindling.

Literature Review
Public transportation is vital to the health of cities. The United States Supreme Court has recognized the right to travel as one of the fundamental rights guaranteed by the 14th Amendment to the U.S. Constitution and is a hallmark of full membership of American society (Sanchez and Brenman 2008). The early challenges to racial discrimination and segregation attacked discriminatory practices that limited access to mobility by minorities; today, this segregation of society still exists and is manifested through access of modes of transit. Sanchez and Brenman, in their 2008 book titled The Right to Transportation, identify several aspects of an equitable transportation system, such as ensuring opportunities for meaningful public involvement in the transportation planning process; distributing the benefits and burdens from transportation projects equally across all income levels and
communities; providing high-quality services—with emphasis on access to economic opportunity and basic mobility—to all communities, emphasizing transit-dependent populations; and equally prioritizing efforts to both revitalize poor and minority communities and expand transportation infrastructure. These facets of equitable transportation systems are critical in the foundation of a true pluralistic society that affords access and opportunities for all.

Urban planners are asked to promote equity and invoke fairness and justice for all populations (Deakin 1996). Often, this involves the endeavor of allocating public goods and services to those in the greatest need, usually low-income, disadvantaged populations. To better allocate public goods, equity and advocacy planning theory emerged in the 1960s and 1970s. This theory argues that planners should represent and advocate for the interests of poor and minority groups and aim to ameliorate social ills that plague urban populations (Paul Davidoff 1965; Garcia-Zamor 2009). Public transit service, as an important general public good, has drawn much attention during this movement (Krumholz 1982). Transit-dependent populations mark a notable group of people who are often excluded from access to employment opportunities, access to retail options, and overall participation in society. However, many public transportation agencies have neglected transit-dependent populations (Garrett and Taylor 1999). Garrett and Taylor (1999) argue that superior political power from suburban communities has created tension among transit planners in regard to meeting demands for low-income, inner-city residents who need transit and meeting the demands for more dispersed, wealthier suburban communities. Today, transit riders, on average, are much poorer than the general population with a disproportionate number of older adult and disabled riders. However, transit subsidies have been concentrated primarily on serving lower-density, higher income areas and improving transit access only for suburban residents, thus failing to respond to the needs of residents who rely on the service.

**Objective**

This study aims to create a clear, concise method for calculating and quantifying the supply of transportation service that can be used for any location. Results from this study can be used, in part, to evaluate a transportation system as a whole. Ideally, this will lead to more efficient and effective allocation of resources, allowing the greatest output (i.e., ridership, social justice) given input (i.e., transportation subsidies/funding).
This study aimed to analyze and quantify gaps between transit demand and supply using GIS in four major U.S. cities. The study created a graphic representation of portions of these cities where there is either an excess of service given the demand of the residents in that particular area or where the supply of transit service is not meeting the demands of the residents in the area. This will shed light on the bigger issue of appropriation of resources.

**Research Methods**

**Research Design**

A gap analysis for transit demand and supply was performed by comparing the level of transit dependency for an area and calculating the difference against the amount of transit supply in a city. The cities selected for this analysis were Charlotte, North Carolina; Chicago, Illinois; Cincinnati, Ohio; and Portland, Oregon. These four cities were chosen to include different-size cities in various geographic regions of the country and also were based on data availability.

**Data**

Demographic data of the four cities were collected from the 2010 U.S. Census. The data were joined in GIS to census block groups to map transit dependency by block group. Municipal boundaries, transit stops, transit routes, bike lanes, and sidewalks were provided by the respective municipal GIS departments and transit agencies in each city. Data for transit frequency, trips, and stops was obtained from Google’s General Transit Feed Specifications (GTFS), a common format for public transportation schedules and associated geographic information developed by Google and TriMet (Portland, OR) to publish data in an interoperable way (Google 2012).

**Measurement**

Transit-dependent populations for each city were calculated at the census block group level based a formula developed by the U.S. Department of Transportation (Steiss 2006)1 and slightly modified in a recent transportation study performed by the Capital Area Transit Authority in Lansing, Michigan (CATA 2011). This formula acknowledges that while identifying transit-dependent populations is an important tool for determining where new transit service should be provided or how existing systems can be modified to better service the population in need, calculating a single value that represents those who are transit-dependent can be difficult. While transit dependents are usually classified as those who are too young, too old, or too poor or who are physically unable to drive, Census data on these topics
do not account for the fact that these groups often overlap. Simply counting each criterion and adding them together may double or even triple count certain individuals. The formula used to calculate transit dependents is as follows:

\[
\text{Household drivers} = (\text{population age 16 and over}) - (\text{persons living in group quarters})
\]

\[
\text{Transit-dependent household population} = (\text{household drivers}) - (\text{vehicles available})
\]

\[
\text{Transit-dependent population} = (\text{transit-dependent household population}) + (\text{population ages 12–15}) + (\text{non-institutionalized population living in group quarters})^2
\]

The above calculation was performed for each block group. For block groups with more vehicles than household drivers, the transit-dependent household population was considered to be zero. The reasoning for this is that no block group should have a negative number of people who are transit-dependent.

This calculation changes the focus from why individuals may not drive (age, income, mobility) to identifying where there are limited vehicles available for individuals to use. This means areas with large disparities between auto drivers and autos available are more likely to be transit-dependent than areas that have nearly a one-to-one ratio of cars to people. Once this calculation was performed, the total number of the transit-dependent population was divided by acres for each block group and a z-score was calculated.

Transit service (supply) was determined by four criteria:

1. number of bus and rail stops in each block group
2. frequency of service for each bus and rail stop per day (weekday service) in each block group
3. number of routes in each block group
4. length of bike routes and sidewalks (miles) in each block group

Each criterion was divided by acres to get a density value and then a z-score value was calculated to standardize them. Finally, the values for each criterion were aggregated to determine the level of supply. In the end, demand and supply are subtracted and a final numerical value was calculated for each census block group to determine an excess or lack of supply (Hulchanski 2010).
Analysis

Using various spatial analysis functions available in ArcGIS, transit demand and supply were calculated. Transit demand per block group was calculated using the formula presented previously. The database was imported into ArcGIS and joined to the block group shapefile by the common block group ID field. Transit supply per block group was calculated in ArcGIS. The four criteria were given z-score values, summed, and then averaged in a final supply total sum. This value was subtracted from the demand z-score values for each census block group to get the transit service discrepancy. The final maps illustrate differences between demand and supply.

Results

Each city’s transit supply and demand were mapped using GIS. Chicago had the largest transit system of the four cities (Table 1). The Chicago Transit Authority (CTA) manages more than 3.1 million trips system-wide, with 148 individual routes (140 bus and 8 heavy rail) and 12,000+ bus and rail stops. Chicago’s massive transit system is spread across its large municipal boundary of 234 square miles, which includes a total population of nearly 2.7 million residents. CTA boasts an average weekday ridership figure of approximately 1.7 million riders. This is split modally by 713,500 riders on Chicago’s heavy rail system, the “L,” as well as 998,600 riders on the city’s buses. Additionally, 304,700 average weekday riders are included on Chicago’s commuter rail, Metra. The city also contains nearly 650 miles of bike lanes and 4,700 miles of sidewalks.

Portland, while much smaller geographically (145 square miles), has a comparably large system, with almost 3 million trips and 7,000 bus and rail stops. Portland’s Tri-County Metropolitan Transportation District of Oregon (TriMet) operates a mixture of light rail and bus services like Chicago. Given Portland’s relatively small population and area, the city boasts an incredibly extensive transit network. Charlotte has the largest urban area but the smallest transit system (in terms of the number of trips per day and the number of total transit stops). Cincinnati has the second smallest urban area and the second smallest transit system, which provides bus service only.

Table 2 shows the top five block groups in each of the four cities with the highest level of demand. The values are reflected in terms of z-scores and are expressed by number of standard deviations from the mean. Most block groups with high demand are often located in low-income inner-city neighborhoods. Chicago and Portland experience the highest levels of demand due to lower rates of car owner-
Table 1. Overview of Transit Systems in Four Cities

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Charlotte, NC</th>
<th>Chicago, IL</th>
<th>Cincinnati, OH</th>
<th>Portland, OR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Charlotte Area Transit System (CATS)</td>
<td>Chicago Transit Authority (CTA)</td>
<td>Southwest Ohio Transit Authority (SORTA)</td>
<td>Tri-County Metropolitan Transportation (TriMet)</td>
</tr>
<tr>
<td>Population</td>
<td>731,424</td>
<td>2,695,598</td>
<td>296,943</td>
<td>583,776</td>
</tr>
<tr>
<td>Area (sq. mi.)</td>
<td>297.7</td>
<td>234.0</td>
<td>79.6</td>
<td>145.4</td>
</tr>
<tr>
<td>Density (pop/sq. mi.)</td>
<td>2,457</td>
<td>11,520</td>
<td>3,730</td>
<td>4,015</td>
</tr>
<tr>
<td>Routes</td>
<td>70 (bus: 69, light rail: 1)</td>
<td>148 (bus: 140, heavy rail: 8)</td>
<td>49 (all bus)</td>
<td>85 (bus: 79, light rail: 4, commuter rail: 1, streetcar: 1)</td>
</tr>
<tr>
<td>Stops</td>
<td>3,634</td>
<td>12,169</td>
<td>4,740</td>
<td>7,019</td>
</tr>
<tr>
<td>Ridership (avg. wkdy)</td>
<td>83,700 (bus: 69,100, light rail: 14,600)</td>
<td>1,712,100 (bus: 998,600, rail: 713,500)</td>
<td>53,100</td>
<td>323,300 (bus: 191,600, light rail: 126,500, commuter rail: 1,600, other: 3,600)</td>
</tr>
<tr>
<td>Trips</td>
<td>0.16 million</td>
<td>3.1 million</td>
<td>0.35 million</td>
<td>3 million</td>
</tr>
<tr>
<td>Length, bike lanes (mi)</td>
<td>65.9</td>
<td>623.9</td>
<td>58.8</td>
<td>648.7</td>
</tr>
<tr>
<td>Length, sidewalks (mi)</td>
<td>3,212.7</td>
<td>4,772.6</td>
<td>N/A</td>
<td>4,759.5</td>
</tr>
<tr>
<td>Demand (per acre)</td>
<td>μ = 0.97</td>
<td>μ = 9.37</td>
<td>μ = 1.81</td>
<td>μ = 3.10</td>
</tr>
<tr>
<td></td>
<td>σ = 1.27</td>
<td>σ = 16.03</td>
<td>σ = 2.35</td>
<td>σ = 5.02</td>
</tr>
<tr>
<td>Supply (per acre)</td>
<td>μ = 0.33</td>
<td>μ = 4.16</td>
<td>μ = 1.16</td>
<td>μ = 7.23</td>
</tr>
<tr>
<td></td>
<td>σ = 0.87</td>
<td>σ = 8.07</td>
<td>σ = 2.39</td>
<td>σ = 9.79</td>
</tr>
<tr>
<td>Gap</td>
<td>μ = -0.64</td>
<td>μ = -5.21</td>
<td>μ = -0.65</td>
<td>μ = 4.13</td>
</tr>
<tr>
<td></td>
<td>σ = 1.27</td>
<td>σ = 13.94</td>
<td>σ = -2.43</td>
<td>σ = 8.77</td>
</tr>
</tbody>
</table>

ship, as the density of these two cities makes it economically and physically more difficult to own and operate an automobile within the city. Most block groups with the highest demand in each city are not adequately met with supply. These are areas that require the greatest attention and resources for planners. The method used in this study evaluates each geography and provides transportation planners with a useful evaluation tool that compares a metropolitan area’s supply and demand level among other geographic areas of the city. For instance, Chicago’s mean level of supply is much higher than the other cities compared. It would be unfair to use this level of service to evaluate other metropolitan areas (i.e., Charlotte and Cincinnati). Maps of demand, supply, and gaps for each city are shown in Figures 1 through 4. In the gap maps, the darker the shading, the greater the gap.
Table 2. Top Five Block Groups within Each City with the Highest Transit Demand

<table>
<thead>
<tr>
<th>City</th>
<th>Location Description</th>
<th>Demand (z-score value)</th>
<th>Supply (z-score value)</th>
<th>Gap (Supply - Demand)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charlotte, NC</td>
<td>Third Ward, low-income area near downtown</td>
<td>7.48</td>
<td>4.96</td>
<td>-2.52</td>
</tr>
<tr>
<td></td>
<td>Montclaire South, medium-income suburban/rural</td>
<td>6.98</td>
<td>0.81</td>
<td>-6.17</td>
</tr>
<tr>
<td></td>
<td>Fourth Ward, higher-income near downtown</td>
<td>5.53</td>
<td>4.97</td>
<td>-0.56</td>
</tr>
<tr>
<td></td>
<td>Briarcreek-Woodland, medium-income suburban</td>
<td>4.70</td>
<td>0.62</td>
<td>-4.08</td>
</tr>
<tr>
<td></td>
<td>Sterling, low-income suburban/rural</td>
<td>4.06</td>
<td>0.41</td>
<td>-3.65</td>
</tr>
<tr>
<td>Chicago, IL</td>
<td>Edgewater Beach neighborhood</td>
<td>24.79</td>
<td>13.73</td>
<td>-11.06</td>
</tr>
<tr>
<td></td>
<td>Edgewater Beach neighborhood</td>
<td>16.88</td>
<td>7.25</td>
<td>-9.64</td>
</tr>
<tr>
<td></td>
<td>West Loop Gate neighborhood</td>
<td>15.65</td>
<td>4.42</td>
<td>-11.24</td>
</tr>
<tr>
<td></td>
<td>Edgewater Beach neighborhood</td>
<td>11.16</td>
<td>0.03</td>
<td>-11.13</td>
</tr>
<tr>
<td></td>
<td>Near North neighborhood</td>
<td>11.08</td>
<td>2.75</td>
<td>-8.33</td>
</tr>
<tr>
<td>Cincinnati, OH</td>
<td>West End neighborhood, low-income historic neighborhood</td>
<td>6.82</td>
<td>2.82</td>
<td>-4.00</td>
</tr>
<tr>
<td></td>
<td>Pendleton neighborhood, low-income historic neighborhood</td>
<td>5.63</td>
<td>2.17</td>
<td>-3.47</td>
</tr>
<tr>
<td></td>
<td>West End neighborhood, low-income historic neighborhood</td>
<td>4.79</td>
<td>1.70</td>
<td>-3.09</td>
</tr>
<tr>
<td></td>
<td>Pendleton neighborhood, low-income historic neighborhood</td>
<td>4.66</td>
<td>3.13</td>
<td>-1.53</td>
</tr>
<tr>
<td></td>
<td>Over-the-Rhine neighborhood, high-income historic neighborhood</td>
<td>3.96</td>
<td>5.54</td>
<td>1.57</td>
</tr>
<tr>
<td>Portland, OR</td>
<td>Central business district, high-income area</td>
<td>12.41</td>
<td>4.06</td>
<td>-8.36</td>
</tr>
<tr>
<td></td>
<td>Goose Hollow neighborhood, medium-income historic area</td>
<td>12.19</td>
<td>2.18</td>
<td>-10.02</td>
</tr>
<tr>
<td></td>
<td>Goose Hollow neighborhood, medium-income historic area</td>
<td>4.32</td>
<td>1.43</td>
<td>-2.88</td>
</tr>
<tr>
<td></td>
<td>Goose Hollow neighborhood, medium-income historic area</td>
<td>4.02</td>
<td>2.21</td>
<td>-1.81</td>
</tr>
<tr>
<td></td>
<td>Central business district, Portland State Univ. campus</td>
<td>3.90</td>
<td>8.93</td>
<td>5.03</td>
</tr>
</tbody>
</table>
Transit Deserts: The Gap between Demand and Supply

Figure 1. Transit deserts analysis in Charlotte, NC
Figure 2. Transit deserts analysis in Chicago, IL
Figure 3. Transit deserts analysis in Cincinnati, OH
PORTLAND, OR

Figure 4. Transit deserts analysis in Portland, OR
**Discussion**

Transit deserts were discovered in areas in all four cities. Spatially, transit deserts were typically concentrated close to the downtown where cities most often have their major transit centers operating on a “hub and spoke” type of system. Supply for each city was relatively predictable; highest concentrations occurred in or near the central business district and service supply decreased as distance from the center increased. The gap analysis yielded some interesting results for each city.

