Volume 13, No. 4, 2010

Journal of Public Transportation

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JOURNAL OF
Public Transportation

Volume 13, No. 4, 2010
ISSN 1077-291X

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The *Journal of Public Transportation* is published quarterly by

National Center for Transit Research
Center for Urban Transportation Research
University of South Florida • College of Engineering
4202 East Fowler Avenue, CUT100
Tampa, Florida 33620-5375
Phone: (813) 974-3120
Fax: (813) 974-5168
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Website: *www.nctr.usf.edu/jpt/journal.htm*

Volume 13, No. 4, 2010
ISSN 1077-291X

CONTENTS

Public Transportation Services in Oman: A Study of Public Perceptions

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Abstract

Public transportation services are vital for civic life. Recently, many countries in the Middle East have turned their attention towards developing and improving their public transport systems, as problems such as traffic congestions in cities, low mobility, high individual costs of transport, and a rural-urban divide in services have arisen. This study is a public needs assessment and opinion survey of an area in one such Middle Eastern country, the Al-Batinah region of Oman. The study finds public transport services in Oman are minimal and do not match demand, and there is an excessive reliance on private cars. Marketing of public transport services is constrained by certain environmental issues, particularly the socio-cultural and physical environments. The study is innovative from both an approach and implementation perspective and will help policy makers in Oman think about long-term strategies towards establishing viable public transport solutions.

Introduction

Public transportation services are integral to societies. Countries need effective public transport services for transit users, apparent or latent, who need and value different modes of public transport. Public transportation is defined as transportation by a conveyance that provides continuing general or special transportation to the public. It excludes school buses and charter and sightseeing services and includes various modes such as buses, subways, rails, trolleys, and ferry boats (Tran and Kleiner 2005). In an urbanized society, an efficient transportation system is one of the basic components of the social, economic, and physical structure, and it has to be competitive and attractive to the transit seekers. To be well regarded, public transport services must follow regular schedules, be safe and rapid, guarantee high service quality, and utilize resources efficiently (Dridi et al. 2005).

Public transportation services vitalize economies of nations. These services improve the life of communities by providing safe, efficient, and economic transport; they ensure personal mobility through making available cost effective modes; and they benefit society by easing traffic congestion, saving money, and creating and sustaining jobs (Tran and Kleiner 2005). Every day in the U.S., publicly-funded transportation systems provide approximately 32 million passenger trips. These systems serve commuters, students, tourists, seniors, persons with disabilities, and others who rely on trains, buses, ferries, vans, and other accessible vehicles and facilities to reach their destinations (Federal Transit Administration 2003). Improvements in the public transportation links between urban and suburban areas result in a shift in the population from urban to suburban areas (Chau and Ng 1998). This reduces the disparities in land prices and helps to reduce congestion and other problems (Disney 1998). Despite the advantages of public transportation, the concept is still not popular in the Middle East, particularly within the Gulf Cooperative Council (GCC) countries.

The Sultanate of Oman, one of the six GCC countries, has less exposure to the different modes and services of public transport. Oman occupies the southeastern corner of the Arabian Peninsula with a total area of 310 thousand square km and a total population of 2.74 million (2007). Oman is the third largest country in the Arabian Peninsula and is divided into nine main administrative regions (governorates), of which Muscat (27 percent) and Al-Batinah (28 percent) account for more than half of the total population (Statistical Handbook of Oman 2008).

Despite catering to the largest population, the Al-Batinah region lacks a public transportation system for commuters. The situation is even worse in other regions of Oman except Muscat, the capital city, where large buses, micro-buses, and taxis are available. People either struggle for the few seats in shared taxis or depend on private cars. While unavailability of public transport causes inconvenience, the excessive dependence on private cars leads to heavy traffic, a large number of accidents, and high individual expenditure on transport.

At this time, when public transport services attract significant attention from policy makers globally, why they are lacking in Oman is a major concern of this study. The implementation of public transport and its acceptability depends on the perception and attitude of citizens. This study reveals people's perceptions of public transport in Oman and identifies facilitators and barriers to such services.

Review of Middle Eastern and Omani Public Transport

The need to strengthen public transportation systems recently gained new momentum in the Middle East. The 1st UITP Congress for the Middle East and North Africa (MENA) region also stressed the importance of developing long-term ambitious plans to expand and develop the public transport sector.

A recent World Bank (2009) report observes serious capacity gaps in the urban and rural transport infrastructure of the MENA countries. Addressing such gaps could help in accelerating economic growth, regional integration, quality of life, and creation of jobs, in addition to reducing vulnerability to accidents, exclusion of people, and poverty in the region. This report observes that the MENA region, although it is far more urbanized than East Asia or South Asia, lacks development in public transport.

To overcome such weaknesses, some of the GCC countries have recently taken certain initiatives in this regard. Bahrain launched a BD 4.5 million (US$11.9 million) public-private sector joint venture, the Arabian Cab Company (ACC), adding a fleet of 350 brand new "London cabs" to its existing pool (*Bahrain Tribune* 2008). This project is expected to boost the economy through regulation, competition, and growth in employment. Looking beyond the basic gains, Qatar is planning to launch electric-powered taxis and battery-powered public buses to acquire ecological and economical benefits (Altaqata 2009a). MidEast.ru (2009) reports that the Road and Transport Authority (RTA) in the UAE is planning to introduce a fleet of buses exclusively for women. Abu Dhabi has enriched its public transport infrastructure with taxis and buses and is offering free services on four routes (Altaqata 2009b). Sharjah aims to ease the travel woes of residents and daily commuters with 25 buses on three routes, which are expected to amount to a fleet of 172 buses on 18 routes (Altaqata 2009c).

Despite these efforts, 72 percent of UAE residents still feel that the public transport system is inadequate and are frustrated with prolonged waiting periods. Public transport usage in Dubai is only 6 percent, as compared to 65 percent in

Singapore or 78 percent in Hong Kong. *Gulf News* (Dubai) recently reported that traffic congestion, the single biggest concern among Dubai's 1.44 million residents, inflicts yearly losses of AED4.6 billion (US$1.25 billion) or 3.15 percent of the Emirate's AED146 billion (US$39.8 billion) annual GDP (Altaqata, 2009d). The effects of the newly-introduced metro system are only beginning to be realized.

Problems with a lack of public transport and resulting initiatives are not limited to the Gulf region alone. Other countries are also facing serious problems due to the rapid growth in private vehicle ownership, inefficient public transport, and the deteriorating urban environment (Imran and Low 2005; Edvardsson 1998). Istanbul, facing similar serious transportation problems, has decided to build at least 1 km of metro annually to integrate its transport infrastructure comprising metro buses, underground metros, and city buses. There is mixed evidence, however, of its overall effects. In Yemen, the transport sector contributes 10-13 percent of GDP, of which 80 percent comes from public transportation. With 8 bus and 6 taxi companies operating between Yemeni cities, the sector offers 8,000 micro buses in the capital city of Sana'a alone (Altaqata, 2009e). Enquist et al. (2007) observe that public transportation in Sweden has been passing through three waves of development, namely production, service, and sustainability.

The situation of Oman is not noticeably different from that of the GCC countries. In order to create a demand for a public transport system and to reduce excessive reliance on private cars, Oman needs to take strong initiatives. Road accidents in Oman have also become a major concern to families and communities (Al-Qareeni 2008). Unfortunately, Oman had the highest fatality rate (23.7/100,000 pop.) in 1996 in the MENA region (Figure 1), and there has been no relief in the past 10 years, despite of advancements in vehicles and road safety measures (Table 1). Among the nine governorates, Al-Batinah records the highest number of fatalities caused by road accidents.

Table 1. Road Accidents and Fatalities in Oman (2001-2007)

	2007	2006	2005	2003	2001
Total Population	2,743,000	2,577,000	2,509,000	2,416,000	2,341,000
Road Accidents	8,816	9,869	9,247	9,460	10,197
Fatalities	650	550	548	490	428
Fatalities/1,00,000	23.7	21.3	21.8	20.3	18.3

Source: Statistical Year Book 2008, Issue 36, October 2008, Ministry of National Economy, Sultanate of Oman.

Therefore, introduction of better modes of public transport is emerging as a public concern that could help in ensuring safety on the roads. Furthermore, there is a need to investigate road safety mechanisms, since transit users' perception of their safety is crucial to their decisions about whether or not to use public transport (Vogel and Pettinari 2002). Implementation and adoption of public transport could address concerns related to Oman's quickly depleting oil reserves and a need to support industrial development and tourism policies.

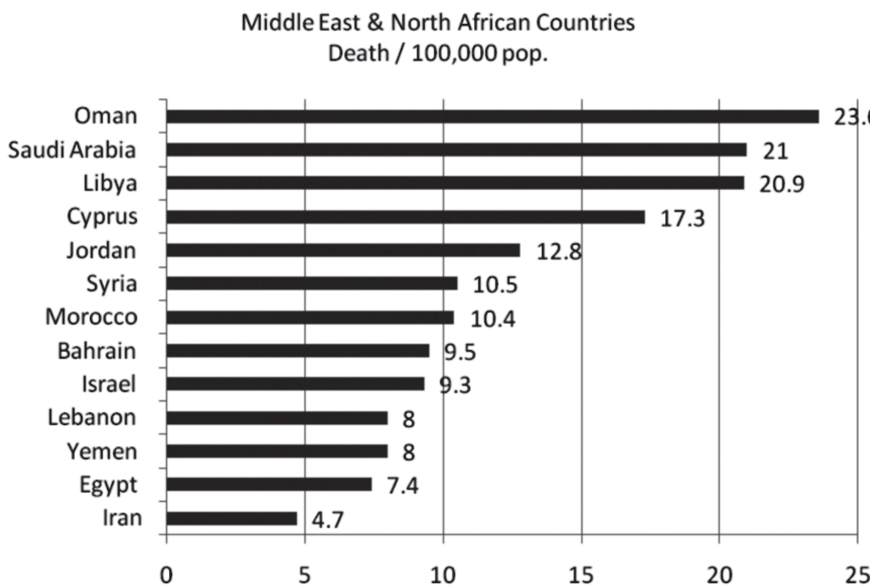

Figure 1. Middle East and North Africa Fatality Risk (1996)
Source: http://www.factbook.net/EGRF_Regional_analyses_Africa.htm

Oman, in our belief, is currently making a beginning where it needs to design and offer different public transportation alternatives. The role of the Oman National Transport Company, established in 1972 and re-established in 1984 by Royal Decree 59/84 to operate public transport services in every part of the Sultanate, has been limited to long-haul public transportation services. For a majority of the public, shared taxis and buses are the current modes of public transport. Oman envisions a 200 km railway track for goods trains between the industrial cities of Sohar and Barka. This could possibly be extended to facilitate passenger transport. The Supreme Committee for Town Planning (SCTP) is preparing to launch a feasibility study covering the development of a National Railway Network. The sooner the initiatives start, the better will be the results.

However, the marketing of products or services and their subsequent adoption are not independent of consumer perceptions. Service quality perceptions have been found to affect behavioral intentions to purchase and could be linked with the marketing efforts in the industry (Perez et al. 2007; Andreassen 1995; Boulding et al. 1993; Zeithaml 1988). Perceived performance, according to Andreassen (1995), is influenced by consumer perceptions of quality, the marketing mix, the brand name, and the image of the service provider. Andreassen (1995) associated some latent variables to reveal consumer perceptions of the quality of public transport services: safety, design /layout, location, quality of vehicles, availability, time spent in traveling, information about services, ticket systems, and price levels. According to Disney (1998), reliability, frequency, friendliness of services, cleanliness of interiors and exteriors comfort, ease of access, reasonable fares, and easy-to-understand timetables were found at the top of positive reasons for utilizing bus services in the UK.

A proper analysis of citizen perceptions of public transport services could help in measuring their perception about, and readiness towards, the adoption of public transport. This study aims to measure citizen perceptions of public transport services in Oman and their readiness to adopt them. We agree that the introduction of public transport is not new to Oman. Though it has existed for a significant period, it has not met its purpose. One of the real contributions of this study is the interrogation it makes of the socio-cultural norms and the physical conditions of the terrain and the behavioral implications that emerge as a result of cultural impediments and transit needs. The following sections specifically lay out the objectives and methodologies.

Objectives of the Study

The drive towards a decent public transport system in the Middle East is not baseless. It is the need of the hour. The above review indicates that the development of a decent public transportation system can ameliorate the transit difficulties faced by the public in Oman. It will not only help in supporting citizens in commuting but will also offer a safe mode of transportation to residents, as well as meet broad social, industrial, environmental, and national requirements. Assessing and revealing the general opinions, perceptions, needs, and expectations of the commuting public were identified as general objectives. More specifically, the following objectives were identified:

1. To assess the needs and perceptions of people towards the establishment of an effective public transportation system in Oman.

2. To study resident characteristics such as usage behavior, experience, sharing habits, and other behavioral aspects about public transportation in Oman.

Methodology

The study was conducted in the form of a public needs assessment and opinion survey. The first phase of the study utilized desk research, observations, and informal discussions with knowledgeable individuals to assess the situation and arrive at some hypotheses to be tested, in line with the stated objectives. The hypotheses postulated are mentioned along with the test results later in Table 12. The second phase concentrated on the data collection and analysis.

Oman was home to around 2.74 million people in 2007 (including expatriates), of which 735,669 dwelt in the Al Batinah region (*Statistical Year Book of Oman* 2008). The Al Batinah region of Oman consists of 12 *wilayats* (districts): Sohar, Ar Rustaq, Shinas, Liwa, Saham, Al Khaburah, As Suwayq, Nakhal, Wadi Al Maawil, Al Awabi, Al Musanaah and Barka. The survey work was restricted to six *wilayats*: Sohar, Shinas, Liwa, Saham, Al Khaburah, and As Suwayq, as these areas contain the majority of the population and account for the mass influx of commuters to Sohar, the main industrial and port city where all the major industries, government directorates and ministries for the region are located.

The respondents from the six *wilayats* were selected using a convenience sampling approach. Individuals from different pockets such as residential areas, market places, government offices, and academic institutions were approached. However, although the selection was largely convenience-based, in order to maintain some randomness, efforts were made to cover every 5th entity while choosing the respondents. Lunneborg (2007) argues that random sampling is almost always difficult and expensive and often prohibitive, and he states that though non-randomness severely limits, it does not completely preclude the possibility of gaining scientific knowledge from data contributed by a convenience sample.

A sample size of 196 was determined to be representative of the Al-Batinah region, based on a sample size calculator (*http://www.surveysystem.com/sscalc.htm*), with a confidence level of 95% and a confidence interval of 7%. Responses were collected using structured questionnaires that contained both open-ended and closed-ended questions. Out of the total, 180 questionnaires were found complete for the purpose of analysis.

The data were analyzed using SPSS-16 and Minitab-15. The reliability of the scales was tested using the Cronbach "alpha" score. Cronbach's alpha determines the internal consistency or average correlation of items in a survey instrument to gauge its reliability, where higher scores indicate higher reliability of the generated scale (Santos, 1999). The Cronbach alpha in this study scored 0.6160, somewhat lower than the most widely referred score of 0.7 (Nunnally 1978). However, an alpha of 0.5 or above is considered by Bowling (1997) as an indication of good internal consistency, while a much higher alpha score may suggest a high level of item redundancy (Streiner and Normal 1989). Hence, it can be argued that measurement scale used in this study met its purpose.

The profile of sample respondents is presented in Table 2. The profile indicates a balance in the number of car owners and their place of residence, gender, and marital status. However, it emerged that there was a higher representation of younger and more educated respondents. This happened by chance because, during the survey, younger and educated respondents revealed a higher interest and cooperation in participation. Others were found to be somewhat conservative in agreeing to our requests for their participation. Notwithstanding, it emerged that those who participated revealed higher propensity towards the acceptance of public transportation than the conservative ones.

Table 2. Profile of Sample Respondents (N=180*)

Car Ownership	# (%)	Driving License	# (%)	Residence in	# (%)
Yes	98 (55.4)	Have	113 (64.9)	Proper city	87 (49.4)
No	79 (44.6)	Don't have	61 (35.1)	Suburb	89 (50.6)
Gender		**Nationality**		**Work Status**	
Male	93 (52.5)	Omani	160 (90.4)	Employed	109 (61.6)
Female	84 (47.5)	Expatriates	17 (9.6)	Unemployed***	68 (38.4)
Age		**Marital Status**		**Education**	
< 30	129 (72.9)	Unmarried	100 (56.5)	Secondary or higher	156 (88.1)
31-50	46 (26.0)	Married	74 (41.8)	Primary	9 (5.1)
> 51	2 (1.1)	Divorced/ widowed	3 (1.7)	None	12 (6.8)

* Mismatches in total represents missing responses.
** The figures in parenthesis represent valid percent.
*** These figures include students as well.