In the case of Charlotte, its 3,600+ stops and 70 routes are concentrated mostly in the city center. Supply follows a logical spatial pattern across the city. However, transit-dependent populations (demand) are most dense on the fringes of the city and the inner-city neighborhoods to the north and west of the downtown. The areas with the highest transit dependency are skewed by the Charlotte Douglas International Airport and a very high-intensity industrial area on the city’s southwest side.

Charlotte’s highest concentrations of transit-dependent populations are fairly well-served. There are a few census block groups with greater demand than supply. Some neighborhoods just north of the downtown do not have demand that is met, however. As can be seen in Figure 1, many of Charlotte’s most transit-dependent areas exist in suburban or rural portions of the city. This may be caused by several areas lacking adequate sidewalk and bike facilities. Since most of Charlotte’s population and area growth occurred since the 1950s, the vast majority of the city is automobile-oriented. This has left much of the area surrounding the central business district to be developed at a low density.

Chicago presents an interesting scenario. Historically, the city has developed around commuter rail lines, which has led to the establishment of some of the city’s most prominent neighborhoods. Today, the level of transit dependency appears very high, particularly in more affluent neighborhoods. The city exhibits, by far, the highest levels of transit dependency, with its highest block group having a score of 24.79 (the city with the next highest was Portland with only half that value). Thus, we see relatively few transit deserts in the city of Chicago, which is well-served by high levels of transportation services (Figure 2). There are instances of transit deserts, however, particularly in the farthest north neighborhoods of the city within the Edgewater neighborhood as well as a few block groups just outside of the city’s “Loop.”
Cincinnati also follows a similar pattern of supply. Transit routes come in to the city center, located along the Ohio River. Spatially, transit deserts are much more random in Cincinnati, occurring in older neighborhoods north and west of downtown, but several more exist in suburban and exurban developments. The highest concentrations are within its historic neighborhoods adjacent to its central business district. The West End and Pendleton neighborhoods are low-income historic neighborhoods, which have the highest rates of dependency coupled with very low rates of supply—the highest block group has a score of 3.13. Interestingly, the Over-the-Rhine neighborhood, a quickly gentrifying neighborhood also located just north of downtown Cincinnati, is considered to be in this category due to its high transit demand, but it has a much higher supply rating of 5.54, thus leaving the area sufficiently served by transit (Figure 3).

By area, Portland has the greatest level of transit service per area and population compared to the other three cities, by far. In fact, the city has gained notoriety for its exceptional transit service. It is similar to Chicago from the standpoint that its transit demand appears high largely because many of the city’s residents choose to not own a car in favor of taking transit. Three of Portland’s five block groups with the highest demand for transit are fairly well-served, and all are located either in the central business district or adjacent to it. Several of the neighborhoods west of the Willamette River are extremely well served, as can be seen in the gap analysis of the city in Figure 4.

Conclusions and Limitations
This research is important for two primary reasons. First, the study aims to illustrate and turn the focus to neighborhoods in major cities whose transit needs are not being met. This is useful in terms of public transit planning where new routes and stops should be located as well as how much service certain areas should receive. Transit-dependent populations mark an increasingly important demographic of people who often are marginalized from society and excluded from access to employment, retail, and overall participation in society. Roseland (2005) opined that “social equity demands that we balance the needs of the biosphere with the needs of the vast majority of the human population, the world’s poor.” From this perspective, social equity is understood as an effort to address the injuries and injustices meted out to those excluded from a protected class. These injuries and injustices manifest themselves in a variety of ways, resulting in traumatic experiences for the physical landscape as well as the human encounter where the fundamental rights of citizens are compromised (Garcia-Zamor 2009).
Second, this study approaches a transportation problem with a new paradigm and establishes a method for quantifying and calculating locations with inadequate transit service given a population’s needs. Relatively no literature was found on this topic, which makes this study an important stepping stone to refine and evaluate public transportation service. In an era with dwindling budgets for public agencies, efficiency and effectiveness are paramount. Public dollars need to be spent as sensibly as possible. This study allows more sensible solutions to be determined and adds to the discourse of transportation planning methods.

There are few limitations in this research. First, it should be recognized that any method to evaluate transit-dependent populations is a difficult one. The method chosen for this study was one that was most pragmatic and sensible. Because of this, the study cannot correlate exactly why high levels of transit dependency occur in certain areas. For example, the analysis of Chicago showed a high transit dependency in the Edgewater Beach neighborhood on the far north side of the city. However, the neighborhood is known to have a satisfactory level of transit service. The reason for this lies in the study’s low geographic scale. One of goals of this study was to obtain a high level of data for the smallest unit of geography possible, thus gaining the more precise knowledge of a particular area. Coupled with Chicago’s high population density, block group geographies in this portion of the city are comparatively very small. While bus or train stops might only be a block away, this is not reflected in the data. Thus, certain areas that, in reality, are served well by transit, are shown as bereft of service.

Last, this study also met data limitations when trying to calculate certain criteria for transit supply. Census data for vehicles available is not publicly available by block group geography and had to be adjusted from the census tract level.

Endnotes

1 U.S. Department of Transportation, Federal Highway Administration (FTA), Bureau of Transportation Statistics. FTA published the *Census Transportation Planning Package 2000 Status Report* in cooperation with the Transportation Research Board Census Subcommittee.

2 Non-institutionalized populations living in group quarters include persons living in dormitories and fraternity, and sorority houses.
References


### About the Authors

**Junfeng Jiao** (jjiao@austin.utexas.edu) is an assistant professor in the School of Architecture at the University of Texas at Austin. He received his Ph.D. in urban planning and MSc in transportation engineering from the University of Washington. His research interests include public transportation, transportation modeling, GIS and GPS applications, and public health.

**Maxwell Dillivan** (mkdillivan@bsu.edu) recently graduated *magna cum laude* from Ball State University with a Master of Urban & Regional Planning degree (emphasis in GIS and Comprehensive Planning). His research interests include public transportation, transportation planning, land use dynamics, and history of urban forms.
Bus Rapid Transit and Economic Development: Case Study of the Eugene-Springfield BRT System

Arthur C. Nelson, Bruce Appleyard, Shyam Kannan, Reid Ewing, Matt Miller, Dejan Eskic
Metropolitan Research Center, University of Utah

Abstract

Bus rapid transit (BRT) in the United States is relatively recent. BRT has many promises, one of which is enhancing the economic development prospects of firms locating along the route. Another is to improve overall metropolitan economic performance. In this article, we evaluate this issue with respect to one of the nation’s newest BRT systems that operates in a metropolitan area without rail transit: Eugene-Springfield, Oregon. While the metropolitan area lost jobs between 2004 and 2010, jobs grew within 0.25 miles of BRT stations. Using shift-share analysis, we find that BRT stations are attractive to jobs in several economic sectors. Planning and policy implications are offered along with an outline for future research.

Introduction

In this article, we assess the relationship between bus rapid transit (BRT) and the change in share of jobs in an urban area during the 2000s. Eugene-Springfield, Oregon, is our case study. The Eugene-Springfield BRT system is well-suited for this analysis because it has one of the nation’s newest BRT systems, so we can assess economic influences in the short-term; its system is reasonably representative of emerging BRT design; and we were able to acquire employment data, allowing us conduct spatially-related analysis. Our analysis covers the years 2004 and 2010,
which were three years before and after the BRT system was opened. Our article includes these sections: Fixed-Guideway Transit Systems and Economic Development; Overview of the Eugene-Springfield BRT System; Research Method and Data; Assessment of Results; and Planning and Policy Implications.

Fixed-Guideway Transit Systems and Economic Development

Bus rapid transit is a specialized form of fixed-guideway transit systems that include heavy or “fifth” rail, such as the New York subway; light rail, such as provided in Charlotte and San Diego; non-tourist-related streetcar, such as seen in Portland and New Orleans; and bus rapid transit, such as the new Eugene-Springfield service operated by the Lane Transit District, known as the Emerald Express or EmX. Fixed-guideway systems reinvent the idea of agglomeration economies, which is a cornerstone of urban economic development. In this section, we review the role of agglomeration economies in economic development, assess how the advantages of agglomeration economies are undermined by automobile dependency, and summarize the role of fixed-guideway transit systems in recreating those economies.

Cities are formed and grow in large part by creating agglomeration economies (Glaeser 2011). Annas, Arnott, and Small (1998) define the term as “the decline in average cost as more production occurs within a specified geographical area” (p. 1427). They arise specific to certain economic sectors, however. As more firms in a related sector cluster together, costs of production fall as productivity increases. These economies can spill over into complementary sectors (Holmes 1999). Cities can become ever larger as economies of agglomeration are exploited (Ciccone and Hall 1996). If cities get too large, however, congestion occurs, which leads to diseconomies of scale. The result may be relocation of firms, but this can weaken economies of scale (Bogart 1998). Highways connecting the city to outlying areas can induce firms to relocate, thereby reducing agglomeration diseconomies of scale through sacrificing some economies, though overall economic improvement is debatable (Boarnet 1997). Cities thus spread out, and although the urban area may contain more people and jobs, the advantages of agglomeration economies are weakened.

One way to preserve agglomeration economies and reduce diseconomies is to improve transportation systems; this is a role of fixed-guideway transit systems. Within about 0.25 to 0.50 miles from transit stations accessing these systems, firms maximize the benefits of agglomeration economies (Cervero et al. 2004). Moreover, some firms can also benefit from expanded access to the labor force residing
within walking distance of transit stations, wherever they are located (Belzer, Srivastava, and Austin 2011).

There is another aspect of agglomeration economies identified by Chapman and Noland (2011). Although transit systems can lead to higher-density development by shifting new jobs and population to station areas, it could lead, instead, to the redistribution of existing development even in the absence of growth.

In part because of their role in facilitating agglomeration economies, there is a growing body of research showing that rail-based public transit enhances economic development (see Nelson et al. 2009). These economies are facilitated when they improve accessibility between people and their destinations (Litman 2009) by reducing travel time and the risk of failing to arrive at a destination (Weisbrod and Reno 2009). At the metropolitan scale, adding transit modes in built-up urban areas increases aggregate economic activity (Graham 2007).

Economic development can be measured in many ways. One is by evaluating how the market responds to the presence of transportation investments, such as rail stations. Higher values closer to stations implies market capitalization of economic benefits, which can occur only when economic activity increases. Only a few studies have shown this with respect to commercial property values (Nelson 1999) and none for BRT, although one study shows positive residential property value effects (see Perk and Catalá 2009).

Our focus here is whether and the extent to which there is a link between a specific form of transit—BRT—and job growth. We know from recent work that not all firms benefit from transit. In their recent study of employment within one-half mile of transit stations serving 34 rail systems, Belzer, Srivastava and Austin (2011) found that while jobs increase in the Arts/Entertainment/Recreation sectors, as well as the Accommodation and Food Services and Health Care and Social Assistance sectors, they fell in the Manufacturing sector. They also found that the Public Administration sector had the greatest share of jobs found near transit stations. Several other sectors also concentrated around transit stations, such as Professional, Scientific, and Technical Services and Retail. On the other hand, as a whole, the station areas experienced declining shares of jobs relative to their regions, with the exception of jobs in the Utilities, Information, and Arts/Entertainment/Recreation sectors. Belzer, Srivastava, and Austin (2011) surmised that much of the metropolitan job growth continues to favor auto-oriented locations. Their study did not report results for individual systems and, as it was based on data through 2008, came just one year after the Eugene-Springfield BRT opened.
There is no research directly linking BRT to economic development, however. Our case study of the EmX system lays the groundwork for determining whether there is a link and, if so, which economic sectors are affected. We also investigate whether distance from BRT stations makes a difference. Literature indicates that economic benefits occur within one-half mile of transit stations, but studies have focused principally on rail systems. Whether BRT has similarly large spatial areas of attractiveness is not known.

Overview of the Eugene-Springfield BRT System
Planning for the Emerald Express (EmX BRT) began in 1996, when local officials and citizens assessed transit alternatives. Unlike many smaller to medium-size metropolitan areas, Eugene-Springfield is constrained from outward urban expansion by an urban growth boundary (see Nelson and Dawkins 2004). A principle objective of urban containment is to use transit to provide more efficient connections within urbanized areas than automobiles. The planning process managed by the Lane Transit District considered light rail and bus rapid transit options. In 2001, the BRT option was selected over light rail because it was the best option for service and price, especially given the area’s modest population size (about 300,000 residents and 140,000 jobs in the metropolitan area1). Moreover, analysis indicates that the BRT option significantly enhances transit service and achieves many of the benefits of light rail but without the cost.

Construction of the BRT system started in 2004 and EmX service began in 2007. The first EmX route connects downtown Eugene with Springfield, Oregon (Thole, Cain, and Flynn 2009). The EmX includes dedicated bus lanes for about 60 percent of the route. This includes lanes separated by curbs or clearly demarcated travel lanes. EmX vehicles share the road with traffic elsewhere. Vehicles are also provided signal priority, including special signaling at intersections. The BRT vehicles are custom-built with doors on both sides that provide for loading from platforms on either side. In 2008, the first full year of operation, EmX carried 1.5 million riders.2

The system is expanding away from the route connecting downtown Eugene and Springfield westward along commercial corridors. In 2011, the Gateway extension opened. It added 7.8 miles to the EmX running north-south on Pioneer Parkway from the Springfield Station to the Gateway Mall and the Sacred Heart Medical Center. On the other hand, efforts by the Lane Transit District to expand the EmX to the west on 11th Avenue are met with opposition from business owners who fear it would disrupt customer traffic.
Research Method and Data
We evaluate the EmX BRT system for its economic development outcomes in terms of employment change within 0.25 and 0.50 miles of BRT stations. To do this, our method is twofold. First, we perform a descriptive analysis of the extent to which the EmX BRT may affect the concentration of new employment within those distance bands around BRT stations. Second, we use shift-share analysis to assess particular patterns of firm location within those distance bands relative to the Eugene-Springfield metropolitan area as a whole to identify those economic sectors that may especially benefit from BRT proximity, and those that do not.

Our experimental interest is whether job changes in the metropolitan area are associated with the BRT route and stations. Our overall research design uses the case study method based on post-hoc outcomes; that is, because we know where the jobs are located throughout the study area, we can test for the shift in share of jobs before the introduction of the BRT in 2007, with outcomes later.

Our employment data come from the Local Employment Dynamics (LED) database. LED data are assembled by the Census Bureau through a voluntary partnership among 45 states. The data provide details about jobs, workers, and the structure of local economies. The LED uses existing data from state-supplied administrative records on workers and employers and is integrated with existing censuses, surveys, and other administrative records.

LED data have been made available annually since 2002 at the Census block level. Blocks can be aggregated into higher-level geographic units for analysis for any given year or set of years. Jobs are reported at the two-digit level of the North American Industrial Classification System (NAICS). For our study, the LED data are collected for Lane County as a whole to analyze employment change between 2004—three years before the EmX began operating—and 2010—three years after operations commenced. The year 2004 was also four years before the Great Recession when the metropolitan area (comprising Lane County) had 139,000 jobs then. In 2010, a year after the Great Recession had passed officially, the metropolitan area had 136,000 jobs. Thus, not only are we able to determine whether and the extent to which EmX influenced employment location patterns but also whether those patterns may have been affected by the economic downturn. Using Census blocks, employment sheds are constructed at 0.25 and 0.50 mile distances around BRT stations. If the BRT system has no effect on job location, we would see no difference in the share of jobs near BRT stations before (2004) or after (2010) system commencement with the added benefit of testing for outcomes with respect to the Great Recession.
Assessment of Results

Table 1 reports our overall assessment of change in employment between 2004 and 2010. We report jobs for areas within 0.25 miles of a station, between 0.25 and 0.50 miles of a station, and the balance of the metropolitan area. Overall, for the metropolitan area outside the 0.50 mile BRT station areas, jobs fell by about 5 percent or more than 5,000. Jobs stayed about the same between 0.25 and 0.50 miles of station areas but increased by about 10 percent or nearly 3,000 within 0.25 miles of station areas.

For the most part, changes in jobs follow similar patterns at three levels of geography, but there are interesting exceptions. Within 0.25 miles of BRT stations, jobs in the Information, Real Estate, Management, Administrative, Education, Health Care, Lodging/Food, and other sectors all increased by more than 10 percent, with Management more than doubling. In contrast, between 0.25 and 0.50 miles from stations, many of those same sectors lost jobs (Information, Professional, Management, and Administrative), while others grew in both distance-bands (Real Estate, Finance, Education, and Health Care). Jobs in the Transportation and Arts/Entertainment/Recreation sector increased substantially between 0.25 and 0.50 miles of BRT stations (160% and 130%, respectively). Retail gained slightly in both distance bands but fell for the balance of the metropolitan area. A surprise based on other research is that jobs within 0.25 miles of a BRT station fell in the Arts/Entertainment/Recreation sector and fell slightly in the Public Administration sector; on the other hand, those sectors gained jobs between 0.25 and 0.50 miles of BRT stations. Also surprising is that the balance of the metropolitan area did far better in gaining jobs in Health Care, Lodging/Food, and Public Administration than station areas.

We surmise that the market is sorting jobs based on competition for BRT proximity. It may be that office uses are able to outbid Arts/Entertainment/Recreation for locations closest to BRT stations (the sector lost nearly 120 jobs within 0.25 miles) but many of those displaced jobs still located within 0.50 miles of BRT stations (the sector gained 46 jobs between 0.25 and 0.50 miles).

We cannot say conclusively that there is a cause-and-effect relationship between BRT locations and increasing concentration of certain kinds of jobs within 0.5 miles of BRT stations; this will be the subject of future research.
### Table 1. Change in Jobs with Respect to Distance from EmX BRT Stations, 2004 and 2010

<table>
<thead>
<tr>
<th>NAICS Code</th>
<th>NAICS Sector</th>
<th>Jobs within 0.25 Mile of EmX Station, 2004</th>
<th>Jobs within 0.25 Mile of EmX Station, 2010</th>
<th>Change in Jobs, 2004–2010</th>
<th>Jobs between 0.25 and 0.50 Mile of EmX Station, 2004</th>
<th>Jobs between 0.25 and 0.50 Mile of EmX Station, 2010</th>
<th>Change in Jobs, 2004–2010</th>
<th>Jobs Balance of Metro Area, 2004</th>
<th>Jobs Balance of Metro Area, 2010</th>
<th>Change in Jobs, 2004–2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>Utilities</td>
<td>475</td>
<td>513</td>
<td>8%</td>
<td>91</td>
<td>136</td>
<td>49%</td>
<td>151</td>
<td>183</td>
<td>21%</td>
</tr>
<tr>
<td>23</td>
<td>Construction</td>
<td>643</td>
<td>520</td>
<td>-19%</td>
<td>400</td>
<td>314</td>
<td>-22%</td>
<td>5,696</td>
<td>4,696</td>
<td>-18%</td>
</tr>
<tr>
<td>31–33</td>
<td>Manufacturing</td>
<td>813</td>
<td>465</td>
<td>-43%</td>
<td>293</td>
<td>174</td>
<td>-41%</td>
<td>18,690</td>
<td>11,685</td>
<td>-37%</td>
</tr>
<tr>
<td>42</td>
<td>Wholesale</td>
<td>427</td>
<td>269</td>
<td>-37%</td>
<td>584</td>
<td>499</td>
<td>-15%</td>
<td>5,313</td>
<td>4,742</td>
<td>-11%</td>
</tr>
<tr>
<td>44–45</td>
<td>Retail</td>
<td>1,769</td>
<td>1,844</td>
<td>4%</td>
<td>1,039</td>
<td>1,073</td>
<td>3%</td>
<td>14,551</td>
<td>14,021</td>
<td>-4%</td>
</tr>
<tr>
<td>48–49</td>
<td>Transportation</td>
<td>484</td>
<td>517</td>
<td>7%</td>
<td>52</td>
<td>135</td>
<td>160%</td>
<td>2,608</td>
<td>2,260</td>
<td>-13%</td>
</tr>
<tr>
<td>51</td>
<td>Information</td>
<td>1,133</td>
<td>1,557</td>
<td>37%</td>
<td>450</td>
<td>389</td>
<td>-14%</td>
<td>1,550</td>
<td>1,360</td>
<td>-12%</td>
</tr>
<tr>
<td>52</td>
<td>Finance</td>
<td>1,285</td>
<td>1,447</td>
<td>13%</td>
<td>422</td>
<td>524</td>
<td>24%</td>
<td>2,105</td>
<td>1,766</td>
<td>-16%</td>
</tr>
<tr>
<td>53</td>
<td>Real Estate</td>
<td>442</td>
<td>488</td>
<td>10%</td>
<td>177</td>
<td>182</td>
<td>3%</td>
<td>1,947</td>
<td>1,516</td>
<td>-22%</td>
</tr>
<tr>
<td>54</td>
<td>Professional</td>
<td>2,366</td>
<td>2,221</td>
<td>-6%</td>
<td>861</td>
<td>811</td>
<td>-6%</td>
<td>2,751</td>
<td>2,597</td>
<td>-6%</td>
</tr>
<tr>
<td>55</td>
<td>Management</td>
<td>291</td>
<td>633</td>
<td>118%</td>
<td>98</td>
<td>75</td>
<td>-23%</td>
<td>1,631</td>
<td>1,733</td>
<td>6%</td>
</tr>
<tr>
<td>56</td>
<td>Administrative</td>
<td>1,320</td>
<td>2,042</td>
<td>55%</td>
<td>1,514</td>
<td>1,031</td>
<td>-32%</td>
<td>5,456</td>
<td>4,441</td>
<td>-19%</td>
</tr>
<tr>
<td>61</td>
<td>Education</td>
<td>1,015</td>
<td>1,249</td>
<td>23%</td>
<td>258</td>
<td>303</td>
<td>17%</td>
<td>13,983</td>
<td>15,800</td>
<td>13%</td>
</tr>
<tr>
<td>62</td>
<td>Health Care</td>
<td>7,751</td>
<td>9,095</td>
<td>17%</td>
<td>920</td>
<td>1,395</td>
<td>52%</td>
<td>9,363</td>
<td>12,102</td>
<td>29%</td>
</tr>
<tr>
<td>71</td>
<td>Arts/Ent/Rec</td>
<td>826</td>
<td>707</td>
<td>-14%</td>
<td>43</td>
<td>99</td>
<td>130%</td>
<td>1,421</td>
<td>1,526</td>
<td>7%</td>
</tr>
<tr>
<td>72</td>
<td>Lodging/Food</td>
<td>2,615</td>
<td>2,919</td>
<td>12%</td>
<td>1,113</td>
<td>1,099</td>
<td>-1%</td>
<td>7,445</td>
<td>8,341</td>
<td>12%</td>
</tr>
<tr>
<td>81</td>
<td>Other Services</td>
<td>621</td>
<td>717</td>
<td>15%</td>
<td>269</td>
<td>294</td>
<td>9%</td>
<td>4,009</td>
<td>3,926</td>
<td>-2%</td>
</tr>
<tr>
<td>92</td>
<td>Public Admin</td>
<td>3,461</td>
<td>3,379</td>
<td>-2%</td>
<td>488</td>
<td>552</td>
<td>13%</td>
<td>1,361</td>
<td>2,084</td>
<td>53%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>27,737</td>
<td>30,582</td>
<td>10%</td>
<td>9,072</td>
<td>9,085</td>
<td>0%</td>
<td>100,031</td>
<td>94,779</td>
<td>-5%</td>
</tr>
</tbody>
</table>

Source: Data from Local Employment Dynamics.
Also, this does not necessarily mean that BRT proximity confers a comparative advantage for selected economic sectors. For this, we turn to shift-share analysis. In particular, because we know where the jobs were located throughout the study area in 2004 and 2010, we can compare shifts in share of jobs before and after the introduction of the EmX.

Shift/share analysis is used to decompose employment changes in local areas. The analysis identifies industries that have a comparative advantage in the local area. In our case, we use the Eugene-Springfield metropolitan area’s non-farming, forestry, fishing, or mining jobs and apply shift-share analysis to determine the nature of employment change with respect to being with 0.25 miles and between 0.25 and 0.50 miles of BRT stations in 2004 and 2010.

Shift-share analysis assigns the change or shift in the share or concentration of jobs with respect to the region, other economic sectors, and the local area. The “region” can be any level of geography and is often the nation or the state. In our case, where we want to see whether there are intra-metropolitan shifts in the share of jobs by sector, our region is the metropolitan area itself. The “local” area is often a city or county or even state, but it can be any geographic unit that is smaller than the region. Our local areas are the station areas within 0.25 miles and between 0.25 and 0.50 miles of the nearest BRT station; we call this the BRT Station Area. As shifts in the share of jobs may vary by sector over time because of changes in economic sector mixes (there are now more high-tech jobs in the Eugene-Springfield metropolitan area than jobs in forestry), there is also an “industry mix” adjustment that we call the Sector Mix. Using notations by the Carnegie Mellon Center for Economic Development (no date), the shift-share formula is:

\[ SS_i = MA_i + SM_i + BRT_i \]

Where,

- \( SS_i \) = Shift-Share
- \( MA_i \) = Metropolitan Area share
- \( SM_i \) = Sector Mix
- \( BRT_i \) = BRT Station Area shift

The Metropolitan Area (MA) share measures by how much total employment in a BRT station area changed because of change in the metropolitan area economy during the period of analysis. If metropolitan area employment grew by 10 percent
during the analysis period, then employment in the BRT station area would have also grown by 10 percent if there is no BRT effect. The Sector Mix (SM) identifies fast-growing or slow-growing economic sectors in a BRT station area based on the metropolitan area growth rates for the individual economic sectors. For instance, a BRT station area with an above-average share of the metropolitan area’s high-growth sectors would have grown faster than a BRT station area with a high share of low-growth sectors. The BRT station area shift, also called the “competitive effect,” is the most relevant component; it identifies a BRT station area’s leading and lagging sectors. The competitive effect compares a BRT station area’s growth rate in a given economic sector with the growth rate for that same sector at the metropolitan area. A leading sector is one where that sector’s BRT station area growth rate is greater than its metropolitan area growth rate. A lagging sector is one where the sector’s BRT station area growth rate is less than its metropolitan area growth rate.³

The equations for each component of the shift-share analysis are:

\[
\begin{align*}
MA &= (BRT \text{ station area}^{t-1} \cdot MA^t / MA^{t-1}) \\
SM &= [(BRT \text{ station area}^{t-1} \cdot MA_t / MA^{t-1}) - MA] \\
BRT &= [BRT \text{ station area}^{t-1} \cdot (BRT \text{ station area}^t / BRT \text{ station area}^{t-1} - MA^t / MA^{t-1})]
\end{align*}
\]

Where:

\(BRT \text{ station area}^{t-1}\) = number of jobs in the BRT station area sector \((i)\) at the beginning of the analysis period \((t-1)\)

\(BRT \text{ station area}^t\) = number of jobs in the BRT station area in sector \((i)\) at the end of the analysis period \((t)\)

\(MA^{t-1}\) = total number of jobs in the metropolitan area at the beginning of the analysis period \((t-1)\)

\(MA^t\) = total number of jobs in the metropolitan area at the end of the analysis period \((t)\)

\(MA_t\) = number of jobs in the metropolitan area in sector \((i)\) at the beginning of the analysis period \((t-1)\)

\(MA^t\) = number of jobs in the metropolitan area in sector \((i)\) at the end of the analysis period \((t)\)
Table 2 reports only the BRT station area shift results for the areas within 0.25 miles, between 0.25 and 0.50 miles, and within 0.50 miles of BRT stations. Figure 1 illustrates the BRT share for all the first two station area distances (0.25 and between 0.25 and 0.50 miles). The stacked bars in this figure allow us to see the individual and combined effects of distance from BRT stations by economic sector.

Table 2. Shift-Share of Analysis of Job Change with Respect to Distance from BRT Stations, 2004 and 2010

<table>
<thead>
<tr>
<th>NAICS Sector</th>
<th>BRT Shift 0.25 Mile</th>
<th>BRT Shift 0.25-0.50 Mile</th>
<th>BRT Shift 0.50 Mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilities (38)</td>
<td>30</td>
<td>(8)</td>
<td></td>
</tr>
<tr>
<td>Construction (8)</td>
<td>(14)</td>
<td>(22)</td>
<td></td>
</tr>
<tr>
<td>Manufacturing (41)</td>
<td>(8)</td>
<td>(50)</td>
<td></td>
</tr>
<tr>
<td>Wholesale Trade (103)</td>
<td>(10)</td>
<td>(113)</td>
<td></td>
</tr>
<tr>
<td>Retail Trade</td>
<td>118</td>
<td>59</td>
<td>177</td>
</tr>
<tr>
<td>Transportation and Warehousing</td>
<td>69</td>
<td>87</td>
<td>156</td>
</tr>
<tr>
<td>Information</td>
<td>361</td>
<td>(86)</td>
<td>276</td>
</tr>
<tr>
<td>Finance and Insurance</td>
<td>187</td>
<td>110</td>
<td>298</td>
</tr>
<tr>
<td>Real Estate and Rental &amp; Leasing</td>
<td>111</td>
<td>31</td>
<td>143</td>
</tr>
<tr>
<td>Professional, Scientific, and Technical Services (7)</td>
<td>0</td>
<td>(7)</td>
<td></td>
</tr>
<tr>
<td>Management of Companies and Enterprises</td>
<td>281</td>
<td>(43)</td>
<td>238</td>
</tr>
<tr>
<td>Administrative/Support/Waste Management/Remediation Svcs</td>
<td>846</td>
<td>(341)</td>
<td>504</td>
</tr>
<tr>
<td>Educational Services</td>
<td>95</td>
<td>10</td>
<td>104</td>
</tr>
<tr>
<td>Health Care and Social Assistance</td>
<td>(615)</td>
<td>242</td>
<td>(373)</td>
</tr>
<tr>
<td>Arts/Entertainment/Recreation</td>
<td>(134)</td>
<td>55</td>
<td>(79)</td>
</tr>
<tr>
<td>Accommodation and Food Services</td>
<td>26</td>
<td>(132)</td>
<td>(106)</td>
</tr>
<tr>
<td>Other Services (except Public Administration)</td>
<td>91</td>
<td>23</td>
<td>114</td>
</tr>
<tr>
<td>Public Administration</td>
<td>(542)</td>
<td>(1)</td>
<td>(543)</td>
</tr>
<tr>
<td>Total</td>
<td>698</td>
<td>12</td>
<td>710</td>
</tr>
</tbody>
</table>

Source: Data from Local Employment Dynamics.
We use Figure 1 in combination with Table 2 to identify economic sectors that seem especially attracted to, or even repelled by, BRT stations. We also offer insights for individual economic sectors and how they relate to broader findings reported by Belzer, Srivastava and Austin (2011).