Analysis and Findings

The descriptive analysis of the respondents' behavior reveals that a majority of them use their personal cars to get to work and only a few (17%) use public transport services (Table 3). Table 3 and Table 4 jointly indicate that more people (15%) use public transport for purposes other than getting to work. It is to be noted that the Al-Batinah region has a very limited access to buses or micro-buses and, therefore, public transport mostly implies the use of shared taxis.

Table 3. Means to Arrive at Work

	Frequency	Percent
Personal Car	107	59.4
Public Transport	31	17.2
Other	39	21.7

Table 4. Respondents' Status: Use of Public Transport Currently

	Frequency	Percent
Yes	59	32.8
No	118	65.6

A majority (67%) of the respondents had experienced public transport services in the past (Table 5) either in Oman or abroad. Their experience was mainly limited to shared taxis, buses, and trains (Table 6).

Table 5. Respondents' Status: Use of Public Transport in the Past

	Frequency	Percent
Yes	121	67.2
No	43	23.9

Table 6. Respondents' Status: Public Transport Service Used

	Frequency	Percent
Shared Taxis	46	25.6
Bus	37	20.6
Train	81	45.0
Other	6	3.3

A majority of the people were not positive about their experience with public transportation services. Only 34 percent of the respondents revealed that their experience was pleasant (Table 7). This indicates that there exists some negative image of public transport.

Table 7. Respondents' Experience with Public Transportation

	Frequency	Percent
Very Unpleasant	9	5.0
Unpleasant	20	11.1
Average	79	43.9
Pleasant	43	23.9
Very Pleasant	14	7.8

To compare the respondents' experience, cross tabulation was attempted between users and non-users (Table 8). No significant difference was observed between the experiences of the two groups (χ^2 = 6.503, p =0.165).

Table 8. Cross Tabulation between Current User Status and Experience

		How you rate your experience?					
		Very Unpleasant	*Unpleasant*	*Average*	*Very Pleasant*	*Pleasant*	*Total*
Currently using public transport?	Yes	6	4	26	15	6	57
	No	3	16	53	27	8	107
	Total	9	20	79	42	14	164

Furthermore, cross tabulation was attempted between users-in-the-past and non-users (Table 9). No significant difference was observed between the experience of users-in-the-past and non-users (χ^2 = 4.473, p =0.346).

Table 9. Cross Tabulation between Past Users Status and Experience

		How you rate your experience?					
		Very Unpleasant	*Unpleasant*	*Average*	*Very Pleasant*	*Pleasant*	*Total*
Used public transit in the past?	Yes	5	13	63	27	10	118
	No	3	7	13	9	2	34
	Total	8	20	76	36	12	152

Only a few respondents (5-6%) depended highly (80-90%) on public transportation services, while 17 percent of them did not experienced public transport at all (Table 10).

Table 10. Respondents' Status: Percentage Use of Public Transport in Daily Activities

Percent Use	Frequency	Percent
0	31	17.2
10	31	17.2
20	17	9.4
30	23	12.8
40	23	12.8
50	19	10.6
60	13	7.2
70	9	5.0
80	5	2.8
90	5	2.8

A majority of the respondents (84%) dwelled in Al Batinah, Muscat, and Ad Dakhliyah governorates (otherwise accounting for 66% of the national population) out of a total of 12 governorates in Oman (Table 11). Their distribution across the nine governorates indicates the possibility of generalizing these findings to some extent for the whole of Oman.

Table 11. Respondents' Status: Place Where Maximum Life is Spent

Administrative Regions	Frequency	Percent
Muscat	28	15.6
Al Batinah	111	61.7
Musandam	1	0.6
Adh Dhahriah	5	2.8
Ad Dakhliyah	12	6.5
Ash Sharqiyah	6	3.3
Al Wusta	1	0.6
Dhofar	9	5.0
Al Buraimi	4	2.2
90	5	2.8

Inferential analyses were made to test the hypotheses. The One-Sample Wilcoxon Signed Rank Test was preferred over the t-test, since normality conditions were not assumed for the population. Since people were not very used to public transport and there was a dearth of such services, the population characteristics were assumed to be skewed in either direction. The Wilcoxon Signed Rank Test is more appropriate for cases in which the data level is ordinal or when the population is not believed to be approximately normally distributed (Whitley and Ball 2002; Groebner et al. 2005). The test checks the proposition whether the value of population median is less (as taken in our case), equal, or more than the hypothesized value (3 in our case).

The results arrived at after testing of hypotheses are expressed in Table 12. The acceptance of a proposition reveals that a majority (more than half) of the population is in agreement with that proposition. The mean and standard deviation scores also support the findings. Taking into account the results of hypothesis testing, it can be said for a majority of the population that people believe that public transportation is important for society. They believe that it adds convenience to their travels and is cost effective. People do not feel any discomfort in sharing taxis/buses with others, although they do find some socio-cultural barriers affecting the use of public transport in Oman. People prefer to use their own car to travel and would do so even if the price of oil were to double. However, they will use public transport if good-quality transport infrastructure is developed.

While considering the propositions in Table 12 that were rejected, we observe that many people do not perceive public transport to be safer in Oman than their private cars. Also, no clear consensus emerges among people in opinions about the sharing of public transport. There are mixed feelings indicating either acceptances or rejections. Similarly, they are divided in stating that public transport belittles their status. Therefore, some sections of the society assign higher status to traveling by personal cars and some prefer to travel by their own car for other reasons, as mentioned in Table 13, and are determined to use private cars (see the results for Hypothesis 12 in Table 12). However, some respondents have experienced public transport services in other GCC countries and have expressed a desire to use it if good transport infrastructure is developed.

Further to the collective hypotheses testing, a gender-wise cross tabulation was attempted to test the same propositions. The responses of the female population differ significantly from the males in certain areas. Females disagreed with the propositions that public transportation adds convenience to their travel (χ^2 = 18.731, p =0.002), that they do most of their traveling by public buses or taxis (χ^2 = 10.483, p =0.033), that they do not feel any discomfort in public buses or taxis (χ^2 = 12.136, p =0.016), and that they do not mind sharing vehicles with male passengers (χ^2 = 51.375, p =0.000).

Table 12. Wilcoxon Sign Rank Test Results
(Test of Median = 3 Versus Median < 3 at α=5 percent)

No.	Hypotheses (Alternative)	N	Wilcoxon	p	Median	Mean	S D	Result
$H1_A$:	People believe that public transportation is important for society.	162	501.0	0.00	1.500	1.64	0.88	Accepted
$H2_A$:	People believe that public transport adds convenience to their travels.	177	3368.0	0.00	2.500	2.66	1.36	Accepted
$H3_A$:	People believe that public transport brings cost economy to them.	176	2631.0	0.00	2.500	2.65	1.20	Accepted
$H4_A$:	People believe that public transport is safer than private transport.	177	6288.0	0.96	3.000	3.17	1.41	Rejected
$H5_A$:	People do most of their travelling by public buses or taxis.	175	7980.0	1.00	3.500	3.44	1.42	Rejected
$H6_A$:	People don't feel any discomfort in sharing taxis/ buses with others.	174	3475.5	0.00	2.500	2.63	1.33	Accepted
$H7_A$:	People don't mind taking a taxi or public bus while going to work.	177	4854.0	0.16	3.000	2.88	1.32	Rejected
$H8_A$:	People don't mind sharing taxis with passengers of the opposite sex.	173	7033.0	0.99	3.000	3.22	1.47	Rejected
$H9_A$:	People find some socio-cultural barriers affecting the use of public transport in Oman.	174	2356.5	0.00	2.500	2.41	1.19	Accepted
$H10_A$:	People consider public transport a low class form of travel.	174	4810.5	0.39	3.000	2.97	1.35	Rejected
$H11_A$:	People prefer to travel by their own car.	175	1527.5	0.00	1.500	1.89	1.93	Accepted
$H12_A$:	People will prefer to use their own car even if the price of oil doubles in Oman.	177	1886.0	0.00	2.000	2.05	1.31	Accepted
$H13_A$:	People have used public transport services in other GCC countries and have found them good.	175	5110.0	0.95	3.000	3.11	1.35	Rejected
$H14_A$:	People will prefer to use public transport if good quality transport infrastructure is developed.	178	1464.0	0.00	2.000	2.15	1.09	Accepted

Responses were measured on Likert Scale from 1(Strongly Agree) to 5 (Strongly Disagree).

Table 13. Reasons for Using Personal Vehicles

Reasons	Importance
Personal convenience, comfort and flexibility	*****
Freedom, ease of use and quick maneuverability	*****
Privacy and safety	*****
Public transportation is not available	*****
Cultural reasons	***
To save money	**
To save time /to be in time	**
For recreational purposes especially listening to music	**
To avoid the heat	*
For taking alternative routes to avoid traffic jams	*
For shopping convenience	*
Special occasions (tourism, wedding, crossing borders) or emergencies	*
To avoid taxis that are prone to accidents (rash driving)	*
To protect children from outside influences and cultural shocks	*
To help friends, families and parents move	*

Table 13 explores the reasons as to why people prefer to use their personal vehicles. The most important reasons that emerged out of open-ended questions were found to be personal convenience, flexibility and maneuverability, privacy and safety, and the unavailability of public transportation. Additional such reasons are given in Table 13. The relative importance has been reflected by using asterisks (*), where a single asterisk against a reason records five respondents mentioning that reason.

Table 14 explores the suggestions from the public as to what can be done to improve public transportation services. The most important suggestions were introduction of railway services, standardization of prices, separation of public transportation for males and females, establishment of more public transport companies, and improvement in the infrastructure. More suggestions are mentioned in Table 14. Again, an asterisk against a suggestion records five respondents mentioning it.

Table 14. Suggestions for Improving Public Transportation Services

Suggestion	Importance
Introduce trains	********
Standardize the prices for better control and affordability	******
Separate public rransportation for males and females	******
Plan for taxis driven by women for women (preferably in a different color)	******
Allow more public transport companies to operate	*****
Increase the availability of buses/taxis and the number of stops	****
Improve roads, build over/under bridges to avoid jams	****
Devise better rules and regulations for drivers and public transport companies	****
Put more number of good quality AC buses with better ergonomics	***
Develop local airports	***
Provide and adhere to the time schedules	**
Increase the awareness among citizens about public transportation	**
Evolve a better system of public transport	*
Increase the number of taxis and buses	*
Provide recreation and refreshments in buses	*
Impose taxes on private cars	*
Improve long-haul transport services	*
Introduction of buses should not affect the plight of taxi drivers	*
Drivers should be trained to have some working knowledge of English	*
Drivers should be polite	*
Drivers to carry badges revealing identity and authorization	*
24 /7 availability of public transport is to be ensured	*
Acceptable luggage limits and pricing policy should be there	*
Metering system in taxis to be introduced for price control	*

Discussion

The findings in the above section reveal that people in Oman are mainly dependent on their private cars for transit. The findings were challenged by a triangulation approach in which free discussions were made with some senior officials from public transport authorities, local industries, Ministry of Social Development, and from the society in general. It emerged that although some cultural issues impede the sharing of transportation, it is no longer an issue in the capital city Muscat (where people have started sharing public transport, even with those of the opposite sex), and there is enough competition between private and public sectors players, although not much regulated nor optimized to gain synergy.

The population density of Oman is low (approx. 8/ square km, 2003), and the population is scattered unevenly in the nine regions, which imposes a serious challenge to transport planners in offering specific solution for a particular region. People are open to using public transport, but are unable to reconcile how it could help them in their daily transits, ranging from their visits to offices, traditional shops, fish markets near the coast, and, more importantly, the hypermarkets from which they purchase most of their groceries. People argue that they will be unwilling to wait for buses/ taxis when the temperature outside, for almost six months, ranges between 40-50 degrees Celsius. On the behavioral side, people are basically addicted to using their private cars, while cars for some are a distinct social status symbol. To get rid of that mentality would be a real challenge for the marketers of public transport. Women, especially, are less willing to adopt public transport, as they feel more comfortable and secure in their personal cars.

Furthermore, traffic regulators need to control unexpected disturbances brought about by external and internal factors. External factors cover elements such as characteristics of transit vehicles, roadway or traffic flow impedance, random delays and unusual passenger demands; internal factors may include elements such as organization and management, scheduling, breakdowns, delays, etc. (Dridi et al. 2005). Going beyond the normal conditions, Liden and Edvardsson (2003) emphasize the design of service guarantees in public transport, especially when a negative industry reputation already exists. Oman will probably need to ensure a guaranteed public transport system to attract and retain customers who otherwise perceive public transport services negatively.

However, certain concerns such as fuel conservation, the increasing number of road accidents, and traffic congestion could support the drive towards public transport. Regulation of different modes and payment mechanisms and their seamless connectivity and interoperability needs multi-modal planning for effective public transport and would be a crucial aspect for its acceptance. Transit riders should not get stuck with a "what to do next" situation in order to reach their intended destinations. All of these demand policy initiatives at various levels.

Conclusions

To ensure the vitality of civic life, industry, and government, effective public transportation services are a must in every country. The use of public transport is growing in developed and developing countries alike. This paper has highlighted such efforts in the Middle East (especially in Bahrain, UAE, Yemen, and Qatar) and other countries such as Turkey and Sweden. Countries, such as Oman, need good public transportation options for commuters where people either struggle for seats in often difficult to find shared taxis or rely exclusively on their private cars.

To offer any solution, the needs and expectations of the people have foremost to be taken into account.

After a survey, this paper attempts to secure the public perception towards public transport services in Oman. The descriptive analysis of the respondents' behavior reveals that a majority of them use their personal cars to get to work and only a few use public transport services. It is not that the people in Oman have not experienced public transport services in the past. They have, but their experience with public transport services has not been pleasant. Only a few respondents depend greatly on public transportation services, while some do not use public transport at all.

The testing of hypotheses reveals that people consider public transportation important for society and believe that public transport is convenient and cost effective. People do not feel any discomfort in sharing taxis/buses with others. People find some socio-cultural barriers affecting the use of public transport in Oman. They prefer to travel by their own cars and are sufficiently convinced of the merit of this mode of travel even if the price of oil doubles in Oman. However, they are willing to use public transport provided good transport infrastructure is developed. The female population does not find public transportation services convenient. They favor personal cars and dislike sharing taxis with males. The most common reasons for preferring personal vehicles are convenience, flexibility and maneuverability, privacy and safety, and the absence of public transportation.

Among the suggestions for improving public transportation services, the most common are the introduction of railway services, the standardization of prices, the separation of public transportation for males and females, the formation of more public transport companies, and improvement in infrastructure. All these factors can help the policy makers and transport authorities to devise well-acceptable public transport services in Oman. There is a pressing need to develop a national policy on public transportation that takes into account the identification and development of public transportation modes, routes, and services; their proper regulation protecting the interest of different service providers; provision of interoperability of transit modes and payment; addressing of socio-cultural barriers; and creation of public transport infrastructure that deals with the adverse climatic conditions. Success gained in this regard can help the country and its economy on many fronts.

Significance, Innovation, Limitation, and Further Research

This research is significant for understanding the perceptions of public in Oman in particular and Islamic countries of the Gulf in general. Moreover, it has helped in forming a positive opinion and attitude among citizens about the benefits of sharing resources for transportation purposes and its easy acceptance and prevalence in society. The study is innovative from the perspective approach and possible implementation in Oman. It could help the nation carve out a long-term strategy of establishing viable public transport modes or alternatives, e.g. trams, waterways, and subterranean /general railways in the country, which could extend the domain of economic benefits from the common man to those in businesses and industries. Limitations on the overall applicability of our conclusions might have been imposed by the small sample size, higher representation of young and more educated respondents in the sample, use of convenience sampling, and possible respondent bias. Notwithstanding these, we believe that well planned and well implemented public transportation could help Oman in strengthening its cultural, educational, economical, and welfare bonds with the society. These areas open a wide scope to future researchers.

References

Al-Qareeni, Hamed bin Hashel. 2008. Traffic Safety Institute Systematic knowledge to enhance road safety. http://www.rop.gov.om/english/articlesdet.asp?articleid=3.

Altaqata. 2009a. Qatar public transport adopting new technologies. http://www.altaqata.com/newsDtls.php?id=1350.

Altaqata. 2009b. Long, hard commute becomes an easy journey in Abu Dhabi. http://www.altaqata.com/newsDtls.php?id=1924.

Altaqata. 2009c. Sharjah to launch public transport buses in May. http://www.altaqata.com/newsDtls.php?id=1472.

Altaqata. 2009d. Limited transport restricts public transport usage: RTA stresses hurdles to Dubai's public transport. http://www.altaqata.com/newsDtls.php?id=1932.

Altaqata. 2009e. Public Transport Sector in Yemen Needing Attention: An Ignored Sector Cries For Attention http://www.altaqata.com/newsDtls.php?id=1876.

Andreassen, T. W. 1995. (Dis)satisfaction with public services: The case of public transportation. *Journal of Services Marketing* 9 (5): 30-41.

Bahrain Tribune. 2008. Bahrain public transport to get a BD4.5m boost. http://www.menafn.com/qn_news_story_s.asp?StoryId=1093213580. 24.09.2008

Boulding, W., A. Kalra, R. Staelin, and V. Zeithaml. 1993. A dynamic process model of service quality: from expectations to behavioral intentions. *Journal of Marketing Research* 30: 7-27.

Bowling, A. 1997. *Research Methods in Health*. Buckingham: Open University Press.

Chau, K. W., and F. F. Ng. 1998. The effects of improvement in public transportation capacity on residential price gradient in Hong Kong. *Journal of Property Valuation & Investment* 16 (4): 397-410.

Disney, J. 1998. Competing through quality in transport services. *Managing Service Quality* 8(2): 112-118.

Dridi, M., K. Mesghouni, and P. Borne. 2005. Traffic control in transportation systems. *Journal of Manufacturing Technology Management* 16 (1): 53-74.

Edvardsson, B. 1998. Causes of customer dissatisfaction – studies of public transport by the critical-incident method. *Managing Service Quality* 8(3): 189–197.

Enquist, B., M. Johnson, and C. Camén. 2005. Contractual governance for sustainable service. *Qualitative Research in Accounting & Management* 2(1): 29-53.

Federal Transit Administration. 2003. *The Public Transportation System Security and Emergency Preparedness Planning Guide*. U.S. Department of Transportation Research and Special Programs Administration. http://transit-safety.fta.dot.gov/publications/security/PlanningGuide.pdf.

Groebner, D. F., P. W Shannon, P. C. Fry, and K. D. Smith. 2005. *Business Statistics: A Decision Making Approach*. New Jersey: Prentice Hall.

Imran, M., and N. Low. 2005. Sustainable urban transport in Pakistan: Fhreats and opportunities. *Management of Environmental Quality: An International Journal* 16 (5): 505-529.

Lunneborg, C. E. 2007. Convenience sample. In *Blackwell Encyclopedia of Sociology*, Ritzer, G. (ed.). Blackwell Publishing.

Lidén, S. B., and B. Edvardsson. 2003. Customer expectations on service guarantees. *Managing Service Quality* 13(5): 338-348.

MidEast.ru. 2009. Bus service exclusively for women in UAE. http://www.en.mideast.ru/336/42107.

Perez, M. S., J. G. Abad, G. M. Marin Carrillo, and R. Sanchez Fernandez. 2007. Effects of service quality dimensions on behavioral purchase intentions- A study in public-sector transport, *Managing Service Quality* 17 (2): 134-151.

Santos, J., and A. Reynaldo. 1999. Cronbach's Alpha: A tool for assessing the reliability of scales. *Journal of Extension* 37(2). http://www.joe.org/joe/1999april/tt3.php.

Statistical Year Book of Oman. 2008. Ministry of National Economy, Sultanate of Oman. Issue 36, October 2008.

Tran, T., and B. H. Kleiner. 2005. Managing for excellence in Public transportation. *Management Research News* 28(11/12): 154-163.

Vogel, M., and J. Pettinari. 2002. Personal safety and transit: Paths, environments, stops, and stations. Final Report (#CTS 02-05), Minneapolis, Minnesota: Center for Transportation Studies.

Whitley, E., and J. Ball. 2002. Statistics review 6: Nonparametric methods. *Critical Care* (6):509-513. http://ccforum.com/content/6/6/509.

World Bank. 2009. Overview: Transport Sector Brief. http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/MENAEXT/0,,contentMDK:20532420~pagePK:146736~piPK:226340~theSitePK:256299,00.html

Zeithaml, V. A. 1988. Consumer perceptions of price, quality and value: A means-end model and synthesis of evidence. *Journal of Marketing* 52: 2-22.

Acknowledgment

The authors acknowledge the anonymous reviewers for their critical comments and suggestions to improve this paper. Comments and suggestions made by Dr. Lance Bode of Sohar University have improved the manuscript.

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Using GIS for Measuring Transit Stop Accessibility Considering Actual Pedestrian Road Network

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Abstract

Bus stops attain their importance to the transit service from being the main points of contact between the passenger and the bus. Considering spatial attributes, both the location and the spacing of bus stops significantly affect transit service performance and passenger satisfaction, as they influence travel time in addition to their role in ensuring reasonable accessibility. Knowing that every transit trip begins and ends with pedestrian travel, access to a bus stop is considered a critical factor for assessing the accessibility of the stop location. In this research, transit stop access coverage is estimated based on the actual pedestrian road network surrounding the stop. Accordingly, new indices are developed to assess a bus stop location on a more spatial basis. These indices measure the accessibility of a bus stop through the surrounding road network in addition to the ratio of actual access coverage to the ideal access coverage of a stop.

Introduction

Being the first points of contact between the passenger and the transit service, access to public transport stops is an important factor affecting overall transit trip travel time. Physical access to a transit stop is interpreted in terms of the proximity of the passenger's origin or destination to the nearest transit stop (TCRP 1996), which is generally achieved by walking, riding a bicycle or driving a car for a short distance (Murray and Wu 2003). In planning for the provision of bus-based transit service, accessing a bus stop is considered to be achieved mainly by walking. Based on an assumed average walking speed of about 1.3 m/s, 5 minutes of walking is considered reasonable in urban areas, which is about 400meters in terms of walking distance (Levinson 1992). Most transit firms consider 400meters an acceptable access/egress standard (Ammons 2001). In Columbus, Ohio, it is stipulated that passengers do not exceed walking distances of 400m to transit stops in urban areas (Central Ohio Transit Authority 1999). In general, access to transit stops affects passenger accessibility and represents the opportunity to use the public transport service (Holtzclaw 1994).

Estimating Bus Stop Access Coverage

Although pedestrian access to a bus stop is achieved through the pedestrian road network surrounding each stop, previous research has not focused on the interaction between bus stop locations and their surrounding pedestrian road networks. Stop access coverage has been estimated using a circular buffer analysis with a radius of the access threshold around the transit stop in order to identify its coverage area. Knowing this area in addition to the population density, the total number of individuals in a region having suitable access can be determined. Another approach for estimating access is by comparing the distance from the centroid of a spatial block to its nearest bus stop. If this distance is within the threshold distance, then coverage is achieved (Murray et al. 1998). Both approaches provide simple estimates for access coverage; however, they are unrealistic and have potential for error by measuring the access distance in terms of a rectilinear distance and ignoring the actual geography of the pedestrian road network surrounding the stops.

Estimating Actual Bus Stop Access Coverage

Bus stop access coverage is a critical measure for evaluating the stop location by estimating the covered area and population lying within a suitable access distance from the bus stop (Foda and Osman 2008). However, much previous research treated stop coverage as a simple circular buffer with a radius of the access threshold around each stop, which causes an overestimation of the stop access coverage. The reason for such an overestimation is the implied assumption that passengers can reach the bus stop from any location within the circular buffer (ideal case), and neglecting the actual geography of the pedestrian road network surrounding the bus stop, as shown in Figure 1.

Figure 1. Bus Stop Access Coverage Based on a Circular Buffer Around the Stop and Neglecting the Actual Pedestrian Road Network

The accessibility to a bus stop from within the circular buffer zone and through the intersected road network located inside the buffer area can be divided into two parts: the first is within the specified limit of 400m, and the other exceeds the limit, as shown in Figure 1. That is, although the start of the walking distance is located within the circular buffer, it exceeds the specified distance of 400m.

While being an important measure for the assessment of a stop location, estimating the actual access coverage is complicated by the practical realities of spatial information. This means that proximity to stops must be interpreted creatively, which is possible using the powerful GIS network analysis functions (Foda and Osman 2006). Fortunately, most commercial GIS packages offer capabilities for carrying out assessment of access on the basis of the actual pedestrian road network. Salvo and Sabatini (2005) suggested a more spatial approach for identifying optimal stop locations. They proposed a methodology to assess public transportation access coverage in urban areas using a geographical information system based on a pedestrian network with the presence of obstacles.

In this research, and using the benefits of the GIS network analysis functions, another approach is presented for estimating transit stop access coverage based on the actual pedestrian road network surrounding the bus stop. The idea here is to identify all the pedestrian road network links that lie within the specified maximum walking distance of the 400m access threshold, measured along the network paths around the bus stop. Joining the ends of those links creates a polygonal area, which is referred to as the "actual access coverage" for the bus stop. This polygonal area is considered more representative than a 400m circular buffer for measuring the access coverage of a bus stop. Figure 2 shows the difference between the ideal access coverage (circular area) and the actual access coverage (polygonal area), which causes an overestimation in assessing the access coverage of a bus stop at a given location.

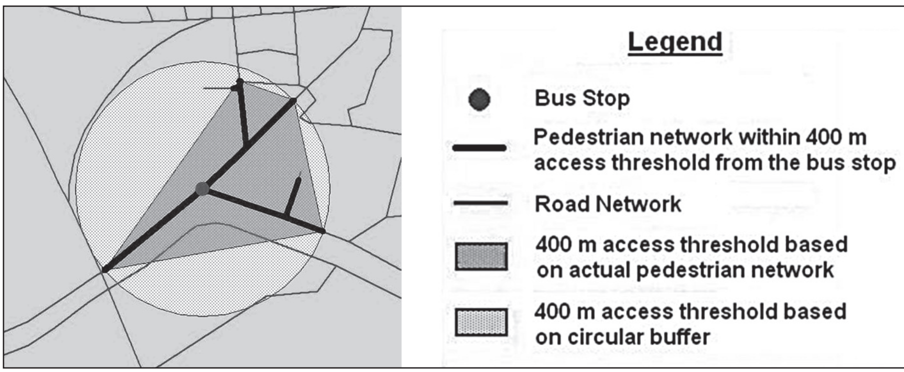

Figure 2. Ideal (Circular) and Actual (Polygonal) Bus Stop Access Coverage

By applying the presented approach for estimating bus stop access coverage, new assessment indices are developed in an attempt to provide a more spatial evaluation of the bus stop location. These indices can be used to evaluate both the accessibility to a bus stop through the surrounding pedestrian road network and the ratio of actual access coverage to the ideal access coverage of a bus stop.

Ideal and Actual Stop-Accessibility Indices (ISAI and ASAI)

First, the Ideal Stop-Accessibility Index (ISAI) can be used to evaluate the accessibility to a bus stop through the surrounding pedestrian road network. This is obtained by dividing the total length of the pedestrian road network links lying within a walking distance of 400m measured along the network paths (Km) by the ideal access coverage area of the bus stop measured as a circle with a radius of 400m and having the bus stop as its center (km^2), as shown in Figure 3.

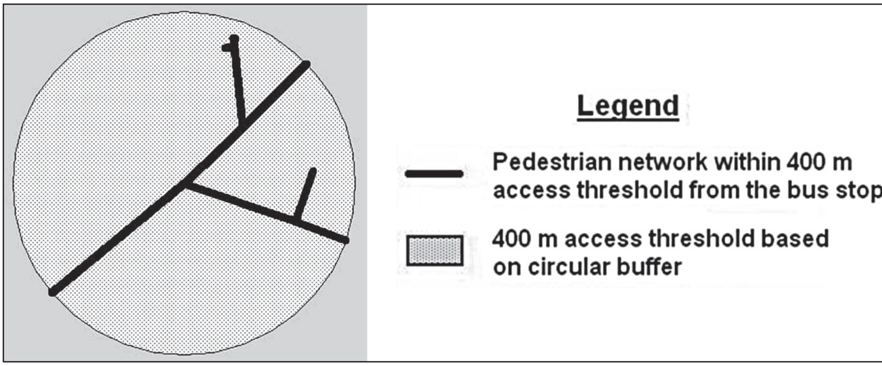

Figure 3. Ideal Stop-Accessibility Index (ISAI)

The denominator value is then the area of a circle with a radius of 400m, which is a constant equal to ($\pi r^2 = \pi \times (0.4)^2 = 0.503$ Km^2), in which the resulting value of such an index represents the ideal pedestrian road network density within the access threshold from a bus stop (Km/Km^2). The flowchart presented in Figure 4 illustrates the sequence of the different actions needed to compute the ISAI within the GIS platform.

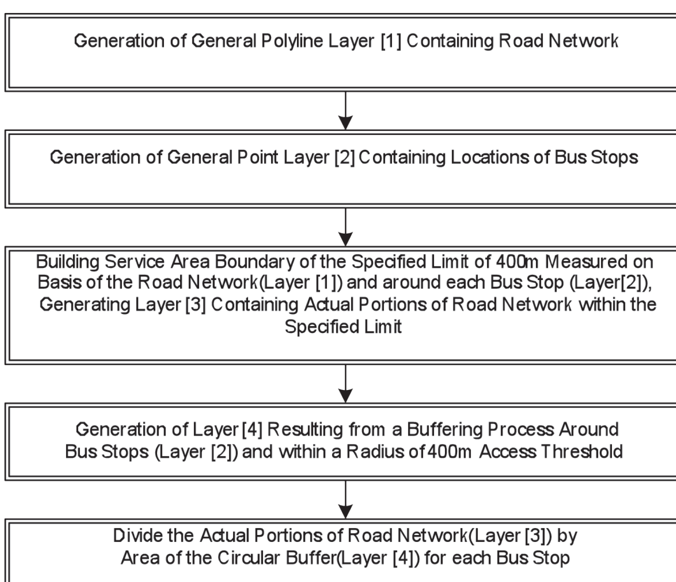

Figure 4. Sequence of Actions to Compute ISAI within GIS Platform

As previously stated, the ISAI value represents the accessibility to a bus stop through the surrounding pedestrian road network. An increment in the index value means that the ideal pedestrian road network density is higher, which is interpreted in terms of a better connectivity between the bus stop and the surrounding pedestrian road network; hence, the bus stop is more likely to be accessible, and vice versa. In other words, the higher the value of the ISAI, the more accessible the bus stop location.

Second, the Actual Stop-Accessibility Index (ASAI) can be used as a more accurate measure of bus stop accessibility through the surrounding pedestrian road network. It is believed that the ASAI provides a more accurate measurement than the ISAI to the pedestrian road network density around a bus stop, where the denominator represents the actual access coverage area for the bus stop within the 400m limit of walking.

The ASAI is obtained by dividing the total length of the pedestrian road network links lying within a walking distance of 400m measured along the network paths (Km) by the actual access coverage area of the bus stop measured on basis of the pedestrian road network serving the same stop (km^2), as shown in Figure 5.

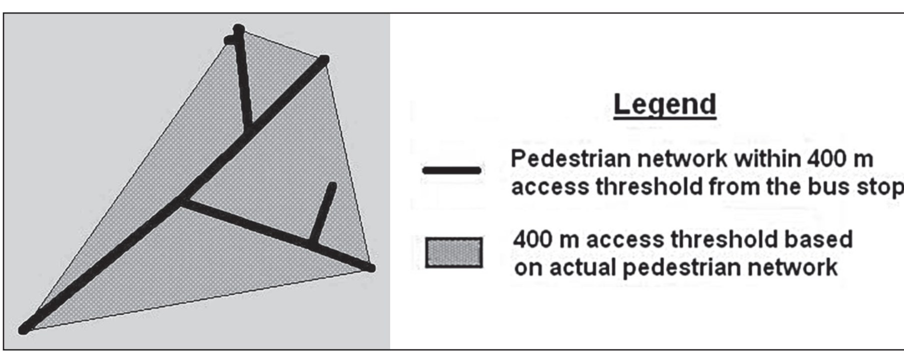

Figure 5. Actual Stop-Accessibility Index (ASAI)

The resulting value of such index represents the actual pedestrian road network density within the access threshold from a bus stop (Km/Km^2). The flowchart presented in Figure 6 illustrates the sequence of the different actions needed to compute the ASAI within the GIS platform.