A number of sectors appear to be displaced by other sectors seeking BRT station proximity, particularly Construction, Manufacturing, and Wholesale Trade. This is consistent with findings of Belzer, Srivastava, and Austin (2011). Jobs in the Utilities sector appear to be displaced with 0.25 miles of BRT stations, but they seem to have shifted to areas between 0.25 and 0.50 miles.

A number of other sectors appear to be attracted to BRT station areas as a whole, although especially within 0.25 miles of a station. These include Retail Trade, Transportation and Warehousing, Finance and Insurance, Real Estate and Rental & Leasing, and other services. This is also consistent with findings of Belzer, Srivastava, and Austin (2011).

An interesting finding is that certain sectors are attracted to the closest BRT locations but considerably less so up to 0.50 miles, and, in some cases, jobs are shifted away from the 0.25–0.50 mile band but into the closer band. For instance, the 0.25–0.50 mile band saw a negative shift in Information, Management of Companies and Enterprises, Administrative/Support/Waste Management/Remediation.
Services, and Accommodation and Food Service. In many instances, the positive shift into the 0.25 mile band was greater than the negative shift out of the 0.25–0.50 mile band. While these are sectors that Belzer, Srivastava, and Austin (2011) expect to be attracted to station areas generally, the fact that their positive shift is so large toward the closer band suggests that, at least for BRT, the location advantage may not reach out as far as for rail modes.

There is also the reverse situation in which there is a negative shift in the closest band but a positive one in the 0.25–0.50 mile band. This is the case with Health Care and Social Assistance in which the shift away from the closer band was the largest of all shifts, while the shift to the 0.25–0.50 mile band was the largest there. Part of this may be explained by a major medical facility that opened in the late 2000s outside the BRT station areas.

Then there is the interesting case of Public Administration, which had the second largest shift away from the closest distance band and there does not appear to any offsetting shift in the 0.25–0.50 band. The explanation is likely severe local government budget cuts during the late 2000s that resulted in hundreds of jobs being cut that were near BRT stations.

There are two other observations. First, of the combined shift in jobs toward BRT station areas of 710 jobs, only 12 are in the 0.25–0.50 distance band. Thus, essentially, the entire overall shift in jobs favoring BRT station areas occurred within 0.25 miles of them. Second, the BRT system may have a resiliency effect. Where the Eugene-Springfield metropolitan area as a whole lost jobs between 2004 and 2010, jobs were actually added within 0.25 miles of BRT stations.

**Planning and Policy Implications**

We are impressed to see how the Eugene-Springfield market responded so quickly to the EmX BRT system. Future research in other metropolitan areas and over longer periods of time in Eugene-Springfield can confirm whether our results are robust. Success, however, is likely due to several factors that need to be considered in planning, designing, and implementing BRT systems. In our view, the key planning lessons include the following:4

1. The success of projects is due, in part, to a high level of cooperation among public agencies, non-profit development communities, and private developers.
2. In cities where the real estate market is not already strong, an active transit agency with a TOD program and/or active community development organization is critical.

3. Real estate developers and owners view permanence as an important factor for building around a BRT system. A key advantage of rail is that once the investment has been made, the real estate industry can usually rely on its permanence over the many decades it takes to maximize profits from high-density investments at or near those stations. However, even in the cities with a relatively low level of infrastructure, BRT may be viewed as permanent when there is a clear long-term commitment by the transit agency. In the case of EmX, this commitment includes substantial capital investment in providing separated lanes for exclusive BRT use and light-rail-like transit stations.

4. The transit corridor must be amenable to high-density development, so the route needs to assure this opportunity. Corridors placed in areas without major employment or housing destinations are not likely to attract development, regardless of mode.

5. Providing financial incentives for TODs at BRT stations does not appear to be as important for attracting developer interest. Developers are much more interested in an expedited permitting or rezoning process, as time is a critical factor in making development projects financially viable.

One implication is that BRT may provide for many more opportunities for smaller metropolitan areas to serve numerous job sectors. We note that an urbanized population of about one million appears to be the smallest capable of supporting light rail, with Salt Lake City being an example. Light-rail-like benefits may be achieved only in smaller metropolitan areas through BRT. Moreover, within metropolitan areas that have light or heavy rail, costs may prohibit their expansion. BRT could be the next-generation solution to increase multimodal options. In either case, the BRT results for Eugene-Springfield’s EmX may provide metropolitan planning organizations with a rationale for investing in BRT for economic development reasons, especially in situations where rail does not “pencil.”

We hope our work stimulates more research in this area. In the case of Eugene-Springfield, we find that the job growth occurred near BRT stations over a short period of time where otherwise the metropolitan area lost jobs as a whole. Further research is needed to determine cause-and-effect relationships between BRT stations and employment change, whether there is variation among economic sectors, whether employment shifts occur in the short term as well as the long term,
and the extent to which local economic benefits improve with respect to BRT, among others. There is also the question of whether and to what extent BRT affects residential location patterns.

It would also be important to know whether BRT technologies have different economic development and residential location outcomes. Most light rail systems, for instance, use the same system design and mechanical technologies. In contrast, BRT systems can vary widely based on rail, station/platform, carriage, signalization, and other features. Success with EmX’s BRT flavor may not be replicated with other BRT flavors.

We hope this article serves as a starting point for advancing discussion on BRT as a viable economic development tool.

Endnotes

1 Compiled from http://www.ltd.org/search/showresult.html?versionthread=45a4b83927fba5cb751c741bf4ac81e3.

2 For a brief history, see http://www.ltd.org/search/showresult.html?versionthread=aac1492116416eb1c13546ffe5d14e6b.

3 We have adapted the Carnegie Mellon Center for Economic Development’s description of how shift-share works for our application.


Acknowledgments

The authors acknowledge that support for research leading to this article was provided by the U.S. Department of Housing and Urban Development through its Sustainable Communities program and the National Institute for Transportation and Communities.
References


About the Authors

Arthur C. Nelson (ACNelson@MetropolitanResearchCenter.org) is Presidential Professor of City & Metropolitan Planning, Executive Director of the Metropolitan Research Center, and Director of the Master of Real Estate Development Program at the University of Utah. His research areas include economic development, public finance, transportation and land use analysis, and metropolitan development patterns.

Bruce Appleyard (bappleyard@cfaconsultants.com) is a Principal of the planning, research and urban design firm CFA Consultants. He has more than 20 years of experience on the intersection between transportation, land use, urban design, and environmental quality in support of a diverse range of sustainability and livability objectives.

Shyam Kannan (E014284@wmata.com) is the Washington Metropolitan Area Transportation Authority’s assistant general manager for planning and joint development. Previously, he was a principal and director of RCLCO’s economic development practice.

Reid Ewing (ewing@arch.utah.edu) is a Professor of City & Metropolitan Planning at the University of Utah, coordinator of the planning doctoral program, and a bi-monthly columnist on planning research at Planning magazine. His research interests are research itself, land use and transportation planning, smart growth, and public health.

Matt M. Miller is a Graduate Research Assistant at the Metropolitan Research Center and a doctoral student in the City and Metropolitan Planning Program at the University of Utah. His research interests are transit-oriented development, urban redevelopment, and urban form.

Dejan Eskic (dejan.eskic@utah.edu) is a Research Analyst at the University of Utah’s Metropolitan Research Center. He holds a degree in Urban Planning with a focus on Regional Planning. His research interests are smart growth, economic and real estate development, transportation and land use relationships, and fiscal analysis.
Assessing Public Transportation Vulnerability to Sea Level Rise: A Case Study Application

Dr. Michelle Oswald, Christian Treat
Bucknell University

Abstract

The potential for sea level rise inundation of critical transportation infrastructure rises as the threat of climate change continues. Inundation of public transportation including railroads and bus routes, specifically those located in low-lying coastal areas, are vulnerable to these impacts. Therefore, identifying vulnerable facilities in order to implement adaptation planning practices is essential to protecting these facilities and avoiding impacts on mobility. This research focuses on the application of the Transit Inundation Modeling Method (TIMM) to a transit network (railways and bus routes) in Philadelphia County, Pennsylvania. TIMM is developed based on the need to identify transit infrastructure systems that are vulnerable to sea level rise using Geographic Information Systems (GIS). Applying TIMM to a real-world transit network provides an example for how transit agencies throughout the nation can begin to identify at-risk links and nodes based on potential sea level rise inundation levels.

Introduction

As climate change continues to threaten both natural and built environments, the risk of impact to public transportation infrastructure rises (FTA 2011). Scientific studies predict that sea level rise will accelerate and, therefore, transportation infrastructure along the coast continues to be vulnerable to inundation (Koetse
Increasing demands on public transportation systems suggest the need for evaluating the potential risk and impacts associated with coastal, low-lying public transportation facilities (Trilling 2005).

Public transportation provides a number of benefits, both environmental and socio-economic, in addition to providing mobility for those who are unable to drive. Currently, public transit operators provide approximately 10 billion trips per year in the United States (FTA 2011). A relatively new stressor, climate change, and the associated sea level rise can lead to increased flooding of subway tunnels, rail tracks, maintenance facilities, bus routes, and intermodal facilities, directly impacting transit-dependent populations.

Although interest in transportation and climate change impacts is rising, discussion and efforts are focused primarily on mitigation or reducing greenhouse gas (GHG) emissions and other contributions to global warming (Valsson and Ulfarsson 2009). Mitigation efforts such as advances in fuel technology and vehicle efficiency are being implemented; however, mitigation efforts are not timely enough to remove all potential impacts associated with global warming (Pew Center on Global Climate Change 2008). As a result, identifying vulnerabilities and implementing adaptation practices that support changes in infrastructure are necessary to reduce vulnerabilities and avoid potential impacts such as sea level rise inundation (Oswald et al. 2012).

Objectives

The primary objective of this research is to apply and evaluate the process of the Transit Inundation Modeling Method (TIMM) to a real-world transit network. TIMM is used to identify transit infrastructure systems that are vulnerable to sea level rise using GIS. Based on a review of existing modeling strategies and a needs assessment, TIMM developed by Oswald and Treat (2013) with the goal of assisting transit agencies with the initial step of adapting, focusing on identifying at-risk links and nodes based on various sea level rise inundation levels. The step-by-step method is described in detail based on its application to a transit network (railway, bus routes, and bus stops) in Philadelphia County, Pennsylvania. Results of the application are used not only to promote adaptation activities within the case study region, but to provide recommendations for future case study applications.

This real-world network application of TIMM is completed with the goal of evaluating the method’s applicability, relevance, and repeatability for transportation infrastructure throughout the country. By using this method to identify vulner-
abilities, transit agencies throughout the nation can begin to implement adaptation practices (elevate, relocate or protect) to existing facilities as well as plan for future transit projects.

**Research Method**
To complete the research objectives, a research framework (Figure 1) consisting of four parts was followed: (1) literature review, (2) TIMM development, (3) TIMM application, and (4) recommendations. The literature review is focused on adaptation concepts, sea level rise impacts, public transportation demand, and GIS modeling opportunities. Then, TIMM was developed based on the improvements that are needed to existing modeling or adaptation efforts. Next, TIMM was applied to Philadelphia County to serve as an example of how transit agencies can implement the method and begin to identify potential vulnerable facilities. This application (part 3) is the focus of this paper to show typical results of applying TIMM to a real-world network. Last, recommendations are proposed for improvements to the method as well as further applications of TIMM to other transit agencies.

**Climate Change**
Scientific research suggests despite the uncertainty with future climate change projections, global warming is unequivocal (U.S. Global Change Research Program
2009). Related alterations in average weather patterns, such as increases in heat waves and very hot days, increases in intense precipitation events, sea level rise, and increases in the frequency of extreme weather events, occur at a global scale and cause region-wide issues (CIER 2007). Projections, developed by the Intergovernmental Panel on Climate Change (IPCC) (2007) are useful in identifying possible impacts associated with varying emissions scenarios. However, current IPCC data indicate that these predictions may be underestimated (Rahmstorf 2007). Therefore, identifying potential risk and vulnerabilities associated with these changes is essential to avoid serious climate change impacts.

**Sea Level Rise**

Sea level rise is one of the most anticipated effects of climate change (Savonis et al. 2008). Although change in sea level has been continuous, it has been exacerbated by thermal expansion of warming ocean waters and deglaciation, causing oceans to rise at a rate much faster than in the past thousand years (Titus et al. 2009). The most serious effects of sea level rise include permanent inundation and temporary flooding due to storm surges, which will continue to worsen in frequency and intensity along with rising water levels.

As the United States population is markedly growing along the coasts, socioeconomic demands and the need for mobility rises (Culliton et al. 1990). Combined with an accelerating sea level rise, this creates regions in the United States that are extremely vulnerable to coastal hazards.

**Adaptation**

Mitigation efforts, or reducing GHG emissions, are not timely enough to remove all potential impacts associated with global warming (Pew Center on Global Climate Change 2008). Therefore, adaptation practices are needed to prepare and protect societies, economies, and the environment. The IPCC (2007) defines climate change adaptation as “the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects which moderates harm or exploits beneficial opportunities.” In support of this definition, The Pew Center on Global Climate Change (2009) defines adaptation as “actions by individuals or systems to avoid, withstand, or take advantage of current and projected climate changes and impacts ... in order to decrease a system’s vulnerability, or increase its resilience to impacts.” These definitions emphasize the need to moderate or avoid harm as a result of climate change impact.
To protect infrastructure from possible inundation, adaptation strategies are being developed and implemented. Possible adaptation strategies include elevation, relocation, strengthening through levees, seawalls and dikes, restricting further coastal development, and using natural ecosystems for protection (eco-engineering) (WILMAPCO 2011). The National Research Council (2010) aligned these general strategies with specific transportation impacts based on climatic impacts and identified the entities best suited to implement each option. Although research on the need for adaptation strategies is initiating, potential impacts on public transportation infrastructure continue to rise.

**Impact to Public Transportation**

Public transportation networks are critical infrastructure, as they are vital to maintaining mobility and accessibility (FTA 2011). Due to the threat of climate change, potential impacts related to rising sea level are posing risk to public transportation facilities. Subway tunnels, rail tracks, maintenance facilities, bus routes and stops, and intermodal facilities are vulnerable to inundation and, therefore, directly impact transit-dependent populations.

**Infrastructure Impacts**

From a planning perspective, identifying vulnerable infrastructure is essential to proactive and cost-effective decision-making. Due to railways often being located in low-lying areas, they are highly vulnerable to inundation (TRB 2008). Railways specifically are at-risk to flooding of underground tunnel and rail tracks, erosion of the rail base, and reduced clearance under bridges (TRB 2008). Tunnels, in particular, are highly vulnerable as a result of two impacts—the risk of flooding to entrances and vents and the hydraulic pressure on the walls of the tunnel increases as the water table rises (Titus 2002).

In addition to tunnels and at-grade railways, bridges are at-risk as well. As a result of frequent storm surge events and rising sea levels, high amounts of flowing water around bridges creates bridge scour. Increased water flow around the bases of bridges exacerbates the removal of soil at the foundations, compromising the integrity of the structure (FTA 2011). Most of the bridge failures in the United States occur as a result of scour impacts (AASHTO 2004). Therefore, the need for developing adaptation practices is crucial because infrastructure is prone to the direct effects of permanent inundation as well as the secondary impacts of sea level rise.
Current Efforts

Transportation agencies have been limited in incorporating adaptation into their planning process as a result of real and perceived barriers (Oswald et al. 2012). However, recently, studies focused on identifying sea level rise impacts on transportation infrastructure are emerging. Research efforts such as Meyer and Weigel (2011) have promoted the use of an adaptive systems framework to manage transportation assets and Oswald et al. (2011) developed a Climate Change Adaptation Tool for Transportation (CCATT) to assist transportation agencies in integrating adaptation practices into long-range transportation plans. In addition to research, practical applications such as the Gulf Coast Study Phase 1 (U.S. DOT 2011a) focused on the process of identifying regional climate change impacts and developing risk assessment tools for use by transportation planners. In continuation of the research, the Gulf Coast Study Phase 2 includes a multimodal approach to determine the criticality of the transportation network in Mobile, Alabama, to climate change impacts (U.S. DOT 2011b). At the state-wide level, a similar study was implemented in Florida where the U.S. Department of Transportation (DOT) funded the development of a method to determine vulnerabilities specific to sea level rise on their infrastructure network (Berry 2012). More local studies on transit vulnerability have also been initiated, including applications to the New York City Transit Authority (City of New York 2011) as well as the Massachusetts Bay Transportation Authority (Kirshen et al. 2005).