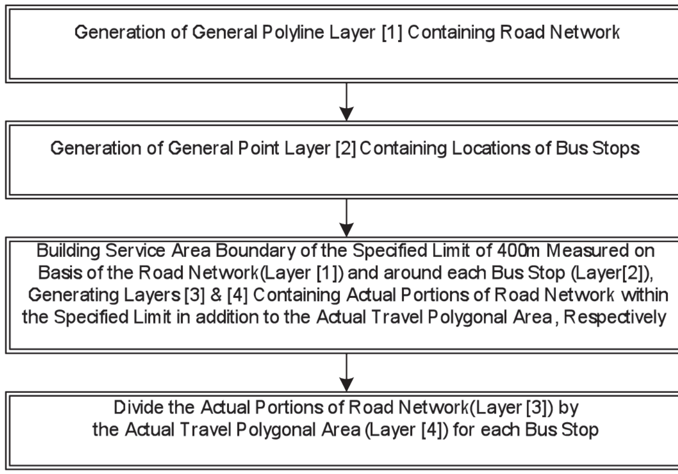

Figure 6. Sequence of Actions to Compute ASAI within GIS Platform

While the ASAI value estimates the actual pedestrian road network density within the access threshold from a bus stop, it may be misleading if used to compare the accessibility of different bus stop locations, as the denominator is not constant and depends on the surrounding road network formation. The denominator, then, will differ whenever changing the bus stop location, and there will not be a fixed reference to refer to in the comparison. So, when the index value increases, it still will not be clear whether the bus stop is more accessible or not, as this may be a cause of a smaller bus stop access coverage area and not an effect of increasing the pedestrian road network length within the suitable access threshold. Moreover, it should be realized that the actual access coverage area and its shape are affected by the geometry of the pedestrian road network around the bus stop within the suitable walking limit. Further, the ISAI value should always not be greater than the ASAI, as the actual access coverage area will not exceed the ideal.

Stop Coverage Ratio Index (SCRI)

The Stop Coverage Ratio Index (SCRI) can be used to evaluate the ratio of actual access coverage to that of the ideal access coverage of a bus stop, which is obtained by dividing the actual access coverage area of the bus stop measured on basis of the pedestrian road network paths (km^2) by the ideal access coverage area measured as a circle with a radius of 400m and having the bus stop as its center (km^2).

The denominator value is then the area of a circle with a radius of 400m, which is a constant equal to ($\pi r^2 = \pi \times (0.4)^2 = 0.503\ Km^2$), as shown in Figure 7.

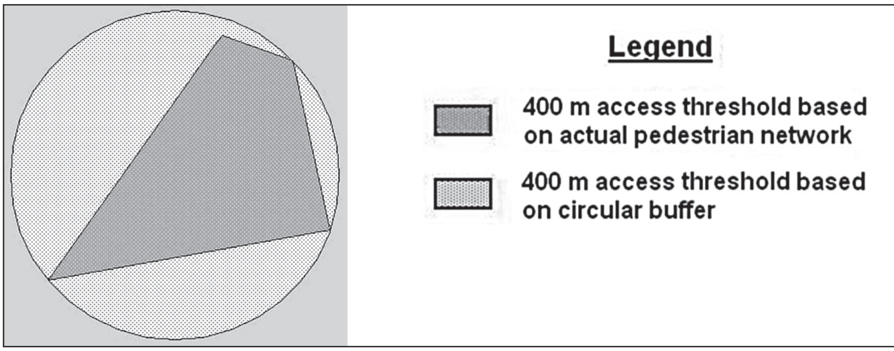

Figure 7. Stop Coverage Ratio Index (SCRI)

The flowchart presented in Figure 8 illustrates the sequence of the different actions needed to compute the SCRI.

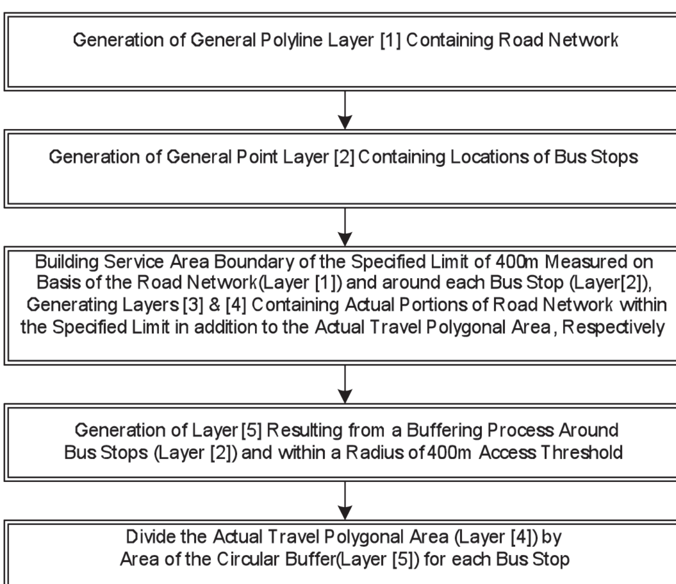

Figure 8. Sequence of Actions to Compute SCRI

The resulting value of the SCRI is dimensionless, in which it represents the ratio of the actual access coverage to the ideal access coverage of a bus stop. An alternative way for evaluating the SCRI is by dividing the ISAI by the ASAI. Such an index is an indicator of the degree in which the location of the bus stop actually covers the surrounding are–in other words, the percentage of actual access coverage with respect to the ideal access coverage. Further, the population coverage of the stop can be calculated by knowing the population density within the stop's actual coverage area. Theoretically, the index value varies from a minimum of 0.0 if the bus stop is not served with a pedestrian road network to a maximum value of 1.0, which is the ideal case, i.e., actual access coverage area is equal to the ideal access coverage area.

Measuring Ideal and Actual Bus Stops Access Coverage

Bus stops locations generally are determined by the passenger transporting authority based on goals addressing both traffic operation and passenger accessibility issues. Specifically, how do the stop locations and spacing serve the demand? Further, bus stop spacing affects the overall travel time and, therefore, demand for transit. Stops should be spaced to minimize pedestrian walking distances near major demand generators and to reduce the number of bus stoppages in order not to increase the transit trip travel time; that is, choosing a bus stop location is a tradeoff between stop spacing and travel time. Ensuring suitable stop coverage is a worthwhile objective, as the time taken to reach a public transit stop has a major impact on total trip travel time, which influences potential patronage.

As one of the major roadways in the city of Alexandria, Egypt, the locations of bus stops along Gamal Abd-Elnaser roadway were identified as a case study for the proposed analysis in this research. Gamal Abd-Elnaser roadway, with a length of about 13.13 Km starting from the Bab Sharki district at the west to El-Montaza district at the east, represents one of Alexandria's major longitudinal roadways. The roadway is densely covered with transit bus routes operated by Alexandria Passenger Transporting Authority (APTA). Using a simple GIS buffer analysis, it was found that an area of 10.98 Km^2 lies within 400m access threshold from the bus routes. Further, 31 bus stops were identified serving the bus routes from west to east, as shown in Table 1.

Table 1. Bus Stops along Gamal Abd-Elnaser Roadway

Stop No.	Stop Name	Stop No.	Stop Name
1	Sharki	17	Ghanaklis
2	El-Nagda	18	Sharawy
3	El-Manara	19	Victorya
4	El-Hadara	20	Gamal Abd-Elnaser
5	El-Ibrahimia	21	El-Seiouf
6	El-Talaba	22	Mohamed Naguib
7	Cliopatra	23	Sedi Beshr
8	Sedi Gaber	24	Gehan
9	Mostafa Kamel	25	Abd El-Razek
10	Roushdi	26	El-Academia
11	Bolkly	27	El-Sharif
12	El-Wezara	28	El-Asafra
13	Fleming	29	Sedi Kamal
14	Gleem	30	Hosni
15	Zezenia	31	El-Mandara Gamee
16	Gamee Yehia		

Figure 9 shows the covered areas within 400m access threshold from the bus routes in addition to the 31 bus stops locations that serve the bus routes along Gamal Abd-Elnaser roadway, numbered from west to east.

As previously discussed, if ideal access to a bus stop is identified to be a specified distance (or travel time) to a public transport stop, then it is possible to identify all of the areas within the threshold distance of all stops. Knowing these areas and their corresponding population densities, the total number of individuals in a region having suitable access to a transit stop can be determined. Simply, this is achieved using a circular GIS buffer analysis around the existing bus stops with a radius of the threshold access distance. Examining the 400m ideal access coverage for the 31 existing bus stops along Gamal Abd-Elnaser roadway shows that an area of 9.86 Km^2 from a total routes coverage of 10.98 Km^2 (approximately 89.80% of the routes coverage) was found to have suitable ideal access coverage to public transit stops, as shown in Figure 10. The previous treatment may lead to an overestimation of bus stop access coverage by implying that pedestrians can reach the bus stops from any location within the circular buffer and neglecting pedestrian's real paths and the presence of possible obstacles (physical barriers), which may actually not provide full pedestrian access as the circular buffer assumes. Thus, bus stop access coverage is recalculated based on the actual pedestrian road network surrounding them. Examining the 400m actual access coverage for the 31 existing bus stops along Gamal Abd-Elnaser roadway shows that only an area of 6.54 Km^2 from a total route coverage of 10.98 Km^2 (approximately 59.56 % of the routes coverage) was found to have suitable actual access coverage to public transit stops, as shown in Figure 11.

Figure 9. Bus Stop Locations along Gamal Abd-Elnaser Roadway

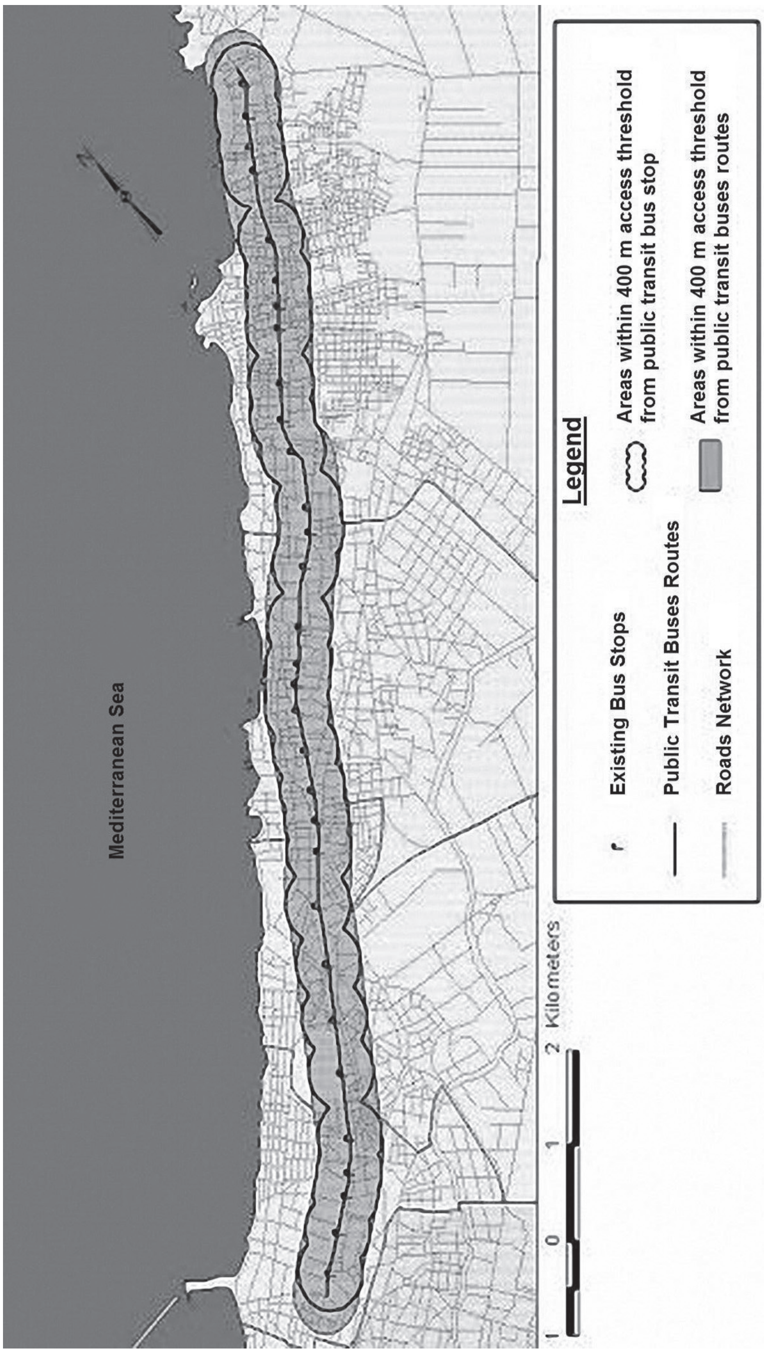

Figure 10. Ideal Bus Stop Access Coverage along Gamal Abd-Elnaser Roadway

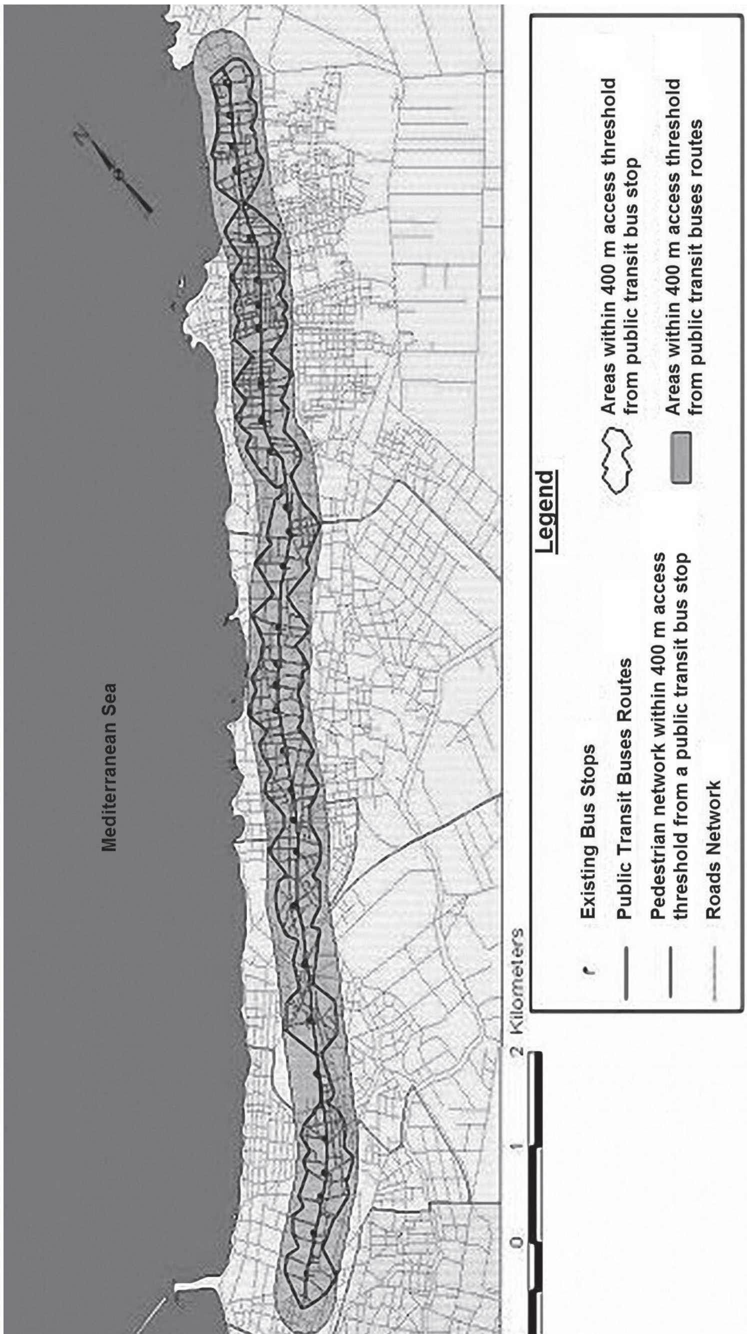

Figure 11. Actual Bus Stop Access Coverage along Gamal Abd-Elnaser Roadway

Comparing both the ideal and the actual access coverage values clearly shows that an overestimation has occurred while calculating the access coverage on bases of circular buffer around the bus stops, as it estimates the coverage area to be 9.86 Km^2 while it is only 6.54 Km^2 on basis of actual coverage and considering the pedestrian's real paths. In other words, the actual bus stop access coverage was overestimated by about 3.32 Km^2 (approximately 30.24 % of the route coverage), which represents a difference of about 50.76 percent in estimating bus stop access coverage.

Evaluating ISAI, ASAI & SCRI for Gamal Abd-Elnaser Roadway Bus Stops

As a step toward a more detailed analysis using the presented indices, the ISAI, ASAI, and SCRI were calculated for each stop along Gamal Abd-Elnaser roadway individually in order to evaluate both the accessibility of each bus stop through its surrounding pedestrian road network and the ratio of actual access coverage to the ideal access coverage at the stop location, as shown in Table 2.