To further refine the goals of the regional studies, national agencies such as the Federal Transit Administration (FTA) and the Federal Highway Administration (FHWA) are supporting projects. FTA is conducting pilot programs for transit agencies to begin implementing inundation modeling and adaptation practices. The pilot programs are located throughout the nation and include the Gulf Coast, Pennsylvania, Los Angeles, San Francisco, Seattle, Chicago, and Atlanta (FTA 2011). FHWA is also overseeing pilot programs for DOT’s to implement their risk assessment framework for climate change adaptation.

GIS Modeling

Many of the regional assessments and studies incorporate the use of spatial analysis to identify vulnerabilities. For example, at the regional level, the Coastal Adaptation to Sea-Level Rise Tool (COAST), developed by NOAA Coastal Services Center (2012), combines inundation layers with employment, wages, and number of businesses to determine and visualize overall economic vulnerability in the Gulf Coast region (Merrill et al. 2010). Similarly, Colgan and Merrill (2008) estimated the
economic cost of inundation in coastal communities in Maine using the hurricane forecasting model SLOSH (Sea, Lake, Overland Flow Surge from Hurricanes). For transportation planning, this scope is narrowed, as planners aim to identify specific lines and nodes vulnerable to inundation. For example, Oswald et al. (2012) conducted a transportation vulnerability study on Delaware focusing on the sea level rise impact on the I-95 corridor (rail, road, and bus routes). These modeling methods serve as the beginning of a more formalized process for using spatial analysis to determine vulnerabilities associated with sea level rise.

**Transit Inundation Modeling Method (TIMM)**

TIMM was developed with the goal of assisting transit agencies to begin adapting by identifying at-risk links and nodes based on various sea level rise inundation levels. TIMM is based on a five-step process that can be applied to transit agencies throughout the country, specifically in coastal areas. The process is repeatable, straightforward, GIS-based, and uses publically-available data. The five steps are listed and described below, however for an explanation of how TIMM was developed refer to Oswald and Treat (2013). In addition, through the case study application, the five steps are explained as they are applied to Philadelphia County, PA.

1. **Define Study Area**
   The study area is defined based on proximity to coastal zones, jurisdiction of the transit agency, and extent of the transportation network. Facilities at-risk are those that are most exposed to sea level rise hazards and necessitate planning strategies and application of TIMM.

2. **Gather Data**
   TIMM is based on publicly-available data that are accessible from agency websites, local university websites, and data clearinghouses such as the U.S. Census Bureau. Information that is relevant for assembling the maps includes county boundary shapefiles, local hydrology, and relevant transportation infrastructure networks. In preparation for the next step—creation of inundation layers—elevation data are available from the U.S. Geological Survey (2012) National Elevation Dataset (NED). Based on the extent of the study area, the resolution of each dataset must be checked to ensure accurate analysis.

3. **Create Inundation layers**
   The elevation data are based on a digital elevation model (DEM), which can be used for extracting inundation layers. DEMs capture elevation informa-
tion on a cell-by-cell basis and, for the purposes of projecting inundation scenarios, a cell is considered inundated if its elevation value is less than or equal to the projected sea level. However, to prevent inland areas from becoming inadvertently mapped as flooded, hydrological connectivity was accounted for by selecting cells with the desired elevation value and were located in connection to ocean (coastal water) cells. Hydrologic connectivity can be restricted to cells connected in the four cardinal directions (“four-side” rule) or in the cardinal and diagonal directions (“eight-side” rule). This method uses the eight-side rule when modeling sea level rise to show maximum potential inundation (Gesch 2009). This enables flooding that follows more accurate hydrologic behavior on the surface while representing maximum potential inundation. Inundation layers were added to the basemaps for use in step 4, data analysis.

4. Data Analysis
The infrastructure (railways, bus routes and bus stops) was symbolized based its location relative to each sea level rise projection in order to reflect its vulnerability to inundation. Thus, a qualitative scale was created where infrastructure located within the 1 meter inundation area has a greater vulnerability than infrastructure located only within the 5 meter inundation area. The impact of each inundation scenario was quantified by extracting infrastructure at each inundation scenario and calculating the summary statistics (mileage or number of stops) for each aspect of the transportation network.

5. Results and Recommendations
Identification of vulnerabilities in the transportation network is an iterative process that allows for proactive decision-making by the transit agency. In addition to information on the location of infrastructure and its relation to projected sea level rise, prioritization of projects can be supplemented by ridership information, facility demand, and facility cost to allow for holistic and sustainable decision-making.

Application of TIMM
To determine the applicability and relevance of the methodology, TIMM was applied to a real-world transit network in Philadelphia County. This location was selected due to its coastal proximity as well as the Southeastern Pennsylvania Transportation Authority’s (SEPTA) proactive interest in adaptation planning. Currently, SEPTA is one of the seven agencies included in FTA’s transit climate change adaptation assessment pilots (FTA 2011).
The case study application of TIMM included applying each of the five steps to
the rail and bus network in the county based on SETPA’s jurisdiction. Therefore,
this application reflects the process that a transit agency, such as SEPTA, would
implement to begin identifying vulnerabilities using a spatial analysis method such
as GIS.

**Methodology**
The five-step process of TIMM, as defined previously, is applied to the case study
region. Each step is defined in detail, and the results are spatially displayed. To com­
plete the application, data were processed and layers were created using ArcGIS 10
and the Spatial Analyst Extension (ESRI 2011).

1. **Define Study Area**
The study area selected for the application of TIMM was Philadelphia
County, located along 20 miles of the Delaware River. Relevant sea level
rise characteristics in this area and in the Delaware estuary have been
documented, including increasing saline levels, flooding of hazardous
waste sites, and a decline of public access to the shore line (DVRCP 2004).
Along with the ecological and social issues of sea level rise in the Delaware
River, inundation also poses significant economic impacts, especially to
the transportation sector. SEPTA has an extensive transportation network,
covering a surface area of 2,202 square miles, an annual ridership of more
than 300 million, 143 routes, and 2,803 revenue vehicles (SEPTA 2012). In
addition, it has developed a five-year Strategic Business Plan for 2010–2014
focused on several objectives, including sustaining the financial health of
the agency, maintaining transportation access for low-income residents to
and from their jobs, prevention of accidents and property damage, increas­
ing frequency and extending service, and rebuilding existing lines and links
(SEPTA 2009). Inundation from sea level rise would not only impact this
widespread network, but also would compromise these established goals.
Furthermore, SEPTA has also identified environmental planning as a cur­
rent and future goal and has launched an awareness campaign to address
this issue. Thus, the methodology not only targets vulnerabilities of the
network, but also coincides with the progressive goals of the transit agency.

2. **Gather Data**
The base layers of the maps include the county boundaries and local
hydrology of the Delaware River. These are vector files that are accessed
via the Pennsylvania Geospatial Data Clearinghouse (PASDA 2012). Trans­
portation infrastructure data were provided by SEPTA and include vector
point and multi-line features of bus stops, bus routes, and rail lines. The bus route data also include ridership information based on total passengers and the total number of trips for each individual bus route. Together, the county boundary, local hydrology, and transportation layers were overlaid to create three different maps for each infrastructure type (railway, bus routes, and bus stops). Elevation information for the digital elevation model was obtained from the National Elevation Dataset at the 1/9 arcsecond resolution (U.S. Geologic Survey 2010). This is the highest quality resolution available in a raster format, where each cell value represents an elevation interval of 1 meter.

3. Create Inundation Layers

The DEM provided the basis for creating sea level rise scenarios. The inundation levels used reflect a range of existing projections from 1 to 5 meters, using an interval of 1 meter. To extract pertinent elevation values, the raster was first reclassified into an output of land and sea level rise increments, where the sea level rise projections reflect the desired range of scenarios (0, 1, 2, 3, 4, and 5 meters), and the land value includes all elevations over 5 meters. Using this output, hydrological connectivity was established to create a more accurate model of inundation. The eight-side connectivity rule was used to eliminate any low-lying areas that would be considered flooded, such as inland lakes, which are not connected to the sea. After establishing hydrological connectivity, the output was then reclassified into land values and true sea level inundation extents. Next, to use the inundation layers in conjunction with the transportation infrastructure layers, the raster was converted into a vector. This was then added onto the inundation layers created in step 2 to analyze and identify vulnerable infrastructure.

4. Analyze Data

The impact of different inundation scenarios was symbolized by color gradation to represent the degree of vulnerability to inundation. The vulnerability of each link/node is defined based on the scale of 1 meter rise (high vulnerability) to 5 meter rise (low vulnerability), and infrastructure was extracted at each inundation level. These inundated infrastructure layers were added to their respective maps.

Figures 2 through 4 are extent maps of southern Philadelphia County showing inundation impacts to the transit facilities. Southern Philadelphia County is highlighted as it is the most vulnerable to sea level rise inundation throughout the county. Figure 2 shows the inundated rail network,
Figure 3 shows the inundated bus routes including ridership, and Figure 4 shows the inundated bus stops. The ridership information is useful for prioritization of at-risk infrastructure, and routes are symbolized based on number of passengers per trip.

Figure 2. Extent map of inundated rail network in Philadelphia County

Source: SEPTA 2012
Figure 3. Extent map of inundated bus routes in Philadelphia County
Figure 4. Extent map of inundated bus stops in Philadelphia County

Source: SEPTA 2012
Summary statistics were calculated for each map to quantify the impact of each inundation scenario on the transportation network. Using the inundation layers and features in the GIS attribute tables allowed for the mileage, or count of infrastructure (number of stops), within each inundation to be calculated. For example, the total miles of rail network inundated at each level, as well as cumulatively, were calculated. This process was also implemented for bus routes and bus stops as shown in Table 1.

Table 1. Vulnerable Infrastructure Based on Sea Level Rise in Philadelphia County

<table>
<thead>
<tr>
<th>Sea Level Rise</th>
<th>1m</th>
<th>2m</th>
<th>3m</th>
<th>4m</th>
<th>5m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus routes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change in miles</td>
<td>3</td>
<td>46</td>
<td>39</td>
<td>49</td>
<td>40</td>
</tr>
<tr>
<td>Cumulative miles</td>
<td>3</td>
<td>49</td>
<td>88</td>
<td>137</td>
<td>177</td>
</tr>
<tr>
<td>Bus stops</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change in # of stops</td>
<td>7</td>
<td>152</td>
<td>170</td>
<td>181</td>
<td>203</td>
</tr>
<tr>
<td>Cumulative total</td>
<td>7</td>
<td>159</td>
<td>329</td>
<td>510</td>
<td>713</td>
</tr>
<tr>
<td>Rail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change in miles</td>
<td>1.4</td>
<td>17.1</td>
<td>10</td>
<td>2.3</td>
<td>2.4</td>
</tr>
<tr>
<td>Cumulative miles</td>
<td>1.4</td>
<td>18.5</td>
<td>28.5</td>
<td>30.8</td>
<td>33.2</td>
</tr>
<tr>
<td>Land</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change in acres</td>
<td>880</td>
<td>4,612</td>
<td>4,421</td>
<td>2498</td>
<td>2,055</td>
</tr>
<tr>
<td>Cumulative acres</td>
<td>880</td>
<td>5,492</td>
<td>9,033</td>
<td>11,531</td>
<td>13,586</td>
</tr>
</tbody>
</table>

Acreage of land inundated was also included in the analysis. The inundation layers created in step 3 include the original water features; therefore to accurately calculate the inundation area, hydrology features for this layer were eliminated. Using a similar approach to calculating the vulnerable infrastructure based on inundation levels, the acreage of land inundated was calculated for each level as well as cumulatively, as shown in Table 1.

5. Synthesize Results and Recommendations

Based on the projected inundation levels, public transportation infrastructure within Philadelphia County is at risk of flooding, even at the lower sea level rise levels. The difference between the amount of infrastructure impacted at 1 meter and 2 meter projections is substantial and, based on scientific research, these sea level rise projections may be conservative. Based on the spatial analysis results, the southern region of Philadelphia is most notably at-risk for inundation. Although comparisons between links and nodes can be made visually, more information about how to prioritize current and future projects is needed. More specifically, a prioritization index, including other factors such as ridership and cost, can be established.
to plan future adaptation projects. Ridership information is included in the bus routes extent (Figure 3) to compare infrastructure based on both sea level rise vulnerability as well as user demand. Including factors, such as ridership, can provide more holistic decision-making when prioritizing future adaptation projects.

**Reflection**

Modeling vulnerabilities in transportation infrastructure due to sea level rise requires accurate elevation data and a detailed transportation network. It is recognized that spatial information is not available for every network; however, following a process such as TIMM, which is based on publically-available sources, can allow agencies to begin using GIS for adaptation planning.

While more accurate DEMs can be derived from contour maps, the hydrologic connectivity method requires knowledge of GIS software; therefore, it is encouraged that agencies have expertise in this area. Furthermore, the transportation data may be agency-specific and include infrastructure owned by only one transit agency, rather than assets from all agencies in the region. The case study region features an area that is within SEPTA's jurisdiction, but several rail tracks and rail yards owned by other companies were not included in the data. In future applications, more holistic network data can allow for multi-jurisdictional analysis. In addition, more detailed local factors that influence storm surge impacts are not included. These variables, which have the potential to alter flooding, include location of storm water facilities, runoff impacts, and permeability of the soil. As inundation modeling methods improve and include local impacts, TIMM can be further developed to allow for more accuracy in identifying potential public transportation vulnerabilities.

Overall, applying TIMM is useful for the transit agency because it allows for the identification of potential at-risk facilities based on a number of scenarios. Identifying these facilities sooner rather than later can lead to proactive and holistic decision-making for adaptation planning.

**Conclusion**

Increasing demands on public transportation systems suggest the need for evaluating the potential risk and impacts associated with coastal, low-lying public transportation facilities (Trilling 2005). The relatively new stressor, climate change, and associated sea level rise, can lead to increased flooding of subway tunnels, rail
tracks, maintenance facilities, bus routes, and intermodal facilities, directly impacting transit-dependent populations. Therefore, adaptation planning and practices are needed to prepare and protect these facilities from inundation.

The Transit Inundation Modeling Method is developed for adaptation planning, specifically to identify transit infrastructure systems that are vulnerable to sea level rise using GIS. The real-world network application of TIMM to Philadelphia County was completed with the goal of evaluating the method's applicability, relevance, and repeatability for transportation infrastructure throughout the country. Although there are limitations associated with data availability and inundation modeling constraints, this application serves as a foundation for using spatial analysis for transit adaptation planning. By using this method to identify vulnerabilities, transit agencies throughout the nation, similar to SEPTA, can begin to implement adaptation practices (elevate, relocate, or protect) to existing facilities as well as plan for future transit projects.

References


Assessing Public Transportation Vulnerability to Sea Level Rise: A Case Study Application


About the Authors

**Dr. Michelle Oswald** (michelle.oswald@bucknell.edu) is a LEED AP and an Assistant Professor at Bucknell University in Civil and Environmental Engineering. She completed her Ph.D. in Civil Engineering at the University of Delaware, specializing in sustainable transportation planning. She received a B.S. in Civil Engineering from Lafayette College and M.C.E. and M.A. degrees in Urban Planning from the University of Delaware.