From Table 2, it can be shown that El-Talaba (stop #6) has the minimum ISAI value, which means that the stop has the minimum pedestrian road network length serving it within the suitable walking standard and, hence, it is not likely to be accessible. Inversely, it can be shown that El-Academia (stop #26) has the maximum ISAI value, which means that the stop has the maximum accessibility among the rest of the stops.

On the other hand, and while evaluating the ASAI values, it was found that El-Nagda (stop #2) has the least value of the index, which means that it has the minimum actual pedestrian road network density among the rest of the stops, and, again, the El-Academia bus stop achieved the highest value of the index, which means that it has the maximum actual pedestrian road network density among the rest of the stops, which is an indication of the suitability of its location from a spatial perspective. As previously discussed, it should be noted that the actual access coverage area and its shape are affected by the geometry and formation of the pedestrian road network surrounding the bus stop within the suitable walking limit and, thus, the ASAI may be misleading if used to compare the accessibility of different bus stops locations.

Finally, while evaluating the SCRI, it was shown that the El-Talaba bus stop has the least SCRI value, which means that it has the least actual access coverage area. Inversely, Cleopatra (stop #7) is found to have the highest SCRI value, which means that it has the highest actual access coverage area among the stops.

Table 2. ISAI, ASAI, and SCRI Values for Bus Stops along Gamal Abd-Elnaser Roadway

Stop No.	Stop Name	400m ideal access coverage (Km^2)	400m actual access coverage (Km^2)	Pedestrian road network within 400m (Km)	ISAI (Km/Km^2)	ASAI (Km/Km^2)	SCRI
1	Sharki	0.503	0.316	3.221	6.40	10.19	0.63
2	El-Nagda	0.503	0.258	2.418	4.81	9.37	0.51
3	El-Manara	0.503	0.325	3.407	6.77	10.48	0.65
4	El-Hadara	0.503	0.306	3.971	7.89	12.98	0.61
5	El-Ibrahimia	0.503	0.289	4.814	9.57	16.66	0.57
6	El-Talaba	0.503	0.073	1.489	2.96	20.40	0.15
7	Cleopatra	0.503	0.365	5.184	10.31	14.20	0.73
8	Sedi Gaber	0.503	0.182	2.514	5.00	13.81	0.36
9	Mostafa Kamel	0.503	0.334	4.570	9.09	13.68	0.66
10	Roushdi	0.503	0.331	5.082	10.10	15.35	0.66
11	Bolkly	0.503	0.217	2.530	5.03	11.66	0.43
12	El-Wezara	0.503	0.346	5.133	10.20	14.84	0.69
13	Fleming	0.503	0.328	4.601	9.15	14.03	0.65
14	Gleem	0.503	0.352	4.786	9.51	13.60	0.70
15	Zezenia	0.503	0.312	4.308	8.56	13.81	0.62
16	Gamee Yehia	0.503	0.299	4.170	8.29	13.95	0.59
17	Ghanaklis	0.503	0.324	4.176	8.30	12.89	0.64
18	Sharawy	0.503	0.31	3.716	7.39	11.99	0.62
19	Victorya	0.503	0.363	5.013	9.97	13.81	0.72
20	Gamal Abd-Elnaser	0.503	0.16	2.168	4.31	13.55	0.32
21	El-Seiouf	0.503	0.322	4.291	8.53	13.33	0.64
22	Mohamed Naguib	0.503	0.299	4.348	8.64	14.54	0.59
23	Sedi Beshr	0.503	0.33	6.336	12.60	19.20	0.66
24	Gehan	0.503	0.323	6.519	12.96	20.18	0.64
25	Abd El-Razek	0.503	0.318	6.618	13.16	20.81	0.63
26	El-Academia	0.503	0.325	6.992	13.90	21.51	0.65
27	El-Sharif	0.503	0.324	6.393	12.71	19.73	0.64
28	El-Asafra	0.503	0.324	5.374	10.68	16.59	0.64
29	Sedi Kamal	0.503	0.291	4.974	9.89	17.09	0.58
30	Hosni	0.503	0.278	3.907	7.77	14.05	0.55
31	El-Mandara Gamee	0.503	0.227	3.537	7.03	15.58	0.45

Conclusion and Recommendations

Using the powerful GIS network analysis functions, three indices were developed to assist in the assessment of a bus stop location, based on the interaction between the bus stop location and the actual pedestrian road network surrounding it:

- The Ideal Stop-Accessibility Index (ISAI) evaluates the accessibility of bus stops through the surrounding pedestrian road network and can be used to assess and compare different stop locations from a spatial perspective.
- The Actual Stop-Accessibility Index (ASAI) gives a more accurate measurement of the pedestrian road network density around a bus stop.
- The Stop Coverage Ratio Index (SCRI) evaluates the percentage of actual access coverage of a bus stop with respect to its ideal access coverage.

Further, a bus stop is considered more accessible if the pedestrian road network surrounding it is more dense and has a higher ISAI value. In addition, the SCRI represents the ratio of the actual access coverage to the ideal access coverage of a bus stop. While the ASAI value estimates the actual pedestrian road network density within the access threshold from a bus stop, it may be misleading if used to compare the accessibility of different bus stop locations.

It is recommended that an extensive detailed analysis be performed for the developed indices in order to study how the geometry of the surrounding pedestrian road network could affect the values of the indices. This study could help transit planners in evaluating the locations of transit stops on a spatial basis rather than just spacing and circular access coverage, in order to select the most suitable places for locating new bus stops or for reallocating currently existing bus stops.

Potential areas for continuing the present study include the following:

1. Accessibility and linkage with potential users of the bus stop and using information on population densities for different urban districts and transforming it in terms of persons per km; hence, an extra important attribute for the polyline layer can be added other than the travel distance or time. This can be viewed as a three dimensional coordinate where the third dimension represents the population. Moreover, the effect of time on the demand variability also can be introduced through the use of appropriate data in morning/evening peak periods or even on a seasonal basis.
2. Distribution of potential users within the circular buffer zone–for example, by creating various circles radiating from the location of the bus stop with

50m increments and locating the share of the total road network length in km within each.

References

Ammons, D. N. 2001. *Municipal Benchmarks: Assessing Local Performance and Establishing Community Standards, Second Edition*. Sage, Thousand Oaks, CA.

Central Ohio Transit Authority. 1999. Planning and development guidelines for public transit. COTA, Columbus, OH.

Foda, M. A., and Osman, A. O. 2006. GIS tools to analyze the public bus transit service network, case study: The City of Alexandria. 16th International Conference on Computer Theory and Applications (ICCTA), Alexandria, Egypt, 5-7 September 2006.

Foda, M. A., and Osman, A. O. 2008. A GIS approach to study the bus transit network accessibility, case study: The City of Alexandria. *Journal of Arab Academy for Science, Technology and Maritime Transport* 34(65): 32-39.

Holtzclaw, J. 1994. Using Residential Patterns and Transit to Decrease Auto Dependence and Costs. National Resources Defence Council for California Home Energy Rating Systems, June.

Levinson, H. S. 1992. Urban mass transit systems. In Edwards, J. D. (ed.), *Transportation Planning Handbook*. Prentice Hall, New Jersey.

Murray, A. T., and Wu, X. 2003. Accessibility tradeoffs in public transit planning. *Journal of Geographical Systems* 5(1): 93-107.

Murray et al. 1998. Public transportation access. *Transportation Research Part D* 3(5): 319-328.

Salvo, G., and Sabatini, S. 2005. A GIS approach to evaluate bus stop accessibility. *Proceedings* of the 16th Mini-Euro conference and 10th meeting of EWGT, Poznan.

TCRP. 1996. *Transit Cooperative Research Program Report 19, Guidelines for the Location and Design of Bus Stops*. Transportation Research Board. National Academy Press. Washington, DC.

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Ingress/Egress Incidents Involving Wheelchair Users in a Fixed-Route Public Transit Environment

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Abstract

The objectives of this study were to characterize the ingress and egress activities of wheeled mobility device (WhMD) passengers using fixed-route large, accessible transit vehicles (LATVs), and to examine factors associated with incidents occurring on ramps. A retrospective review of public transit video surveillance footage of WhMD-seated passengers accessing fixed-route LATVs was conducted. Ingress and egress activities were characterized based on travel conditions and characteristics of the WhMD and LATV ramp. Incidents were identified based on predetermined criteria, and chi-square analysis was performed to identify WhMD and/or ingress/egress characteristics associated with incidents. Video records of 250 WhMD trips were analyzed. A total of 39 incidents occurred during ingress and 12 incidents occurred during egress. Results indicated that the frequency of incidents was significantly greater for scooter users and passengers who ascended the ramp using a rear-facing WhMD orientation. Narrow LATV ramp width was associated with the greatest number of incidents, followed by problems related to LATV door width and steep ramp slope.

Introduction

Fixed-route, large, accessible transit vehicles (LATVs) provide the opportunity for wheeled mobility device (WhMDs) users to independently participate in everyday activities, including traveling to and from employment, shopping, healthcare, and social and recreational activities. However, 20 years after the passage of the Americans With Disabilities Act (ADA), WhMD users still encounter obstacles to safe and accessible use of fixed-route LATVs (Buning et al. 2007; Fitzgerald et al. 2007).

In general, LATVs represent a relatively safe mode of travel (Shaw and Gillispie 2003). This is due in large part to overall vehicle mass and the slow speed of LATV travel associated with intercity routes. Despite this relatively safe environment, the U.S. National Highway Transportation Safety Administration (NHTSA) reported that 35 percent of injuries and deaths that occurred between 1990-1995 involving wheelchair users were due to improper or no securement of the wheelchair, with 17 percent of these incidents occurring in LATVs. Additionally, 25 percent of overall injuries or deaths involving wheelchair users were attributed to either lift malfunctions or falling on/off a ramp during ingress/egress (National Highway Traffic Safety Administration 1997).

The authors previously conducted a retrospective records review of six years of WhMD-related adverse incident reports maintained by a metropolitan transit agency (Frost and Bertocci 2010). Findings revealed that the majority of adverse incidents occurred when the LATV was stopped during ingress/egress (42.6%). Furthermore, injuries were more likely to result from incident scenarios involving a combination of the WhMD tipping and the passenger falling from the WhMD (61.8%). These incident scenarios were 1.8 times more likely to happen during ingress/egress than while at the securement station (either during transit or when LATV was stopped).

Ingress and egress involve many factors that may contribute directly or indirectly to an adverse incident. These factors include the WhMD, the WhMD-seated passenger's navigational skills, the built environment (e.g., surface terrain, sidewalk height, lamp posts), and adaptive transportation equipment (vehicle ramp). This study sought to provide an in-depth review of video surveillance footage of WhMD ingress and egress activities on LATVs in order to characterize aspects of the ingress and egress process, and to provide a more comprehensive understanding of factors associated with adverse incidents during ingress and egress. Characteristics of the ingress/egress environment, WhMDs, and ingress/egress scenarios are described and quantified, and adverse incidents are summarized and examined to identify factors associated with unsuccessful outcomes.

Research Methods

Approval to conduct this study was obtained from the University of Louisville Institutional Review Board (IRB No. 170.07)

Video Recordings

Digital video surveillance footage of WhMD activities on LATVs was obtained from a metropolitan transit agency located in the southeastern region of the U.S. during the 21-month period of June 2007 through February 2009. Signs were posted in each camera-equipped LATV notifying passengers that activities within the bus were being monitored and recorded for public safety.

During the period of the study, the transit agency operated 57 LATVs that were equipped with the GE® MobileView III Video Surveillance System® (GE Security, Bradenton, FL). This system records digital video images at a rate of 30 frames/second with up to 640x480 pixel resolution. Each video surveillance system consists of 4-5 permanently-mounted video cameras. One camera is directed at the front door to capture all WhMD ingress and egress events. This camera view includes the front door, access ramp, and approximately one-meter distance beyond the LATV door (Figure 1).

Figure 1. Output from GE® Security's WaveReader Software

Video footage was logged onto a 120 GB digital video recorder (DVR) that recorded a continuous loop for 30 hours. DVRs are interchangeable storage disks that can be removed from the LATV and inserted into a docking station that allows viewing and recording of video and audio footage on a connected computer using GE® WaveReader software. Randomly-selected DVRs were reviewed by the researchers 2–3 times per month throughout the two-year study period. All ingress and egress events involving WhMD-seated passengers were recorded and analyzed using GE® WaveReader viewing software.

Data Collection and Analysis

Ingress and egress events were recorded per trip or per WhMD-seated passenger. Thus, a video record contained one ingress and one egress event. Ingress and egress events were abstracted and recorded as categorical and continuous data using a FileMaker Pro 8 database (Ver. 2 for Mac OS X). Ingress was defined as starting when the front wheels of the WhMD contacted the LATV ramp, and ending when the rear wheels of the WhMD contacted the vehicle floor and were off the ramp. Egress was defined as starting when the front wheels of the WhMD contacted the LATV ramp and ending when the rear wheels of the WhMD left the ramp and contacted outside surface terrain.

All ingress and egress events were characterized based on three categories of data: general travel data, WhMD data, and ingress/egress data. These variables are defined in Table 1. Additionally, the LATV ramp (Lift U® Division, Hogan Manufacturing; Escalon, CA) is mechanically interlocked with the kneeling suspension of the vehicle, preventing ramp deployment without vehicle kneeling. Thus, each ramp deployment indicates that the LATV was kneeled, although the extent of kneeling could not be determined based on video review.

A *difficulty* was defined as either an ingress or egress event involving two or more maneuvering attempts by the WhMD-seated passenger or a minor impact with an interior or exterior LATV component(s) while the WhMD was in contact with the ramp. A minor impact was defined as an impact that did not cause the WhMD to come to a stop. An *incident* was defined as an event during which the WhMD tipped and/or the passenger fell from the WhMD, or the WhMD and/or passenger had a major impact with an interior or exterior LATV component while the WhMD was in contact with ramp. A major impact was defined as an impact that caused the WhMD to stop moving in its predetermined direction.

Descriptive statistics were used to present summary information describing general travel data and WhMD and ingress/egress characteristics. Independent samples chi-square analysis was performed to examine difficulties and incidents based on WhMD type, weather condition, whether or not bags/items were carried by the passenger or attached to the WhMD, ramp extension level, surface terrain, and WhMD orientation on the ramp. All statistical analysis was conducted using PASW (formerly SPSS) statistical software (Ver. 17 for Mac OS X).

Table 1. Variable Definitions

Variable	**Definition**
WhMD Type	Manual wheelchair, power wheelchair, scooter.
Time of Travel	Daytime (between 6:00am – 6:00pm) or Evening/Night (> 6:00pm and < 6:00am).
Weather Condition	Sun, overcast, rain, snow, cannot determine.
Ingress Time of Process	Period of time beginning when front wheels of WhMD contacted ramp and ending when rear wheels contacted vehicle floor and were off ramp.
Egress Time of Process	Period of time beginning when front wheels of wheelchair contacted ramp and ending when rear wheels contacted outside terrain and were off ramp.
Ramp Extension Level	Street, sidewalk
Surface Terrain	Smooth concrete/pavement, uneven concrete/ pavement, dirt/ grass, gravel.
WhMD Orientation	Forward-facing or rear-facing.
Assistance Required	Whether or not passenger used assistance to board/exit LATV.
Assistance Provided by Whom	LATV operator, personal assistant, other passenger.
Difficulty	Events involving 2 or more maneuvering attempts by passenger and/or a minor impact (bump) with LATV component(s) that did not cause WhMD to come to a stop.
Incident	Events during which WhMD tipped and/or passenger fell from WhMD, WhMD and/or passenger impacted LATV door/frame or other object while WhMD was in contact with ramp and such impact caused the WhMD to come to a stop, or a WhMD wheelchair component broke/dropped.

Results

The participating metropolitan transit agency serves a population of approximately 1.3 million and operates 240 large, accessible, public transit vehicles. The transit agency estimates approximately 250 WhMD boardings per week, averaging 10,400-13,000 annual WhMD trips. During the 21-month period (June 2007 – February 2009), video recordings of 250 WhMD trips were reviewed and abstracted (each WhMD trip consisted of one ingress event and one egress event). Because DVRs record data over a 30-hour continuous loop, there were instances in which a DVR contained a video record of an ingress event but not the corresponding egress event, or partial video of an ingress or egress event. This was the case for nine WhMD trips. In one instance, partial video of the ingress process was missing, and in eight cases, some or all video of the egress process was missing. As a result, sample size variations exist among the data and figures presented.