**Christian Treat** (cat022@bucknell.edu) is a senior majoring in animal behavior at Bucknell University. In the summer of 2012, he received a grant sponsored by the Andrew W. Mellon Foundation for this research project with the goal of integrating spatial thinking into environmental and engineering based projects.
Efficient Space Dedication to Bus Rapid Transit and Light Rail Systems

H.-S. Jacob Tsao, San Jose State University
Agus Pratama, Workday, Inc.

Abstract

Dedicating two lanes and passenger platforms to transit typically requires taking the same space away from general use. This may affect public support. This paper proposes efficient geometric configurations for a two-dedicated-lane BRT or light rail system that requires a minimum amount of right-of-way along a busy commute arterial. In many current busy commute corridors, a significant part of the street median is underused or unused for traffic purposes. The efficiency is achieved mainly by using the street median between a left-turn lane and its counterpart located at the intersection on the other end of the same street section and slanting part of the two dedicated lanes with respect to the longitudinal direction of the street. Instead of the three-lane or even four-lane conversion required of the prevailing configurations, the proposed configurations require conversion of only two lanes from general use, even for a section equipped with passenger platforms.

Introduction

Public transportation is perhaps one of the few sustainable transportation solutions for urban or suburban areas. Most, if not all, cities have public transportation systems. However, relatively few provide rapid transit systems. An urban rail or light rail system is the classical and conventional transit system used in most developed countries as well as in some cities of emerging economies (New Delhi, Beijing, Shanghai, etc.) while bus rapid transit (BRT) is a relatively new mass-transit concept that has been adopted by both developed countries and emerging economies
(Levinson et al. 2002; Jarzab et al. 2002; Diaz et al. 2004; Miller et al. 2006; Kittelson & Associates et al. 2007). The operational concepts and geometric configurations proposed in this paper are applicable and beneficial for both BRT and light rail. For ease of discussion, we address BRT explicitly in the rest of the paper and provide geometric sketches and justification only for BRT operations.

To minimize travel time and its variability for BRT, traffic lanes together with spaces required for the concomitant passenger activities along a street median can be dedicated to form a dedicated transitway (Li et al. 2009). In addition, transit signal priority (TSP) and other technologies can be adopted to improve system performance. However, the current vehicular traffic of many cities is dominated by automobiles. Such cities include perhaps most U.S. cities, with few exceptions (New York City and Chicago), and many cities in other developed nations or emerging economies. Dedicating two lanes in the street median and the additional spaces needed for bus stops often requires taking the same space away from use by automobiles. In prevailing geometric designs for dedicated BRT systems, passenger activities at a bus stop are accommodated with either two physically-separate passenger platforms (one for each direction) or one dual-use platform. In either case, the width of the required space is approximately the width of two traffic lanes. This kind of lane conversion could lead to heavy congestion during peak commute hours unless parallel streets or even corridors have sufficient capacity to accommodate the redirected traffic. In addition, the possible low bus-traffic volume on such a dedicated transitway before the demand for bus services can be gradually built up could lead to the impression of space underutilization; such impression is sometimes referred to as the “empty-lane syndrome.” Such possible congestion and syndrome could lead to strong motorist resentment against implementation of BRT on a dedicated transitway. An alternative to such lane conversion is right-of-way purchase, but the cost may be prohibitively high and land-owner resentment may be strong. These may be primary reasons why few such dedicated systems have been implemented in North America.

Phase I of the Viva BRT system, designed for the York region of Ontario, Canada, was opened in 2005, and its Phase II, featuring several dedicated transitways accommodated on the street median called “rapidways,” is being implemented with a full funding commitment of $1.4 billion Canadian by the Province of Ontario (York Region Rapid Transit Corporation 2012). Much of the required additional right-of-way was purchased. Although the Orange Line of LA Metro has recently been implemented almost entirely on exclusive lanes (except for several blocks
near the western end at the Warner Center), these lanes occupy the abundant right-of-way of an abandoned railroad and were built as a new, stand-alone road (Callaghan and Vincent 2007). For wide acceptance of BRT implemented with such a dedicated transitway in developed nations, conversion of existing right-of-way without significant right-of-way acquisition may be necessary and, therefore, efficient dedication of right-of-way for transit use is a critical issue. This motivated our research into this issue.

Many BRTs with a dedicated transitway have been implemented in emerging economies, in a societal context where the vast majority of the population already relies on public transportation. Such BRT systems, if implemented appropriately, would improve transit services for the majority, and proposals for building such systems tended to receive popular support. For widespread implementations of such BRT systems in the U.S. or other nations where urban and suburban transportation systems have been primarily developed for and used by automobile traffic, the benefit to transit users must be sufficiently compelling for winning over car drivers, and the negative impact on the automobile traffic must be minimized. Simply put, in emerging economies, bus transit is already popular and BRT is only expected to make it better; in the U.S., however, a successful BRT system must make transit popular. This is particularly true at the initial stages of a U.S. implementation, before transit-oriented development (TOD) can begin. The success of BRTs with a dedicated transitway in the U.S. may hinge upon efficient lane dedication or conversion and TSP.

Also motivated by the fact that the right-of-way required for a conventional two-dedicated-lane BRT along many busy corridors either does not exist or is too costly to acquire, we proposed a one-dedicated-lane two-way (dynamically reversible) BRT system (Tsao et al. 2009a, 2009b, 2009c). A set of detailed operating rules, including design rules for giving signal priority to BRT vehicles at intersections along the one dedicated lane, for performance optimization has been developed (Tsao et al. 2010).

This paper proposes efficient geometric configurations for a two-dedicated-lane BRT system that require a minimum amount of the precious right-of-way along a busy commute arterial provided with frequent protected left-turn lanes. The efficiency of right-of-way utilization achieved with the proposed configurations results from capitalizing on the widespread existence of right-of-way unused or underused for traffic purposes along many current busy commute corridors in the U.S. The space in between the through lanes of one direction and the through lanes of the
other direction is often occupied by one left-turn lane (or more) in each of the two
directions and the median in between. The median is often quite long and planted
with trees or shrubs. Although the plants serve aesthetic and other purposes, such
a median is typically unused or underused for traffic purposes. The authors most
certainly do not advocate paving over such green spaces in a first attempt to gain
the required space; rather, we consider it only as a last resort and as a final enabler.
A main idea behind the efficient configurations to be proposed in this paper is to
add the two dedicated lanes in a slanted fashion (with respect to the longitudinal
direction of the street) so as to more fully utilize such a median for traffic purposes.

The efficiency gain across the entire length of a BRT system is achieved indepen­
dently and additively through such fuller utilization for individual sections. There­
fore, the proposed configurations offer the highest efficiency-gain potential if the
corridor consists of long sections and is equipped with a left-turn lane at each
end of each of its sections. Instead of the three-lane or even four-lane conversion
required for the prevailing configurations, the proposed configurations require a
right-of-way width equivalent to only two lanes, even for a section equipped with
passenger platforms. (Such a BRT system is not operated entirely on dedicated
space, however, because its traffic lanes intersect with cross-streets at grade.)

Conventional light rail or BRT systems, already implemented (e.g., Lane Transit
District 2002; Carey 2006) or being planned (e.g., AC Transit 2012a & 2012b), do not
capitalize on such unused or underused right-of-way, and their designs typically
require dedication of right-of-way equivalent to three or four traffic lanes, particu­
larly for sections accommodating a bus stop. In many cases, the three to four lanes
have been or are to be converted from general-use lanes. We capitalize on such
unused or underused median space and propose several geometric configurations
accordingly. With the conversion of left-turn lanes to passenger platforms (only) at
selected sections, we propose bus-lane configurations that require conversion of
only two lanes throughout the system, for sections with or without a bus stop. We
also propose a geometric configuration that uses the unused or underused right-of­
way even more efficiently and requires conversion of exactly two lanes throughout
the system. In this configuration, the left-turn lanes are retained, and one passenger
platform (used for both directions) is located between the two dedicated bus lanes
and is accommodated with the unused or underused median space. However, this
platform must be accessed through mid-block pedestrian cross-walks.

In addition to the prevailing concepts of a two-dedicated-lane BRT system, many
BRT or light rail concepts have been proposed or implemented for operations
in mixed traffic (e.g., Institute for Transportation and Development Policy 2009; Levinson et al. 2002; Jarzab et al. 2002; Diaz et al. 2004; Miller et al. 2006; Kittelson & Associates et al. 2007). Together with these concepts, the configurations and operational concepts proposed in this paper and those proposed in our earlier work for a one-dedicated-lane two-way system hopefully constitute a more complete spectrum of implementation options, at least from the viewpoint of dedicating right-of-way along street median. For more details about the two-dedicated-lane system proposed in this paper or about how the one-dedicated-lane system proposed previously can be easily expanded to two dedicated lanes, the reader is referred to Tsao et al. (2009a, 2010).

The remainder of this paper is organized as follows. We first point out the right-of-way currently unused or underused for traffic purposes in the median along many busy commute corridors. We next discuss the conventional geometric designs for a two-dedicated-lane BRT system and propose more efficient designs in three separate sections. Concluding remarks are then given, together with related research findings that could not be reported in this paper due to space limitation and with worthy subjects for future research.

### Unused or Underused Median Space in Right-of-way of Urban Corridor with Frequent Left-turn Lanes

Although the right-of-way of an arterial serving a busy corridor may be wider at interactions with major cross streets, the total width of the right-of-way dedicated to the rest of the roadway of such a corridor changes only occasionally. In particular, the width of a section between two adjacent intersections equipped with one left-turn lane for each (but opposite) direction typically remains constant. When compared to the length of such a section, a typical left-turn lane is rather short. On many arterials serving a busy corridor, a significant amount of median space exists along the roadway between two such adjacent intersections, and such median space is not useful for facilitating the through traffic on a conventional roadway. As a result, such median space is typically planted with trees or shrubs or is used for left-turning convenience into store parking lots. We, therefore, refer to such median space as “unused median space” or “underused median space.” For discussion convenience, we use the former in the remainder of this paper. Figure 1 is a geometric sketch for such unused median space. This seven-lane configuration is used mainly to illustrate the existence of such unused space. It will be used later to illustrate how two general-purpose lanes can be converted efficiently to accom-
moderate two dedicated BRT lanes, without requiring any additional right-of-way. (This efficient conversion is illustrated in Figure 3.)

![Diagram showing unused or underused median space](image)

**Figure 1. Unused or underused median space on typical arterial section provided with one left-turn lane on each of two ends**

All geometric designs sketched in this paper are used for illustration and comparison. For ease of comparison, the traffic moves along the east-west direction, i.e., horizontally between the left- and right-hand sides of the diagram, in all the sketches. For ease of discussion, the width of right-of-way is measured in the unit of a traffic lane, regardless of whether the traffic lane is a through lane for regular traffic, a left-turn lane, or a dedicated bus lane. Moreover, a passenger platform is treated as being as wide as a traffic lane, regardless of whether it is dedicated to use by only passengers heading in one direction or is shared between passengers heading in either of the two directions. We ignore possible curbside parking altogether in the diagrams. We refer to the portion of a street delimited by two adjacent intersections as a section. For ease of discussion, we refer to a section in which a bus stop is provided as a bus-stop section and refer to a section not provided with a bus stop as a non-bus-stop section.

**Efficient, Slanted Geometric Design for Non-bus-stop Section Capitalizing on Unused Median**

The dedicated lanes of the prevailing geometric design for a non-bus-stop section are straight and are perfectly parallel to the longitudinal orientation of the arterial, as illustrated in Figure 2. This configuration provides two general-purpose lanes, one left-turn lane, and one dedicated BRT lane for each direction and requires right-of-way whose width spans eight traffic lanes. This may be a simple and obvious option and may be aesthetic, but it requires more space than necessary. This “straight” configuration and its variations are also the standard configurations
throughout the VTA light rail system operated by Santa Clara County in California, for sections without a passenger platform. The efficient right-of-way allocation proposed in this paper provides, for this particular example, an identical set of traffic lanes but requires right-of-way that is only seven-lane wide, as illustrated in Figure 3.

Figure 2. Straight but inefficient geometric design for “non-bus-stop” section of two-dedicated-lane BRT on eight-lane right-of-way: Accommodating two general-purpose through lanes and one left-turn lane for each direction, creating even more unused or underused median space

Figure 3. Slanting of dedicated lanes of two-dedicated-lane BRT system and saving of one lane on seven-lane right-of-way for a non-bus-stop section: Accommodating two through lanes and one left-turn lane for each direction
If we allow part of the dedicated lanes to be slanted with respect to the longitudinal orientation of the arterial, then we can use the otherwise unused or underused median space and, hence, save one lane. We illustrate this idea of slanting by first examining the configuration sketched in Figure 3 for a non-bus-stop section. With slight slanting of the dedicated lanes, the space requirement can be reduced by one traffic lane, from eight (of Figure 2) to seven (of Figure 3) in this particular example.

Often, acquiring additional right-of-way along a busy corridor is infeasible, and dedicated BRT lanes can only be provided through conversion of general-purpose lanes. In such cases, the proposed slanting of BRT lanes can reduce the impact of such conversion on the general traffic to the minimum. It incurs conversion of only two general-purpose lanes. For example, the configuration of Figure 3 can be converted from a roadway of the same width that accommodates three through lanes and one left-turn lane in each direction, as illustrated in Figure 1. This conversion, however, does not allow mid-block left turns for convenient access to locations on the other side of the roadway.

In cases where the available right-of-way cannot accommodate two dedicated BRT lanes but can accommodate one, transit agencies can resort to the operational concept of dynamically reversible one-dedicated-lane BRT system proposed in Tsao et al. (2009a, 2009b, 2009c, and 2010). In that concept, the unused median space can be used for buses traveling in opposite directions to cross each other.

**Efficient, Slanted Geometric Design for Bus-stop Section with Passenger Platforms Converted from Selected Left-turn Lanes**

In this section, we first discuss a common geometric design for a bus-stop section of a two-dedicated-lane BRT system and propose an efficient configuration that saves one lane. Although multiple designs for a bus-stop section exist, the required amount of right-of-way is similar. Figure 4 illustrates such a design (AC Transit 2012b). Note that the only difference between this configuration and the one shown in Figure 2 (for a non-bus-stop section) is that parts of the unused median space of the latter are used for passenger platforms. The BRT of this configuration occupies three to four lanes, and three through lanes are taken away from general-purpose traffic. Although the middle portion of the dedicated space spans four lanes, the portions of the dedicated space located on the two opposite ends of the section occupy only three lanes each. Therefore, this configuration takes away three lanes, not four, for the dedication.
Figure 4. Straight but inefficient geometric design for “bus-stop” section of two-dedicated-lane BRT on eight-lane right-of-way, occupying four lanes, taking away three lanes and accommodating two through lanes and one left-turn lane for each direction.

If the left-turn lanes can be sacrificed, the system illustrated in Figure 4 can be improved so that one lane can be saved. Such an improved design is illustrated in Figure 5. Note that the two left-turn lanes on this section, one in each direction, are converted to BRT passenger platforms, and the two dedicated lanes are slanted with respect to the longitudinal orientation of the roadway. Like the configuration illustrated in Figure 4, the two passenger platforms are located on two opposite ends, i.e., east and west, of the section. However, each of the two platforms is located on the opposite end of the section with respect to its counterpart shown in Figure 4. Note that this configuration differs from the one illustrated in Figure 3 (for a non-bus-section) in that the left-turn lanes of Figure 3 are replaced with the two corresponding passenger platforms.
A variant of the geometric design of Figure 4 is illustrated in Figure 6, and it is perhaps the prevailing geometric design. Although different, the two configurations occupy the same amount of space. In fact, Figure 6 can be thought of being formed by “cutting” the eastern half of the bus-stop section of Figure 4 and “pasting” it to the west of the intersection bordering the western half of the same bus-stop section. This design has the advantage of both platforms being located at the same intersection.

Similarly, this configuration can be improved to save one lane. An alternative design is illustrated in Figure 7. In this alternative, two passenger platforms are located on two sides of an intersection. This alternative configuration may have an advantage in that the passenger activities of this bus stop are concentrated at one intersection. Like their conventional counterparts, Figure 7 can be thought of being formed by “cutting” the eastern half of the bus-stop section of Figure 5 and “pasting” it to the west of the intersection bordering the western half of the same bus-stop section.
Figure 6. Prevailing, straight but inefficient geometric design for "bus-stop" section of two-dedicated-lane BRT on eight-lane right-of-way occupying four lanes, taking away three lanes and accommodating two through lanes and one left-turn lane for each direction; platforms at one interaction.

Figure 7. Slanting of dedicated lanes of two-dedicated-lane BRT system and saving of one lane on seven-lane right-of-way for a bus-stop section, sacrificing left-turn lanes for passenger platforms, occupying only three lanes, taking away only two lanes and accommodating two through lanes and one left-turn lane for each direction; platforms at one intersection.
Efficient Geometric Design for Bus-stop Section with Passenger Platform Converted from Unused Median

Suppose that the left-turn lanes of the configuration illustrated in Figure 5 are not to be sacrificed. Then, the passenger activities can be accommodated in the middle of the section to fully use the unused or underused median space, as illustrated in Figure 8. Note that the platform can be accessed via mid-block crosswalks. However, additional traffic signals will be required for safety, and impact on traffic may be significant. Pedestrian safety may also be an issue because drivers may not be used to such mid-block crosswalks and the companion signals. To enable passenger boarding and alighting, buses must also be equipped with doors on the left-hand side.

![Diagram](image)

**Figure 8.** Two-dedicated-lane BRT system taking away two lanes in bus-stop section without sacrifice of left-turn lanes but with bus stop accommodated completely on unused median space

**Conclusions**

In merging economies or urban or suburban areas of developed nations where bus transit is already popular, faster and more reliable bus service would be considered “rapid” and may suffice for public support. However, in the U.S., where automobile is the primary mode of personal transportation and only (heavy) commuter rail transit systems, e.g., Bay Area Rapid Transit (BART) system of the San Francisco Bay Area, New York City Subway, etc., have been considered as “rapid” by the general public, their expectation on the speed of a bus *rapid* transit system may be much higher. This higher speed expectation may only be achievable with a dedicated median busway and TSP, and, hence, the concomitant necessity of efficient space dedication is critical.
For many current busy commute corridors, a significant part of the street median is underused or unused for traffic purposes. We capitalized on this phenomenon and proposed geometric configurations that more fully use the street median. The efficiency gain is achieved independently and additively through such fuller use for individual sections. Therefore, the proposed configurations offer the highest efficiency-gain potential if the corridor consists of long sections and is equipped with a left-turn lane at each end of each of its sections. In such cases, as long as the street right-of-way is seven-lane wide, a BRT with two dedicated lanes should be geometrically feasible, leaving the remaining five lanes to accommodate two through lanes and one left-turn lane for each direction.

The benefit of the proposed configurations hinges upon two important factors: (1) the prevalence of left-turn lanes along busy commute corridors and (2) the minimum length requirement for a section to accommodate the slanting. We studied two corridors well known to San Jose, California, residents but focused on a non-downtown portion for each. We found an overwhelming presence of left-turn lanes on both. We also derived the minimum length of the slanting portion of the two dedicated lanes as a function of the design speed, superelevation, coefficient of side friction, and lane width. Our study of the geometric configurations of the two non-downtown portions reveals a large amount of unused median (approximately 58%) and a high likelihood of section-length sufficiency for accommodating the required slanting. Due to the page limit, these findings will be reported separately.

If the right-of-way required for any of the configurations proposed in this paper is not available, then the concept of one-dedicated-lane dynamically-reversible BRT we proposed in an earlier paper may offer a solution (Tsao et al. 2009a, 2009b, 2009c, 2010). When sufficient right-of-way or public support becomes available for a two-dedicated-lane BRT system after implementation of a one-dedicated-lane system, the one-dedicated-lane system can be expanded with ease to two dedicated lanes (Tsao et al. 2009a, 2010). Further efficiency of right-of-way utilization can be achieved for a BRT system (with either one or two dedicated lanes) with the advanced technologies of automated lateral control (Tsao 1998; Al-Kadri et al. 1998).

In addition to the prevailing concepts of a two-dedicated-lane BRT system, many BRT concepts have been proposed or implemented for operations in mixed traffic. Together with these concepts, the configurations and operational concepts we proposed in this paper and those we proposed earlier for a one-dedicated-lane system hopefully constitute a more complete spectrum of implementation options.
at least from the view point of dedicating right-of-way along a street median. Implementation of any surface transportation system tends to be site-specific; a particular BRT implementation may involve several or even all of these options.

Acknowledgements

The authors would like to thank California Department of Transportation (Caltrans) and California Partners for Advanced Transit and Highways (PATH) for funding this research under the category of New and Innovative Research Idea (Contract No. 65A0268-6197). They are grateful for the guidance and support generously provided by Mr. Weibin Zhang of PATH and Ms. Sonja Sun and Mr. Bradley Mizuno of Caltrans. Any opinions expressed herein do not necessarily reflect those of Caltrans or PATH. Valuable comments made by two anonymous reviews of the original version of this manuscript are gratefully acknowledged. Some of the configurations proposed in this paper were conceived in an earlier project about (dynamically reversible) one-dedicated-lane BRT funded by Mineta Transportation Institute of the San Jose State University.

References


**About the Authors**

**H.-S. Jacob Tsao** (jacob.tsao@sjsu.edu) holds a Ph.D. in Operations Research from University of California at Berkeley and is a Professor in the Department of Industrial and Systems Engineering of San Jose State University (SJSU). He is also a Research Associate at the Mineta Transportation Institute of SJSU. Prior to joining SJSU in 1999, he worked at the Institute of Transportation Studies at University of California, Berkeley for seven years and at the AT&T Bell Laboratories for four years. Details can be found at http://www.engr.sjsu.edu/jtsao.

**Agus Pratama** (pratamaagus@gmail.com) holds an M.S. in Industrial and Systems Engineering and an M.S. in Software Engineering, both from San Jose State University. He is currently working as a Software Engineer at Workday Inc.
Bicycle-Transit Integration in the United States, 2001–2009

Rui Wang and Chen Liu
UCLA Luskin School of Public Affairs

Abstract

This paper analyzes the recent trend in bicycle-transit integration in the U.S. It reviews data from the National Household Travel Surveys (NHTS) to show the characteristics of bicycle-transit integrated trips, where the integrators were from, and to which population groups the integrators belonged. Bicycle-transit integration was increasingly observed in commuters and younger travelers, and became more imbalanced by gender. Results indicate the rise in socio-economic diversity of bicycle-transit integrators, despite a racial gap. There was a clear concentration of bicycle-transit integrators in large and high-density urban areas, where most transit users lived. Evidence does not support that rail attracts more bike access/egress trips than bus. More transit users used bicycles to access/egress in the Pacific, East North Central, and Mountain regions. Given the non-trivial role of bicycles compared to transit in the U.S., the focus on bicycle use and the marriage between bicycle and transit should be further emphasized.

Introduction

As concerns about the efficiency of public transit, public health, energy supply, and climate change have risen in recent decades, U.S. policy makers have shifted from a highway-centric framework to a multimodal transportation system, which encourages the use of public transit and, increasingly, non-motorized modes. However, both transit and non-motorized modes provide limited mobility and accessibility to users. The maximum feasible travel distance of bicycling makes wide use of this
mode impossible in U.S. cities, which have been designed largely for automobiles. Transit can reach a much longer distance, but transit services cannot stretch to every corner of an urban area. Therefore, current shares of bicycle and transit trips in U.S. cities are quite low compared to many foreign cities in the developed world.

Foreign experience has shown that the benefits of bicycle and transit travel are greater when combined (e.g., Repogle 1984, 1992). Since 53 percent of all people nationwide live less than 2 miles from the closest transit facility and 2 miles is likely accepted as a feasible riding distance by most cyclists, there is great potential for bicycle-transit integration to increase bicycle and transit use (FHWA 1994). The private and social benefits of bicycle-transit integration include increasing transit ridership by enlarging transit’s catchment area (through solving the first/last-mile problem), improving cyclists’ mobility by overcoming distance, topographical, weather, safety, and infrastructure barriers, lowering the necessary investment in park-and-ride facilities, and reducing air pollution and traffic congestion (TRB 1994, 2005).

The federal Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 and the subsequent Transportation Equity Act for the 21st Century (TEA-21) of 1998 enabled many state and local authorities to conduct planning studies, programs, and projects linking bicycles and transit in the 1990s. TEA-21 further encouraged bicycle-transit integration by allowing the federal share of transit enhancement grants that link bicycles and transit to reach 95 percent, instead of the usual 80 percent for transit enhancement activities (FTA 1999). As a result, since the 1990s, there has been significant growth in bicycle-transit integration in the U.S. In the early 1990s, bicycle-transit integration consisted mainly of bicycle parking. By the mid-2000s, a range of bicycle services (e.g., mounting bicycle racks on buses, allowing bicycles to board trains, installing bicycle racks and lockers at transit stations, and providing staffed bicycle parking facilities at major transit hubs) were offered by agencies of all sizes in many parts of the U.S. (TRB 2005).

This study provides one of the earliest evaluations of the status and trends of bicycle-transit integration in the U.S. Using the National Household Travel Surveys (NHTS) data, it describes the recent changes in using bicycles to access/egress transit and how the behavior of bicycle-transit integration relates to the characteristics of trips, geography, and travelers. Section Two of this paper reviews the existing literature, in particular empirical evidence, on bicycle-transit integration. Section Three describes data and methodology, followed by results and discussions presented in Section Four. Section Five concludes the paper with suggestions for policy makers and researchers.
**Literature**

Perhaps due to the marginality of combining cycling and transit in North America, there is a shortage of reliable data and empirical studies on bicycle-transit integration (Bachand-Marleau et al. 2011). For example, as of 2005, few transit agencies had collected detailed data about bicycle-on-transit rider characteristics or bicycle parking use (TRB 2005). Hindered by the lack of boarding counts, Hagelin (2005) was unable to provide a meaningful cost-benefit analysis of bike-on-bus programs in Florida. Most of the existing empirical analyses on bicycle-transit integration are descriptive and use data from Western Europe (Givoni and Rietveld 2007; Martens 2004, 2007; Pucher and Buehler 2009, 2012; Rietveld 2000).

Martens (2004, 2007) examined the bicycle-transit integration experiences of European countries and cities, including places with relatively high shares (27% in the Netherlands and 26% in Copenhagen), medium shares (13% in Munich), and low shares (2% in the UK) of bicycles in transit access. The majority of bike-and-ride trips were made for commuting purposes (work and education). Most users traveled under six kilometers to a public transit stop, with longer access distances reported for faster transit modes. Across all locations, except the UK, regional transit (e.g., train, suburban rail, and express bus) had higher shares of bicycle access than local transit (e.g., city bus, metro rail). For Dutch rail transit riders, bicycle use for transit access/egress decreased with the level of urbanization—highest in suburban areas, followed by medium-sized cities and large towns, and lowest in main cities. In addition, there was an imbalance between Dutch transit riders’ home- and activity-end shares of bicycle use. For work, education, and shopping transit trips, bicycle use at the home-end was much higher than at the activity-end. Also, Martens found that choosing to use a combination of bicycle and train did not seem to be associated with the availability of a car, but car availability was clearly correlated with the levels of bike-and-ride for slower modes of transit.

Givoni and Rietveld (2007) found that most of the surveyed Dutch rail passengers chose walking, bicycling, and public transport to get to or from rail stations. From 1978 to 2005, walking, cycling, and transit dominated access to home-end rail stations, while walking and transit dominated access at the activity-end rail stations. Similar to Martens (2004), they found that the availability of a car did not correlate with the mode choice to access the stations. The bicycle was used much more often at the home-end than at the activity-end for transit access/egress, while the opposite held for walking and transit. Walking and bicycling were both used more often for station access distances under, rather than above, three kilometers.
By compiling data from 150 on-board vehicle passenger survey datasets (more than 496,000 public transit riders sampled in total) conducted by public transportation agencies from 2000 to 2005, the American Public Transportation Association (APTA 2007) found that the primary means of transit access and egress was walking (59.6% for access and 63.8% for egress). The second most common mode of public transit access and egress was transferring from another transit vehicle, accounting for 17.2 percent and 21.6 percent of access and egress trips, respectively. Automobiles and other private vehicles accounted for 21.0 percent and 12.0 percent of access and egress trips, respectively. The bicycle was combined in the “other access/egress modes” group, totaling 2.2 percent and 2.6 percent of access and egress, respectively. These results are consistent with the Transit Performance Monitoring System (TPMS) reports, the other major U.S. source on transit access and egress. Data from 58 surveys conducted from 1996 to 2003 suggest that the dominant access/egress modes were walking, transit, and automobile. On the other hand, the bicycle was combined in the “other access/egress modes” group, totaling 0.6–1.3 percent of access and 1.1–1.5 percent of egress (APTA 2007).

Only a small number of studies provide more in-depth analysis of bicycle-transit integration behavior. Using a nested logit model, Debrezion et al. (2009) studied the joint access mode and railway station choices of Dutch railway users. They found a steeper negative distance effect on the utility of accessing departure stations by walking and bicycle, compared to car and public transport. Availability of parking spaces and bicycle standing areas had a positive effect on the choice of accessing departure railway stations by car and bicycle. Through analyzing access to railway stations’ effect on rail use, Brons et al. (2009) found that in Dutch cities, improving the infrastructure network for access and expanding access services to the railway station can substitute for improving and expanding the services provided in the rail network, and were probably more cost effective for increasing rail use.

Bachand-Marleau et al. (2011) analyzed online survey data to identify current or potential groups of bicycle-transit integrators in the region of Montreal, Canada. Bringing a bicycle on transit was the preferred form of integration by the survey respondents, although they were likely to use bicycle parking or a public bicycle more regularly. Using on-board survey data, Bergman et al. (2011) analyzed the access mode choice by riders of the newly-constructed Westside Express Service (WES), a suburb-to-suburb commuter rail in the Portland, Oregon, metropolitan area. They found the importance of pro-sustainability attitudes in choosing bike access and strong access mode choice effects of feeder bus lines and parking provi-
sion in station area. Assessing the costs and cyclists’ preferences of four common bicycle and transit integration strategies (i.e., bike on transit, bike to transit, two bike—one for access and one for egress—and shared bike) in five communities, Krizek and Stonebraker (2011) suggested that cyclists mostly preferred transit with bicycles aboard but the growth potential of bike on transit was limited. Enhancing bicycle parking at transit stops proved most cost-effective, although security was an important concern for cyclists.

In general, it seems that in-depth and rigorous analysis of bicycle-transit integration in the U.S. needs more reliable empirical evidence. Furthermore, almost all of the statistics on bicycle-transit integration reported in the existing literature are not accompanied with standard errors. Due to the small mode shares of transit and bicycle (not to mention the share of bicycle-transit integrated trips) and the limited sample sizes in most analyses, omitting standard errors is extremely problematic.

**Research Design**

To describe patterns and progress in bicycle-transit integration in the U.S., this study relies mainly on the recent NHTS in 2001 (Version 4.0, July 2005) and 2009 (Version 2.1, February 2011), which provide detailed information on the access/egress modes of transit riders. Information from earlier national travel surveys in 1983, 1990, and 1995 were used to provide a longer time series of trends in transit and bicycle usage. Total number of day trip observations increased from 45.3 thousand in 1983 to 149.5 thousand in 1990, 409 thousand in 1995, 642.3 thousand in 2001, and 1.17 million in 2009.