The geographic region sits on a wide, flat flood plane with gently rolling hills. The mean annual temperature is 56.9 °F (13 °C); with annual temperatures ranging from an average low of 47.9 °F (8.3 °C) to an average high of 66.0 °F (18.9 °C) (NOAA 2009). The average monthly precipitation is 3.7 inches (9.4 cm) (NOAA 2009). Consistent with the moderate climate, weather conditions during the majority of WhMD trips were fair/dry (n=237; 94.8%). Rain/wet weather was only observed during 13 WhMD trips (n=13; 5.2%). The greatest percentages of trips were observed during summer and fall (n=104; 41.6% and n=74; 29.6%, respectively), followed by trips during winter and spring (n=53;21.2% and n=19; 7.6%, respectively).

The number of male passengers observed traveling was approximately 10 percent greater (n=138; 55.2%) than females (n=112; 44.8%). However, more female passengers (n=25; 61.0%) were observed traveling during evening/overnight hours (6:00 pm to 6:00 am) compared to their male counterparts (n=16; 41.6%).

WhMD Data

The majority of observed WhMD trips were taken by passengers who used a power wheelchair (n=168; 67.2%). Passengers who used a manual wheelchair (n=64; 25.6%) were observed less frequently, followed by scooter users (n=18; 7.2%) (Figure 2). Nine passengers used and/or were equipped with an additional form of assistive technology during travel; three WhMD passengers carried a cane, three traveled with service dogs, two had augmentative communication devices mounted to the WhMD, and another passenger had a tray mounted to his WhMD.

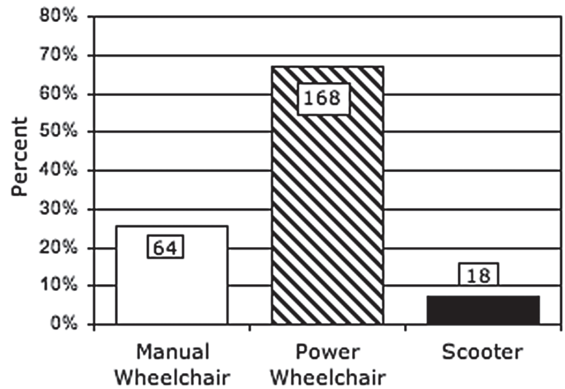

Figure 2. Distribution of WhMDs Observed During All Ingress/Egress Events (n=250)

Seventy-five percent of all passengers either had a backpack/bag attached to their WhMD or carried a package/item by hand or other means. In the majority of cases (n=111; 76.0%), a backpack/bag was attached to the WhMD. Fewer passengers carried a package/item (n=97; 38.8%) using their hand or arm or by placing the package/item in their lap or on their footrest.

Ingress Data

Ingress Events—Ramp Extension Level, Surface Terrain, WhMD Orientation and Assistance Provided. Frequency and percentage data for all ingress events are provided in Table 2. During ingress, the ramp was most often extended to sidewalk level (n=228; 91.2%). Ingress from street level occurred far less frequently (n=20; 8.0%). In two cases passengers ambulated into the LATV using the ramp; one passenger carried a manual wheelchair into the LATV, and another passenger ambulated while using his/her manual wheelchair as a walker. The outside surface terrain was typically smooth concrete/pavement (n=204; 81.6%). A smaller but equal number of passengers had to traverse uneven concrete/pavement (n=22; 8.8%) or dirt/grass (n=22; 8.8%) prior to contact with the ramp. In two cases (0.8%), the surface terrain could not be reliably determined.

Table 2. Percentage and Frequency Data for Ingress and Egress Variables

	Ingress (n=250)	Egress (n=244)
Ramp Extension Level		
Sidewalk	91.2% (228)	79.1% (193)
Street	8.0% (20)	18.9% (46)
Could not be determined	--	1.2% (3)
Other/not applicable	0.1% (2)	0.8% (2)
Surface Terrain		
Smooth concrete/pavement	81.6% (204)	78.8% (197)
Uneven concrete/pavement	8.8% (22)	12.3% (30)
Dirt/grass	8.8% (22)	5.7% (14)
Could not be determined	0.8% (2)	1.2% (3)
WhMD Orientation on Ramp		
Forward-facing	72.0%	99.2% (242)
Rear-facing	27.2% (68)	0.0% (0)
Not applicable (ambulated)	0.8% (2)	0.4% (2)
Assistance Provided by Whom		
No assistance	87.2% (218)	81.9% (199)
Bus operator	7.2% (18)	14.0% (34)
Personal assistant/Traveling companion	2.9% (7)	2.9% (7)
Other passenger	1.2% (3)	1.2% (3)

The majority of passengers (n=180; 72.0%) ascended the ramp using a forward-facing WhMD orientation (Figure 3). These passengers were predominantly power wheelchair users (n=135; 75.0%), followed by manual wheelchair users (n=35; 19.4%) and scooter users (n=10; 5.6%). Passengers who ascended the ramp using a rear-facing WhMD orientation (n=68; 27.2%) also were more likely to be power wheelchair users (n=33; 48.5%), followed closely by manual wheelchair users (n=27; 39.7%), then scooter users (n=8; 11.8%). Most passengers boarded the bus without assistance (n=217; 87.1%). When assistance was provided during ingress, it was most often provided by the LATV operator (n=18; 7.2%) or a personal assistant/traveling companion (n=10; 4.0%). In a few cases, assistance was provided by another passenger (n=3; 1.2%).

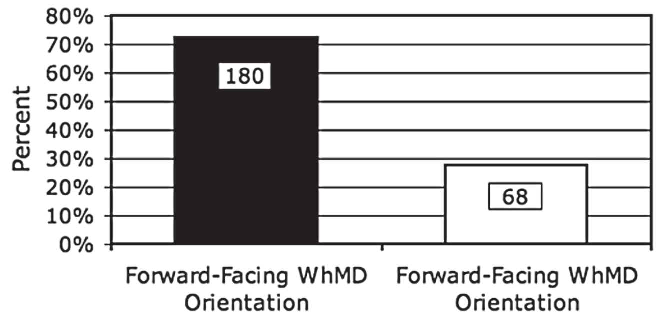

Figure 3. WhMD Orientation on Ramp During Ingress (n=248)

Ingress Events—Overview of Incidents and Difficulties, Time to Complete Ingress. Video recordings were examined to determine whether or not a difficulty or incident (as defined in Table 1) occurred during ingress. Of the 250 WhMD trips reviewed, one ingress event (0.4%) involved an incident and 38 ingress events (15.3%) were classified as involving difficulty, totaling 39 (15.6%) ingress incidents/difficulties. The single incident occurred during early afternoon, in light rain, and involved a male passenger who used a 3-wheeled scooter. The LATV was at a designated bus stop and the ramp was extended to a smooth concrete sidewalk. The scooter user approached the ramp using a forward-facing orientation and ascended the ramp to the point that the forward-most wheel crossed the interior vehicle threshold at the top of the ramp. Forward motion of the WhMD then stopped, and the passenger appeared to shift his body position slightly forward while toggling the controller with his right hand. The scooter and passenger then began to descend the ramp rearward. As the rear wheels contacted the exterior rubber threshold at the base of the ramp, the front wheel of the scooter began to rise upward off of the ramp surface. The scooter rotated rearward and toward the front of the vehicle, then fell to the sidewalk on its right side. The passenger fell rearward, landing on his buttocks and posterior torso (Figure 4). The passenger did not appear to be wearing a postural support lap belt. The passenger stated he was not injured and declined the LATV operator's request to call an emergency medical service.

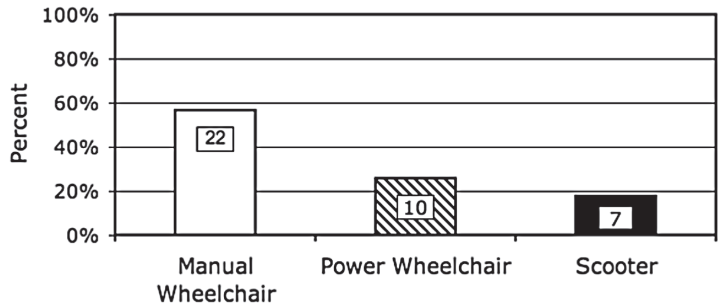

Figure 4. Distribution of WhMDs Involved in Incidents/Difficulties During Ingress (n=39)

Video review of the 38 ingress events categorized as *difficult* revealed many instances of WhMD passengers encountering apparent difficulty due to the narrow width of the ramp. Seventeen videos revealed WhMDs contacting ramp edge barriers such that the impact required them to descend the ramp, in full or in part, and re-align their WhMD before ascending successfully. In 6 of these 17 videos, the WhMD required three or more attempts before successfully boarding the LATV. Nine videos showed WhMD passengers encountering difficulty related to the narrow width of the LATV door, as evidenced by impacting the LATV door. In two videos, WhMD passengers impacted both the LATV door and ramp edge barrier(s). Each instance required the passenger to descend the ramp and re-align the WhMD before ascending and entering the LATV successfully. Seven videos revealed apparent difficulties related to the slope of the ramp. These videos displayed a similar scenario: as the WhMD approached the top of the ramp, forward motion slowed or stopped, giving the appearance that the WhMD did not have enough power to overcome either the ramp slope or interior vehicle threshold; the passenger descended rearward down the ramp before attempting to ascend again. Two manual wheelchairs users and one power wheelchair user ascended almost to the top of the ramp, then reached out and grabbed a door handrail to pull themselves up the remainder of the ramp and into the LATV. In another instance, the LATV operator re-kneeled the bus and re-deployed the ramp before a scooter user was able to successfully ascend the ramp. Three videos indicated WhMD passengers had difficulties crossing the exterior ramp threshold, and in three videos the surface terrain adjacent to the ramp appeared to be the primary cause of WhMD passenger difficulties. In the first difficulty related to surface terrain, the left edge of the ramp was resting on the curb cut and the right edge of the ramp was resting on the sidewalk, creating a cross slope. In the other two difficulties, the ramp was extended to a parcel of grass between the street and sidewalk, and the apparent uneven terrain required the WhMD passenger to make multiple maneuvers prior to successfully crossing the exterior ramp threshold. In one of these situations, another passenger assisted the WhMD passenger by pushing the WhMD.

Mean time to complete ingress for events that did not involve an incident or difficulty was 5.28 seconds (±7.43 seconds). For the subset of 38 ingress events that involved difficulty, mean time to complete ingress was 19.58 seconds (±16.54). Only one ingress event involved an incident, and the time to complete ingress during this event was 2 minutes, 31 seconds.

Ingress Incidents & Difficulties—Descriptive Statistics and Chi Square Analysis. Because only one event was categorized as an incident, it was combined with the 38 events categorized as difficulties, resulting in 39 ingress incidents/difficulties that were analyzed in further detail. Incidents/difficulties occurred in 15.6 percent of total ingress events.

The majority of ingress incidents/difficulties occurred during daytime hours (n=34; 87.2%). Passengers who experienced an incident/difficulty were predominantly power wheelchair users (n=22; 56.4%), followed by manual wheelchair (n=10; 25.6%) and scooter (n=7; 17.9%) users (Figure 5). Although scooter users represented a small percentage (7.2%) of all WhMD passengers, more than a third of scooter users (38.89%) experienced an incident/difficulty during ingress. Similarly, a smaller percentage of WhMD passengers ascended the ramp using a rear-facing orientation (30.8%/), yet more than two thirds of these passengers experienced an incident/difficulty (n=27; 69.2%). Over half of the WhMD passengers who experienced an incident/difficulty carried a bag or item (n=22; 56.4%), and many had a backpack or bag attached to the WhMD (n=16; 41.0%). During most ingress incidents/difficulties, the ramp was extended to sidewalk level (n=36; 92.3%), and the surface terrain leading to the ramp was smooth concrete or pavement (n=31; 79.5%). Weather did not appear to be a factor associated with incidents/difficulties. Weather conditions were fair/dry in all but two incidents/difficulties (n=37; 94.9%). Rain was present during one difficulty and during the single incident.

Figure 5. Video Footage of Ingress Incident

Analysis to compare successful ingress events to those that resulted in an incident or difficulty showed mixed results. Chi-square analysis confirmed the observation that the number of incidents/difficulties involving scooter users was significantly greater than expected ($\chi^2(1) = 8.1$, $p=0.017$). Analysis also revealed that significantly more incidents/difficulties occurred when passengers used a rear-facing WhMD orientation during ingress ($\chi^2(1) = 40.36$, $p<0.001$) rather than forward-facing WhMD orientation. Fewer incidents/difficulties than were expected occurred when a backpack or bag was attached to the WhMD, and this result also was significant ($\chi^2(1) = 5.161$, $p=0.023$). There was no significant difference between successful ingress events and incidents/difficulties during ingress based on ramp extension level, surface terrain, weather condition, or whether or not bags/items were carried by the passenger.

Egress Data

As mentioned previously, the continuous loop video recording system yielded partial video records for some WhMD trips. During three WhMD trips, partial video of the egress process was recorded, and there was no video depicting egress activity for six WhMD trips. As a result, sample size variations exist among the data and figures presented. Frequency and percentage data for all egress events is provided in Table 2.

Egress Events—Ramp Extension Level, Surface Terrain, WhMD Orientation, and Assistance Provided. During egress, the ramp was extended to the sidewalk level (n=193; 79.1%) more often than street level (n=46; 18.9%). In three events ramp extension level could not be determined, and in two events (0.8%) it was categorized as "other." In one of these events, the ramp was deployed to a grass-covered slope. In the other event, the LATV was not aligned parallel to the sidewalk curb cut; the right edge of the deployed ramp rested on the street, and the left edge rested on the curb cut several inches above street level.

Surface terrain beyond the ramp was typically smooth concrete/pavement (n=197; 80.7%), followed by uneven concrete/pavement (n=30; 12.3%) then dirt/grass (n=14; 5.7%). In three cases (1.2%), the surface terrain could not be determined with certainty. Similar to ingress, most passengers exited the LATV without assistance (n=199; 81.9%). When assistance was provided during egress, it was most often provided by the LATV operator (n=34; 14.0%). In several cases, assistance was provided by a personal assistant/traveling companion (n=7; 2.9%) and in a few cases by another passenger (n=3; 1.2%).

Egress Events—Overview of Incidents and Difficulties, Time to Complete Ingress. One incident and 11 difficulties were observed during egress. The single incident during egress occurred during early afternoon on a fair/dry day, and involved a female passenger who used a power wheelchair. Two canvas bags were looped around and behind the wheelchair headrest, and a purse was looped around the left armrest. The LATV stopped parallel to the designated bus stop and the ramp was deployed onto a smooth concrete sidewalk. The passenger's WhMD appeared to be properly aligned within the ramp edge barriers as the passenger approached the top of the ramp. However, as the front wheels crossed the interior vehicle threshold, the right front wheel began turning toward the right ramp edge barrier, and the rear casters began moving toward the left LATV doorframe. The passenger's forward motion continued, and the front right wheel drove over the ramp edge barrier. The WhMD pitched forward causing one rear caster to rise off the ramp surface (Figure 6). A passerby and the LATV operator provided immediate assistance. The passerby lifted the front of the WhMD and placed the front wheels back onto the ramp surface while the operator tilted the WhMD rearward. The LATV operator provided the passenger with verbal guidance to re-align her WhMD and assisted her down the ramp by holding the WhMD seatback canes until the passenger successfully exited the ramp. The WhMD-seated passenger was uninjured and remained seated in her WhMD throughout the incident.

Figure 6. Video Footage of Egress Incident

The majority of difficulties encountered by WhMD passengers during egress appeared to be related to issues involving a combination of ramp slope and narrow ramp width. Six videos revealed WhMD passengers impacting the ramp edge barriers; requiring them to reverse direction and/or re-align their wheels in order to descend the ramp successfully. Three events involved the front wheel of a power wheelchair becoming wedged in the gap between the LATV door and the ramp edge barrier (Figure 7). In four videos, the passenger turned the WhMD at the base of the ramp before the rear wheels cleared the ramp; in one of these videos, the LATV operator assisting the WhMD passenger turned the WhMD too early. In each of these four situations, the WhMD tilted laterally as a rear wheel drove over the ramp edge barrier. Only one of these difficulties appeared related to the surface terrain beyond the ramp.

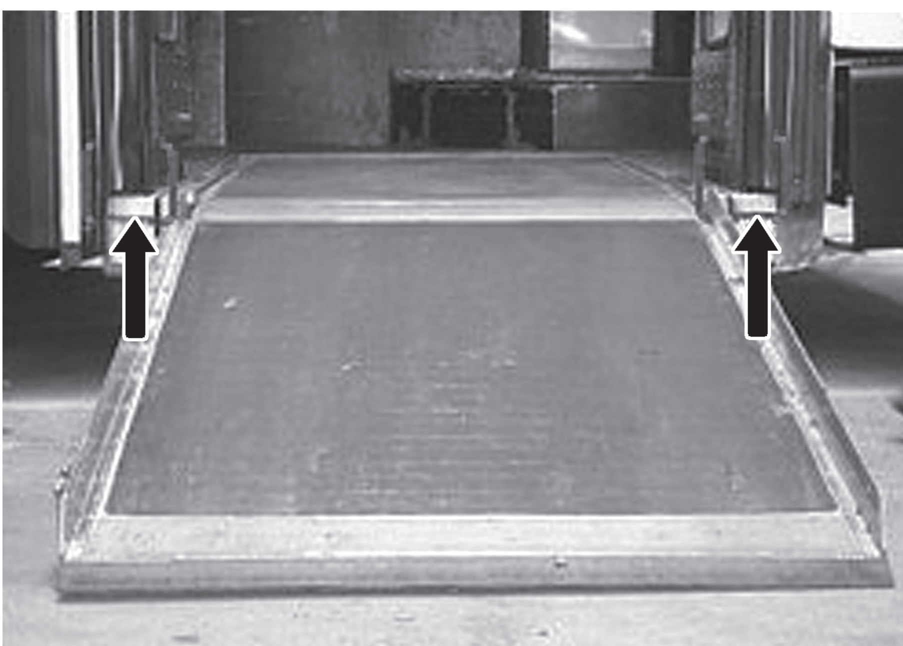

Figure 7. Horizontal Gap between LATV Door and Ramp Edge Barrier

Mean time to complete the egress process for events that did not involve an incident or difficulty was 4.21 seconds (± 3.12). For the subset of 11 difficult events, mean egress time was 8.36 seconds (± 6.53). The time required to complete egress for the one incident was 33 seconds.

Egress Incidents & Difficulties—Descriptive Statistics and Chi Square Analysis. For purposes of this analysis, the single egress incident was combined with egress events categorized as difficulties, resulting in 12 ingress incidents/difficulties that were analyzed in further detail. Incidents/difficulties occurred in 4.9 percent of the egress events.

The majority of egress incidents/difficulties occurred during daytime hours (n=11; 91.7%). Passengers who experienced an incident/difficulty were predominantly power wheelchair users (n=10; 83.3%); only one manual wheelchair (8.3%) and one scooter user (8.3%) were involved in an incident/difficulty (Figure 8). When normalized by WhMD type, power wheelchair users were found to have the greatest incidence (5.9%) of difficulty during egress. Fifty-percent (n=6) of WhMD users carried a bag or item, and most had a backpack or bag attached to their WhMD (n=8; 66.7%). Weather conditions were fair/dry in all but two incidents/difficulties (n=10; 83.3%), and rain was present during one egress event.

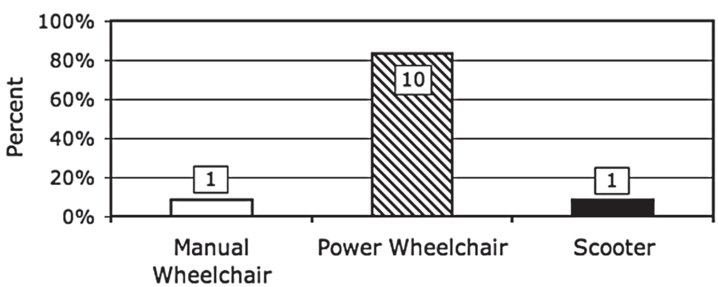

Figure 8. Distribution of WhMDs Involved in Incidents/Difficulties during Egress (n=12)

During most egress incidents/difficulties the ramp was extended to sidewalk level (n=8; 66.7%), and the surface terrain beyond the ramp was smooth concrete or pavement (n=7; 58.3%). Uneven concrete or pavement was present during three incidents/difficulties (25.0%), dirt or grass was observed in one instance (8.3%), and the surface terrain could not be reliably determined in one instance (8.3%). Chi-square analysis indicated no significant difference between successful egress events and those that resulted in an incident/difficulty based on WhMD type, weather condition, ramp extension level, surface terrain or whether or not bags/items were carried by the passenger or attached to the WhMD.

Discussion

To our knowledge, this is the first observational study of WhMD activities on LATVs based on in-vehicle video footage of actual events. Our objective was to characterize ingress and egress events to provide a better understanding of difficulties and incidents experienced by WhMD-seated passengers in the LATV environment.

Our findings indicate that LATV ingress and egress present a barrier to independent WhMD transport. WhMD users frequently have difficulty when attempting to board or exit an LATV. Difficulties and incidents were three times more likely to occur during ingress than egress. They were also more likely to occur during ingress when the WhMD passenger ascended the ramp using a rear-facing WhMD orientation, or if the passenger used a scooter. This particular transit agency recommends that WhMD-seated passengers ascend the ramp in a rear-facing orientation during ingress. A rear-facing orientation helps maintain the combined center of gravity of the WhMD and passenger toward the uphill portion of the ramp and closer to the LATV, increasing stability and reducing the risk of tipping. However, traversing rearward up a relatively narrow, sloped surface requires significant navigational skill, and is not a viable option for some WhMD users. Our observations suggest that visibility issues related to neck range of motion and/or limited visibility of the front casters associated with being overweight or obese may contribute to difficulties when aligning the WhMD at the base of the ramp and/or maintaining proper alignment while ascending/descending.

Narrow ramp width appeared to be associated with the greatest number of difficulties/incidents during both ingress and egress. During ingress, 17 difficulties were associated with an inability to maintain WhMD alignment within the ramp; and during egress, 6 difficulties were associated with issues related to narrow ramp width. The majority of difficulties involved the wheels of the WhMD impacting the ramp edge barrier(s); requiring the passenger to partially or completely descend/ascend the ramp to re-align their WhMD before proceeding with ingress or egress. During ingress difficulties, most WhMD passengers were able to successfully ascend the ramp on their second try, but in six instances, WhMD passengers required three or more tries before successfully entering the LATV. Additionally, physical and/or verbal assistance by the LATV operator was necessary in six egress cases and seven ingress cases. The transit agency's LATVs are equipped with fold-out Lift-U® ramps manufactured by Hogan Manufacturing, Inc. (Escalon, CA). The ramp platform surface width (between edge barriers) on model 2008 and 2009

LATVs was measured by the researchers at 76.2 cm (30 in). Although compliant with ADA requirements, this ramp width allows for less than 2 cm of maneuvering space on either side of a "common wheelchair" (76.2 cm width x 121.9 cm length, or 30 in width x 48 in length) as defined by the ADA. Bariatric or "over-sized" wheelchairs, which are becoming more common (LaPlante 2003), may exceed the specified "common wheelchair" dimensions, resulting in even less maneuvering clearance when attempting to use the ramp. We observed three passengers using bariatric wheelchairs in this study. Regardless of WhMD overall dimensions, video observations of actual ingress and egress activities indicate that navigation up or down an inclined ramp, with little clearance on either side of the WhMD, can be very challenging. These observations indicate a need for additional study regarding the effect of ramp width on successful ingress and egress given variations in WhMD passenger navigational skills and WhMD dimensions. We also recommend that ramp and LATV manufacturers further explore the need and potential design implications of wider access ramps.

The narrow LATV front entry door width was also associated with difficulties. Video observations showed nine instances in which the WhMD either struck one or both of the folding entry doors or a WhMD armrest was retained in a handrail mounted to the door during ingress. In these cases, passengers had to partially descend the ramp and re-align the WhMD before successfully navigating through the LATV door. No difficulties were observed related to door width during egress; however, the authors have previously reported instances where the WhMD struck the door during egress (Frost and Bertocci 2010). These findings suggest that LATV vehicle manufacturers would be warranted in examining the cost-benefit of designing a wider front entry door or collapsing handrails. During egress, the presence of a gap between the ramp edge barriers and LATV door was also associated with challenges. This gap, measuring 5.08 cm (2 in) on each side, enables the ramp to fold into the floor of the LATV. It was found that slight misalignment of the WhMD with the ramp during egress contributed to wheels becoming lodged in this gap, preventing WhMD passengers from descending the ramp. Attention to such design details at the interface between the ramp and vehicle is critical to enhancing accessibility and safety for WhMD passengers traveling in LATVs. Difficulties related to LATV door and ramp width emphasize the need for LATV vehicle and ramp manufacturers to work together to identify solutions to improve WhMD passenger safety.

Ramp slope appeared to be associated with 7 of 39 difficulties/incidents during ingress and a contributing factor in 7 of 12 difficulties/incidents during egress. Interestingly, in each of these cases the ramp was deployed to the sidewalk, not street level. We had expected to observe more difficulties related to ramp slope when the ramp was extended to street level. Only one difficulty involving ramp slope occurred when the ramp was extended to street level. In this case, a female passenger using a scooter was not able to successfully ascend the ramp after two attempts, requiring the LATV operator re-kneel the LATV and redeploy the ramp prior to successful ingress. The ADA Accessibility Specifications for Transportation Vehicles (U.S. Architectural and Transportation Barriers Compliance Board [Access Board] 1990) state that ramps shall have the least slope practicable. However, as currently written, it is virtually impossible to assure compliance with these ramp slope requirements (Table 3), given variations in the environment (e.g., curb height), road surface terrain, and the extent of vehicle kneeling implemented by the LATV operator.

Table 3. ADA Ramp Slope Specifications for Buses and Vans*

Ramp Deployment Level	Maximum Slope
Ground [street] level	1:4
Vehicle floor <3 in above 6-inch curb	1:4
Vehicle floor >3 in and <6 in above 6-inch curb	1:6
Vehicle floor >6 in and <9 in above 6-inch curb	1:8
Vehicle floor >9 in above 6-inch curb	1:12

**ADA Accessibility Specifications for Transportation Vehicles, Subpart B-Buses, Vans and Systems*

Since no known data have been published describing actual LATV ramp slopes in the built environment, we measured ramp angles on the same LATVs used in this study during full kneeling and minimal kneeling conditions when the ramp was extended both to street and sidewalk level. Ramp angles measured with the ramp deployed to the street ranged from 1:4 (fully kneeled) to 1:3.2 (minimally kneeled). Ramp angles measured with the ramp deployed to the sidewalk curb ranged from 1:8.1 (fully kneeled) to 1:5.7. Given the measured heights from the vehicle floor to the ground, these findings indicate non-compliance with ADA ramp slope requirements for minimally kneeled conditions (Table 4). These findings further highlight the need for educating LATV operators on the impact that vehicle kneeling can have on ramp slope, and subsequently, WhMD passenger access and safety. This exercise also illustrates that the current ADA ramp slope specifications, as written, are impractical to apply in the highly variable built environment.

Table 4. Actual LATV Ramp Angles

LATV Height Based on Kneel Condition (measured from ground surface to LATV floor)	Sidewalk Level (15.24 cm / 6 in curb) (degrees)	Street Level (degrees)
Fully Kneeled (27.94 cm/11.0 in)	7	14
Minimally Kneeled (35.56 cm/14.0 in)	10*	17*

**Angles exceed ADA maximum ramp slope specifications (49 CFR Part 38). When height of vehicle floor is >15.24 cm (6 in) and ≤22.86 cm (9 in) above a 15.24 cm (6 in) curb, a maximum slope of 1:8 (7 degrees) is permitted; when ramp is deployed to ground level, slope shall not exceed a maximum slope of 1:4 (14 degrees).*

In late 2008, the U.S. Architectural and Transportation Barriers Compliance Board (Access Board) published its second draft of proposed revisions to the ADA Accessibility Guidelines for Buses and Vans for public comment. The proposed revision regarding ramp slopes reads: "Ramps and bridgeplates shall have slopes not steeper than 1:6 (9.5 degrees) when deployed to boarding and alighting areas without station platforms and to the roadway" (*www.access-board.gov/news/vehicle-draft2.htm*) (U.S. Architectural and Transportation Barriers Compliance Board [Access Board]). If adopted, the maximum ramp slope permitted when the ramp is deployed to ground (street) level will be reduced from 1:4 to 1:6. Additionally, the proposed revision eliminates varying slope specifications based on the vertical distance between the curb and vehicle floor, taking into account the transportation industry's move towards low floor LATVs. It was not possible to assess actual ramp slopes associated with ingress/egress events in our study. Thus, we cannot know whether or not the observed difficulties related to ramp slope could have been prevented if the Access Board's proposed revisions were in effect.

Uneven exterior ramp thresholds were also thought to be associated with difficulties during ingress. Exterior ramp thresholds were constructed of beveled rubber and met the ADA specification of a slope of 1:2. However, as shown in Figure 9, threshold warping from repeated usage and weathering could result in vertical gaps between the environmental surface terrain and exterior threshold. Additionally, uneven surface terrain and slight ramp surface cross slopes could contribute to vertical gaps at this interface. Some WhMD passengers had apparent difficulties navigating their WhMD over this vertical threshold gap. Such barriers to ingress could be addressed through the improved design of exterior thresholds providing a smooth transition between the ramp and environmental surface terrain.

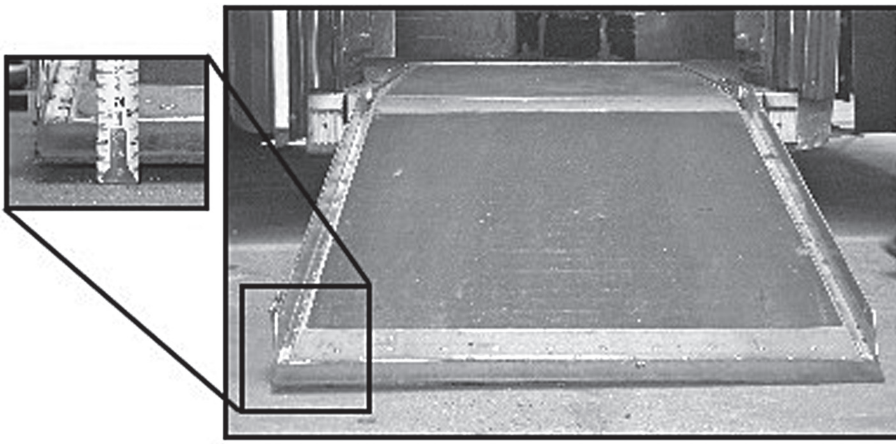

Figure 9. Exterior Ramp Threshold Showing Signs of Wear

Despite the described barriers to ingress/egress, it is important to note that the majority of WhMD passengers successfully boarded and alighted the LATV, reaffirming the relative accessibility of fixed-route, large accessible transit vehicles. However, we posit that in addition to physical barriers, WhMD navigational skills play an important role in successful vehicle ingress/egress. To address this challenge, assistive technology providers, in combination with transit agencies should provide vehicle ingress/egress training to WhMD users intending to travel seated in their WhMD while using public transit. Such efforts may further reduce the number of difficulties and incidents involving WhMD passengers during LATV ingress/egress.

Our findings are representative of one transit agency operating in a medium-sized metropolitan city and are not necessarily generalizable to other transit agencies or geographical regions. Additionally, videos were recorded at a relatively slow frame rate and, in some cases, views may have been blurred or obscured requiring judgment of factors contributing to WhMD user ingress/egress difficulty or incidents. While attempts were made to obtain a randomized distribution of observations during the study period, the distribution of WhMD types and navigational skill of WhMD users may vary across regions and transit agencies. These limitations must be taken into consideration when interpreting and using the findings of our study.

Conclusions

Boarding and exiting an LATV was found to present unique challenges to WhMD users and, in some cases, compromised safety. In our study, ingress difficulties/incidents occurred in 15.6 percent of boardings, while egress difficulties/incidents occurred in 4.9 percent of observations. When observations were normalized by WhMD type, scooters were found to have the greatest incidence (38.9%) of difficulty during ingress, while power wheelchair users were found to have the highest incidence (5.9%) of difficulty during egress. The three most common vehicle-related factors contributing to WhMD user difficulties during ingress/egress were ramp width, LATV door width and ramp slope.

Acknowledgments

This study was funded by the National Institute on Disability and Rehabilitation Research (NIDRR) and the Rehabilitation Engineering Research Center (RERC) on Wheelchair Transportation, Grant #H133E060064. The opinions expressed herein are those of the authors and do not necessarily reflect NIDRR opinions.

References

Buning, M. E., C. A. Getchell, G. Bertocci, and S. G. Fitzgerald. (2007). Riding a bus while seated in a wheelchair: A pilot study of attitudes and behavior regarding safety practices. *Assistive Technology* 19: 166-179.

Fitzgerald, S, T. Songer, C. A. Rotko, and P. Karg. (2007). Motor vehicle transportation use and related adverse events among persons who use wheelchairs. *Assistive Technology* 19: 181-188.

Frost, K. L., and G. Bertocci. (2010). Retrospective review of adverse incidents involving passengers seated in wheeled mobility devices while traveling in large accessible transit vehicles. *Medical Engineering & Physics* 32(3): 230-236.