We focus on the surveys’ day trip data, which were collected in a 24-hour period. The purposes (types) of trips include home-based work (HBW), home-based shopping (HBS), home-based social/recreational (HBSR), other home-based (OHB), and not home-based (NHB). This study analyzes the most commonly-used transit: local public transit buses, commuter buses, commuter train, subway/metro rail, and streetcar/trolley. Other public transportation modes such as school/charter/tour/intercity bus, hotel/airport shuttle, taxi, Amtrak, airplane, or passenger line/ferry are excluded from this analysis unless otherwise specified.

All reported statistics are weighted using household level weights adjusted for non-response in the datasets. Whenever possible, statistical variances are calculated and 95 percent confidence intervals (CI) are reported using jackknife replicate weights.
Results

Overall Pattern and Trend of Transit and Bicycle Usage

Figure 1 presents the general picture of transit and bicycle usage over the past three decades. Among the day trips with mode reported (more than 99.9% of trips in each survey), overall transit mode share decreased steadily from 2.3 percent in 1983 to 1.6 percent in 2001, but bounced back to 1.9 percent in 2009, slightly below the 1990s level. When expanding the definition of transit from local and commuter public buses and (sub)urban rail to include school bus, charter/tour bus, shuttle bus, Amtrak, and airplane, the transit mode split more than doubles to 5.2 percent in 1983, 4.7 percent in 1990, 4.1 percent in 1995, 3.6 percent in 2001, and 4.6 percent in 2009, while the overall trend remains the same. Based on the narrow definition of transit, transit trips have been dominated by bus (mode shares of 64–75%), subway (14–29%), and commuter rail (5–10%) during 1983–2009. The trend in bus mode share follows that of transit overall, while the aggregate share of rail modes (commuter, metro, and light rail) was fairly stable over time.

The detailed access and egress of transit trips were only reported in the recent two NHTS surveys. Figure 2 presents the mode shares of access/egress to transit trips by trip type. Transit access/egress was dominated by walking for all trip purposes, but slightly less so for home-based work (HBW) trips and more so for home-based shopping (HBS) trips. Bicycle use for transit access/egress was close to 0 percent (95% CI: 0.02–0.3%) in 2001, but rose to 0.6 percent (95% CI: 0.3–0.8%) in 2009.
The trend for bicycle usage, however, differs from that of transit. Bicycle mode share increased slowly from 0.7 percent in 1983 to 1 percent in 2009, with a small decrease from 1995 to 2001. An obvious but often neglected observation is that the bicycle mode is not a trivial mode compared to transit (even with its expanded definition). Bicycle mode share grew from 31 percent of transit (narrowly defined) mode share in 1983 to 54 percent by 2009.

The Uneven but Changing Picture of Bicycle-Transit Integration

Two types of statistics were used to interpret bicycle-transit integrated travel behavior in the NHTS data. The first statistic is the share of bicycle-transit integrated trips in different, mutually exclusive, but together exhaustive categories, reflecting the distribution of the number of bicycle-transit integrated trips. The second is the mode share of bicycle in transit access/egress across categories, showing how the role of bicycle in transit access/egress varies by trip, geographical, and traveler characteristics. Combined with the distribution of transit trips across categories, the second statistic can often explain the pattern changes of the first statistic.

Variations by Trip Characteristics

From 2001 to 2009, the average bicycle-transit integrated trip became longer (both overall and access/egress distances). The mean total trip distance of bicycle-transit integrated trips increased from 10.7 miles in 2001 to 16.7 miles in 2009, accompanied by a rise in the average time of bike access/egress to transit from 8.8 to 11.9 minutes.

There are two notable changes in transit-bicycle integration in terms of trip characteristics. The first is the increased importance of commute trips. In 2001, there
was no statistically significant difference in the share of bicycle-transit integrated trips by trip type. However, in 2009 it became clear that HBW trips were the most important trip purpose, as shown by the proportions and 95 percent CIs in Figure 3. In 2009, bicycle mode share in transit access/egress was also higher for HBW transit trips than HBS and HBSC transit trips, as shown in Figure 4. However, even for 2009 HBW transit trips, the 95 percent CI of bicycle's share in access/egress was below 4 percent. For most trip types, bicycle mode share in transit access/egress did not show a statistically significant increase over time. The only exception was a marginally significant increase in HBW trips from nearly zero in 2001 to 1.3 percent (95% CI: 0.8-2.4%) in 2009, which seems to be the main contributor to increased bicycle use for transit access/egress in Figure 2.

![Figure 3. Shares of bicycle-transit integrated trips by trip type](image)

![Figure 4. Bicycle's share in transit access/egress by trip type](image)
Secondly, in 2009, more bicycle-transit integrators used the bus than the subway or streetcar, and there were fewer integrated trips by subway than by bus or commuter train, as shown in Figure 5. However, the bicycle mode shares for the access/egress of different types of transit were statistically indistinguishable (Figure 6). Under no transit mode or year could the bicycle mode share in access/egress be considered higher than 7 percent, based on 95 percent CI estimates. Also, the mode share of bicycles in transit access/egress did not show a statistically significant increase over time for most transit mode categories, except a marginally significant increase for bus. Overall, the evidence is unsupportive for, if not against, the claim that the faster mode (rail) attracts more bike access/egress trips, a pattern found in Europe (Martens 2007).
Geographical Variations

It is well-known that different regions in the U.S. vary in their bicycle culture. As shown in Figure 7, in both 2001 and 2009, the Pacific region (Alaska, California, Hawaii, Oregon, and Washington) has more bicycle-transit integrators than all other regions, except East North Central (including Indiana, Illinois, Michigan, Ohio, and Wisconsin). However, among transit users, the shares of those who use bicycles to access/egress did not have a statistically significant difference among regions in 2001. In 2009, bicycle mode share in transit access/egress became significantly higher in the Pacific region than in all other regions, except the East North Central and Mountain (including Arizona, Colorado, Idaho, New Mexico, Montana, Utah, Nevada, and Wyoming) regions. Overall, results suggest that more transit riders used bicycles to access/egress in the Pacific, East North Central, and Mountain regions, but the absolute number of integrated trips was higher in the first two regions, probably due to their larger population sizes and/or higher public transit mode share.

Figure 7. Shares of bicycle-transit integrated trips by division
As shown in Figure 9, in both 2001 and 2009, more than half of the bicycle-transit integrated trips were in metropolitan areas with three million people or more. However, it is statistically unclear whether transit users in larger urban areas are more or less likely to use bicycles for access/egress than urban areas of smaller sizes (Figure 10). In none of the urban size groups can data suggest significant bicycle mode share increase in transit access/egress. None of the urban size groups had a bicycle share in transit access/egress that was higher than 3 percent.
Using community data, there also seems to be an obvious concentration of bicycle-transit integrators in high-density communities (measured by population density of census tracts), as shown in Figure 11. Figure 12 shows a statistically significant increase of bicycle mode share in transit access/egress from 2001 to 2009 in tracts of the highest density category (more than 10,000 people per square mile), although no result indicates that transit riders in high density communities were more likely to use bicycles to access/egress. Analysis using block group-level data has similar results.
Overall, evidence has shown a clear concentration of bicycle-transit integrated trips in large and high-density urban areas. However, such a concentration may be mainly due to the larger number of transit trips in those areas, instead of the transit users’ higher likelihood of using bicycles for access/egress.

**Demographical Variations**

It is widely known that bicycle use is gender imbalanced in the U.S. In terms of bicycle-transit integration, between 2001 and 2009, the gender gap actually grew (Figure 13). In 2001, the number of bicycle-transit integrated trips by men was statistically no different from those by women. However, in 2009, the vast majority of integrated trips were taken by men, indicating a clear and dramatic shift in gender balance. Figure 14 explains the likely reason of such a change. From 2001 to 2009,
bicycles’ share in transit access/egress trips increased significantly for men, and remained low, if had not decreased, for female transit riders.

The average bicycle-transit integrator also became younger. Figure 15 suggests that the age distribution of bicycle-transit integrators became more concentrated in the age groups of 19–35 and 35–65 from 2001 to 2009. The average age of bicycle-transit integrators decreased from 41 in 2001 to 36 in 2009, due to a significant increase in bicycle mode share for transit access/egress in the 19–35 age group (Figure 16). Among age groups, transit riders 65 or older were least likely to use a bicycle to access/egress in 2009. The decrease in the age of the average integrator
also seems consistent with the increase in the distance and travel time for the average bicycle-transit integrated trip (both whole trip and access/egress).

White people took the majority of bicycle-transit integrated trips. The gap between white and minority integrators did not seem to shrink between 2001 and 2009 (Figure 17). This was probably due to the fact that white transit riders were more likely to use bicycles for access/egress, given that only about 40 percent of the transit riders were white (APTA 2007). None of the racial groups had a statistically significant increase in bicycle mode share in transit access/egress (Figure 18). Additionally, there was no notable pattern of bicycle-transit integration across household size or household lifecycle categories.
Socio-Economic Variations

No notable pattern emerged from the distribution of bicycle-transit integrated trips across household income categories (Figure 19). However, Figure 20 shows a significant increase in using bicycles to access/egress transit among transit riders from households of the lowest income group (earning less than $25,000).
Correspondingly, there was a clear rise of bicycle-transit integration among least educated people. As indicated in Figure 21, bicycle-transit integrators with graduate degrees outnumbered most other groups in 2001. By 2009, there was no longer an apparent pattern in education level. Among transit riders, the least educated group (without high school degrees) was the only group that showed a significant increase in bicycle use to access/egress (Figure 22).
Coherent patterns can also be observed in housing tenure type, unit type, and community housing tenure composition. Shown in Figure 23, in 2001 homeowners were the clear majority among bicycle-transit integrators. However, due to the significant increase in renters’ use of bicycles to access/egress transit (Figure 24), such an owner-renter divide disappeared by 2009. Similarly, relative to other communities (defined by block groups), those with high (>55%) proportion of rental units gained bicycle-transit integrated trips between 2001 and 2009, as shown in Figures 25 and 26. Such results can also be found when communities are defined by census tract. As a result of the significant increase in using bicycle for access/egress among transit riders living in duplex or townhouse units, Figures 27 and 28 show that the
dominance in bicycle-transit integration by those residing in single-family houses (SFH) in 2001 disappeared by 2009.

**Figure 23. Shares of bicycle-transit integrated trips by housing tenure**

**Figure 24. Bicycle's share in transit access/egress by housing tenure**
Figure 25. Shares of bicycle-transit integrated trips by block group composition

Figure 26. Bicycle's share in transit access/egress by block group composition
Consistent with Martens’ (2004) findings in three European countries, household vehicle ownership, a variable with potential impact on transit and bicycle usage, did not show meaningful association with the integration of bicycle and transit. Among household groups with zero, one, two, and three-plus vehicles, one could not tell from the data which group(s) had more bicycle-transit integrators. Neither could one tell which group(s) had statistically different or significant changes in bicycle mode share in transit access/egress.
Conclusion
Sound policy making should be based on rich empirical information and robust analysis. There is a considerable gap in bicycle-transit integration research in the U.S. This study provides an early evaluation of status and trend in bicycle-transit integrated travel over the first decade of this century. It reviews NHTS statistics to provide statistically robust evidence about the characteristics of the bicycle-transit integrated trips, where the integrators were from, and to which population groups the integrators belonged.

Evidence shows that bicycle-transit integrated travel became more popular (especially among commuters) and, on average, longer in distance/time. Contrary to the European experience, evidence does not support that a faster transit mode (rail) attracts more bike access/egress trips than a slower transit mode (bus) in the U.S. Across geographical regions, more transit riders used bicycles to access/egress in the Pacific, East North Central, and Mountain regions, although the absolute number of integrated trips was higher only in the first two regions, likely due to their larger numbers of transit trips. Similarly, there remained a clear concentration of bicycle-transit integrated trips in large or high-density urban areas, but it was mainly due to the larger numbers of transit trips in those areas, instead of the transit users’ higher likelihood of using bicycles.

On the socio-demographic side, bicycle-transit integrators became younger but much more male-dominant, as bicycle’s share in transit access/egress trips increased significantly for men but not women. Results indicate the rise of bicycle-transit integration by increasingly diversified population groups, except for a persistent racial gap. White people took the majority of bicycle-transit integrated trips, which was probably due to the fact that white transit users were more likely to use bicycles for access/egress. However, patterns by socio-economic status are different. Bicycle-transit integration was not mostly for high-income people or vehicle owners (in 2001 or 2009). Also, by 2009, bicycle-transit integration was no longer mostly for the well-educated, home owners, or those living in single family homes, because of the rise in using bicycles for transit access/egress among the bottom income group, least-educated, renters, and those living in multifamily units.

Amid certain similarities, it seems that bicycle-transit integration exhibits different patterns in the U.S. compared to Europe, with respect to, for example, urban area size/type and type of transit. The trend also implies the promise of utilizing bicycles to further enhance the accessibility of people with lower socio-economic status, who are often the captive users of transit.
Perhaps contrary to the impression of many, although Americans choose both transit and the bicycle for a small share of their daily travel, the bicycle is not a trivial mode compared to transit. However, even with the rising attention to bicycles as a travel mode in the U.S., it seems that little resources have been allocated to bicycle compared to transit initiatives. Few transit agencies have incorporated bicycle services into their performance measures (TRB 2005). It is a mistake for policy makers and researchers to focus their attention on transit as the only important alternative mode to the automobile. Bicycle use and, as this paper suggests, the marriage between bicycle and transit, should be emphasized much more. Cities should develop bicycle parking/rental at transit stops, provisions for taking bikes aboard transit vehicles, and coordination of bike routes with transit services, as suggested by the TRB (1994, 2005) and Pucher and Buehler (2012). Furthermore, the enlarged gender and persistent racial imbalances suggest that more information about their causes and better policy design are necessary to encourage women and minorities to take advantage of the benefits of bicycle-transit integration.

Future research should delve deeper into why these socio-demographic changes occurred and how exactly the planning and service levels of transit and bicycle transportation and other transportation policies affect bicycle-transit integration across space and over time. The NHTS is limited in its transit and bicycle sample size and cannot be relied on to study detailed travel behavior patterns and changes except the most significant ones. More modally-focused data and detailed information matching transit access and egress trips to their locations (home- and activity-end) should be collected and more in-depth analysis of bicycle-transit behavior should be conducted for better planning and policy making.

Endnotes

1 It is worth noting that the statistics are calculated without differentiating between access and egress, due to the difficulty of knowing what (home-end or activity-end) each access/egress trip refers to. Still, one may suspect that the majority of bicycle-transit integration is at the home-end instead of the activity-end of the transit trip, as found in the Netherlands (Martens 2007).

2 A related claim by Martens (2007) is that faster modes (rail) attract longer bike access/egress trips. The NHTS data seem to agree. In 2001, the average access/egress time by bike to bus was 8.1 minutes, compared to 11.8 minutes to rail. The
gap increased in 2009, when the average bike access/egress time to bus was a similar 8.3 minutes, but the time to rail was 17.2 minutes.

References


**About the Authors**

**Rui Wang** (*ruiwang@ucla.edu*) is an Assistant Professor of Urban Planning at the UCLA Luskin School of Public Affairs. His research focuses on the policy analysis of urban development and sustainability, particularly green transportation, climate change, air quality, public health, and environmental economic geography in the U.S. and/or China.

**Chen Liu** is a recent graduate of the UCLA Urban and Regional Planning program with a focus in transportation planning and housing development. In Los Angeles, he is interested in promoting successful transit-oriented development, especially affordable housing in transit station areas.