LaPlante, M. (2003). Demographics of wheeled mobility device users. Wheeled Mobility Device Users Workshop Proceedings, Center for Inclusive Design and Environmental Access, State University of New York, Buffalo.

National Highway Traffic Safety Administration. (1997). Wheelchair users injuries and deaths associated with motor vehicle related incidents. Research Note. Department of Transportation.

National Oceanic Atmospheric Administration (NOAA) and National Weather Service, U.S. Climate Graphs, © 2003 - 2007 rssWeather.com. Retrieved September 2009 from *http://www.rssweather.com/climate/*.

Shaw, G., and T. Gillispie. (2003). Appropriate protection for wheelchair riders on public transit buses. J Rehab Res & Dev 40(4): 309-19.

U.S. Architectural and Transportation Barriers Compliance Board (Access Board). Draft revisions to the ADA accessibility guidelines for buses and vans, November 19, 2008. Retrieved August 2009, from *http://www.access-board.gov/news/vehicle-draft2.htm*.

U.S. Architectural and Transportation Barriers Compliance Board (Access Board). (1990). Americans with Disabilities Act (ADA): Accessibility guidelines for transportation vehicles. 36 CFR Part 1192, Washington, D.C.

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Traffic Safety and City Public Transport System: Case Study of Bengaluru, India

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Abstract

Vehicle crashes are a major concern in rapidly growing urban agglomerations. They also have attracted the attention of researchers, academicians, and policy makers. A large body of research literature exists that throws light on the magnitude of this problem and also indicates the interventions required. In a vast majority of Indian cities, buses are the main mode of public transport. An externality of the bus-based public transport system, like any other mode of transport, is the injuries and fatalities arising out of the crashes involving them. Buses are involved in 12-20 percent of fatal crashes in Indian cities. This paper presents an analysis of the fatal crashes that involved public transport buses in Bengaluru, India. The study suggests that low floor buses with mechanical doors and segregated pedestrian and bicycle lanes can have a major impact on reducing fatal crashes of bicycles and pedestrians involving buses.

Introduction

In low and middle income countries, buses are likely to remain the primary mode of mass transit for the foreseeable future (Tiwari 1994). In most transportation scenarios, reliance on buses has a positive impact on air quality because they pollute less per person mile and create less congestion because of their smaller road-use footprint. In addition to these benefits, it is usually assumed that buses are among the safest modes of transport available because they are much larger in size and mass than most other road vehicles. Biomechanics and crash investigation studies have confirmed that occupants of buses are at much lower risk of dying in the event of a crash (Bhalla et al. 2006) However, bus users face risks of road traffic injuries on access trips and buses also are associated with road traffic crashes with other road users (Bhalla et al. 2007, Mohan et al. 2009).

The total motor vehicle population in India has increased from about 300,000 in 1951 to about 73,000,000 in 2004 (see Table 1). The basis of this figure is the number of new vehicles registered each year. The vehicles registered each year are accumulated to arrive at the total figure of vehicles on road, notwithstanding that vehicles do have a specified life. Out-of-use vehicles remain on record. Recent studies have estimated that actual number of vehicles on the road in Delhi is 60-70 percent of the official statistic (Expert Committee 2002; CRRI 2007). The figures in Table 1 reveal that motorcycles are more than five times as numerous as cars and that the total of buses, goods vehicles and other vehicles is similar in magnitude to the number of cars. These proportions of vehicle types are different from those in high-income countries and can influence fatality rate patterns. In the U.S. in 2005, for example, passenger cars constituted 66 percent of vehicles on the road, trucks and vans 30 percent, motorcycles only 3 percent, and buses 1 percent. The number of vehicles in a city with a population of about 6 million (Bengaluru) is indicated in Table 2.

Statistics about road crashes in India are compiled at the national level by the Ministry of Road Transport and National Highways. This is based on the reports received from the state governments. The National Crime Records Bureau (NCRB) of the Government of India also gathers data about fatalities and injuries in road crashes. They source their data from police records. According to official statistics, 105,725 people were killed and 452,922 people were injured in road traffic crashes in India in 2006 (NCRB 2007). Traffic fatalities increased by about 5 percent per year from 1980 to 2000, and since then have increased by about 8 percent per year for the four years for which statistics are available (Figure 1). This is attributable partly to an increase in the number of vehicles on the road, and partly to the absence of a coordinated official policy to control the problem. The fatality rate has increased from 36 fatalities per million persons in 1980 to 95 fatalities per million persons in 2006 (Mohan et al. 2009). However, a study done in Bangalore shows that while the number of traffic crash deaths recorded by the police may be reasonably reliable, the total number of injuries is grossly underestimated (Gururaj

Table 1. Total Number of Registered Motor Vehicles in India, 1951-2004 (in thousands)

Year (as of March 31)		All Vehicles	Two-Wheelers	Cars, Jeeps and Taxis	Buses		Good Vehicles	Others*
1951		306	27	159	34		82	4
1956		426	41	203	47		119	16
1961		665	88	310	57		168	42
1966		1099	226	456	73		259	85
1971		1865	576	682	94		343	170
1976		2700	1,057	779	115		351	398
1981		5391	2,618	1,160	162		554	897
1986		10,577	6,245	1,780	227		863	1,462
1991		21,374	14,200	2,954	331		1,356	2,533
1996		33,786	23,252	4,204	449		2,031	3,850
1997		37,332	25,729	4,672	484		2,343	4,104
1998		41,368	28,642	5,138	538	@	2,536	4,514
1999		44,875	31,328	5,556	540	@	2,554	4,897
2000		48,857	34,118	6,143	562	@	2,715	5,319
2001		54,991	38,556	7,058	634	@	2,948	5,795
2002		58,924	41,581	7,613	635	@	2,974	6,121
2003	(R)	67,007	47,519	8,599	721	@	3,492	6,676
2004	(P)	72,718	51,922	9,451	768	@	3,749	6,828

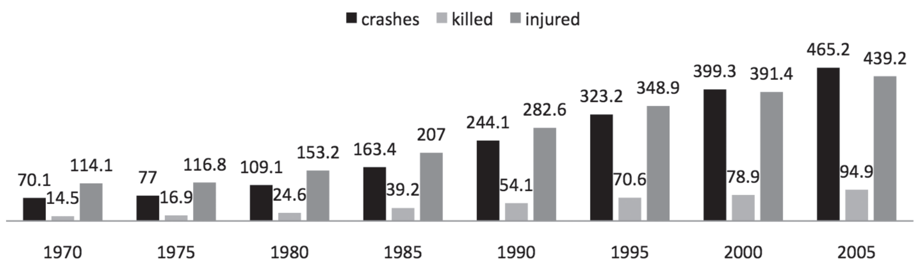
**Others include tractors, trailers, three-wheelers (passenger vehicles), and other miscellaneous vehicles that are not separately classified.*
@Includes omni buses.
Source: Ministry of Road Transport and Highways Web site.

Table 2. Cumulative Number of Vehicles Registered in Bengaluru City

Year	Two-Wheelers	Three-Wheelers	Cars	Jeeps	Taxis	Buses
1991	279,498	31,864	36,602	3,051	1,046	9,706
2000	1,164,204	68,734	230,388	7,986	8,638	6,380
2005	1,876,498	92,722	340,168	9,171	14,250	11,708
2006	2,161,663	94,587	415,645	6,280	19,802	13,032
2007	2,405,727	109,405	486,657	8,775	27,723	14,739

Source: Office of the Transport Commissioner, Government of Karnataka.

2006). According to that study, deaths were underestimated by five percent, and the number injured who needed treatment in hospitals was underestimated by a factor of more than two. In that study, the ratio of injured people reporting to hospitals versus those killed was 18:1. The numbers for crashes and those injured in Figure 1 are, therefore, gross underestimates. The age profile and gender of the crash victims is also available both at the state and the national levels.



Source: morth.nic.in., Ministry of Road Transport and Highways, Goverment of India)

Figure 1. Road Crashes in India (in thousands)

Data for road user types killed are not available at the national or state levels in India (Mohan et al. 2009). Some studies in the past have attempted an analysis of the fatalities in cities due to road crashes. Mohan and Tiwari (2000) concluded that pedestrians, bicyclists, and motorized two-wheeler riders accounted for 60-90 percent of all traffic fatalities. Another study (Mohan et al. 2009) obtained fatalities data from the Delhi police in the form of a consolidated spreadsheet. The data consisted of a list of incidents identified by the time and location at which each incident occurred, the involved road-user type, the number of fatalities and injuries in the crash, a general categorization of the fatality by age and gender, and whether a pedestrian was hit. The dataset provided a reliable view of some characteristics of fatalities that are not available otherwise at the state or national levels. A similar analysis was carried out for the study of Mumbai (Tiwari et al. 1999). Both studies revealed that pedestrians, cyclists, and motorized two-wheeler riders account for 80-90 percent of all the fatalities. The study of Delhi analyzed different categories of road users by the time of day. There were four relevant findings. First, despite the fact that nighttime exposure is likely to be substantially lower than daytime exposure, nighttime crashes account for a large proportion of fatalities. Second, trucks have a high involvement in both daytime and nighttime. Third, buses feature prominently from about 700 hrs to about 2,100 hours. Fourth, the proportion of unknowns is substantial, especially during nighttime.

Figures for fatalities in crashes in all cities having a population exceeding one million were analyzed for the year 2007 (see Table 3). In Bengaluru,[1] the total number of fatal crashes in 2007 was 957, of which 12 percent involved buses of the public transport system (Figure 2). The number of fatal crashes caused by public transport buses in selected Indian cities is shown in Table 4. Fatal crash rates[2] vary from 0.13 in Kolkata to 4.36 in Chennai.

Table 3. Comparison of Road Crash Fatalities in Indian Cities

City	Fatalities in Road Crashes	Population (millions)	Fatalities per Million
Ahmedabad	256	4.5	57
Bengaluru UA	957	5.8	165
Chennai UA	1,146	6.5	176
Delhi	2,141	13.8	155
Hyderabad	391	3.7	106
Kolkata UA	462	13.2	40
Greater Mumbai	651	16.43	40
Pune UA	414	3.76	110

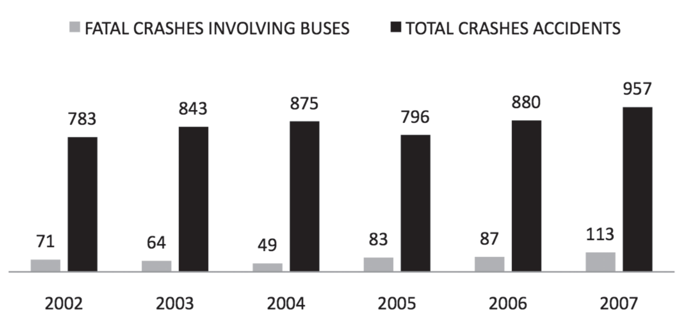


Figure 2. Fatal Crashes in Bengaluru City (Total and Those Involving Buses)

Table 4. Fatal Crashes Caused by City Buses by Ownership

S. No.	STU		Fleet Held	Fatal Crashes per 100 Buses	Vehicle Miles Traveled (million km)	Fatalities per Million Bus km
1	BEST (Mumbai)	35	3,391	1.03	240	0.15
2	AMTS (Ahmedabad)	11	521	2.11	45	0.24
3	BMTC (Bengaluru)	77	3,468	2.22	329	0.23
4	CSTC (Kolkata)	1	741	0.13	26	0.04
5	DTC (Delhi)	63	2,578	2.44	181	0.35
6	PMT (Pune)	15	845	1.77	61	0.25
7	MTC (Chennai)	121	2,773	4.36	219	0.55

Source: Based on figures published by CIRT, Pune.

A comparative analysis of the road crash fatalities in Indian cities was done by Mohan in 2004. He concluded that data show that most of the city rates are higher than the average for India as a whole (80 fatalities per million). Most of the cities have similar rates (100 +/- 20 fatalities/m persons), except a few that are lower than 80/m and higher than 140/m. The same study also confirmed that there were no detailed studies available to come to any firm conclusions regarding the differences in crash rates in different cities. However, low rates in Kolkata and Mumbai may be attributed to lower vehicle speeds on some of their main arteries, as compared to cities like Delhi and Hyderabad where some of the main arterial roads have much more space available for vehicle speeds to be high, especially during non-peak hours. A study on "Transportation Polices and Strategies in Urban Areas" (Wilbur Smith Associates 2008) did a comparative analysis of the crash fatalities in Indian cities. They developed an Accident Fatality Index and a Road Safety index to compare vulnerability of different cities to road crashes. It was concluded that cities with higher slow-moving vehicles in the traffic stream such as Guwahati, Varanasi, Kanpur, Raipur, Amritsar, etc. (populations of less than 3 million) have a worse safety index and are unsafe. It also found that due to the absence of separate lanes for slow-moving vehicles, the right-of-way is shared by all, leading to unsafe roads. It also was brought out in the study that larger cities are safer than smaller and medium cities, as larger cities generally have lower speeds, efficient public transport, and better traffic management.

A major reason why comparisons of fatalities between cities are made difficult is that the geographical jurisdictions of a city are different for different agencies. For example, the city government has well-defined municipal boundaries, but the boundaries of city police are not coterminous with that of the city government. The census that gives the population figures defines a new set of boundaries for itself: the urban agglomeration, the bus transport company plies within limits that are decided by the state government, the urban planning body has a much bigger geographical jurisdiction, the transport department that registers the vehicles and licenses the drivers follows its own territorial jurisdiction which is totally distinct from that of other agencies. Therefore, capture of data by different agencies is from a different base and, hence, comparisons without applying correction factors may give misleading results.

From the above it could be concluded that the data about fatalities are available at the city, state and national levels. However, these data do not capture vital details about crashes, which could throw light on the cause of the crashes. Another limitation of these data at the city level is that the data are reported by the traffic police whose jurisdiction does not coincide with that of other agencies.

Objective

The number of fatal vehicular crashes in cities is on the rise, and a significant number of these fatal crashes involves public transport buses. The objective of this study was to analyze these crashes and identify the major factors responsible for such crashes so that remedial policy measures could be recommended.

Method

All cases involving fatal crashes were studied to capture different parameters of each crash. These parameters were then analyzed to evolve trends and patterns in these crashes. Based on the analysis, measures have been suggested to reduce such crashes.

The records maintained by the bus operating organization in Bengaluru[3] were obtained for five years (2003-2007). The BMTC (Bengaluru Metropolitan Transport Organisation)—the bus operating company—maintains records of all major crashes involving its fleet of buses. Maintenance of such records is used for taking internal corrective measures within the organization and also for deciding on compensation claims. The police also maintain crash records, but these records do not have vehicle and driver details as recorded by the bus company. The analysis was confined to fatal crashes only, as fatal crash records are more reliable and also because injury crashes are under-reported and the record keeping for other crashes is not as meticulous as it is for fatal crashes.

Four hundred cases for the years 2003-2007 were examined, and different parameters for each crash were tabulated. The parameters analyzed for each crash given in Table 5.

Table 5. Parameters Analyzed for Each Fatal Crash

General Details	• Vehicle # • Date of crash • Time of crash • Runover or impact • Straight road or intersection
Vehicle Details	• Bus with or without pneumatic doors • Rear door or middle door • Standard or articulated • Mechanical failure, if any
Driver Details	• Age • Was the driver drunk? • Did inquiry reveal driver's fault?
Victim Details	**If Pedestrian:** • Age • Profession • Gender • Impact from which side of bus? • Run over by which wheel? • Whether crossing or walking alongside • If crossing, left to right or otherwise?
	If Cyclist: • Age • Profession • Gender • Impact from which side of bus? • Run over by which wheel? • Crossing or walking alongside? • If crossing, left to right or otherwise?
	If Motorcyclist: • Age • Profession • Gender • Impact from which side of bus? • Run over by which wheel? • Whether crossing or walking alongside • If crossing, left to right or otherwise?
	If Bus Passenger: • Age • Profession • Gender • What was the victim doing: sitting inside, boarding, alighting? • Run over or impact? • At bus stop or en route?

The results of the analysis and the suggested measures to reduce the number of fatalities are discussed in the following paragraphs.

Results and Analysis

Trend in Road Traffic Crashes

Figure 3 shows the statistics regarding fatal crashes involving buses for the years 2003-2007. The fleet of buses has increased by almost 80 percent during this period (2003-2007), as have the number of crashes. The fatal crash rate per 100 buses, as shown in Figure 4, has not shown any increasing or decreasing trend, thus establishing that the number of crashes is almost directly proportional to the fleet size in the absence of specially-targeted effective countermeasures.

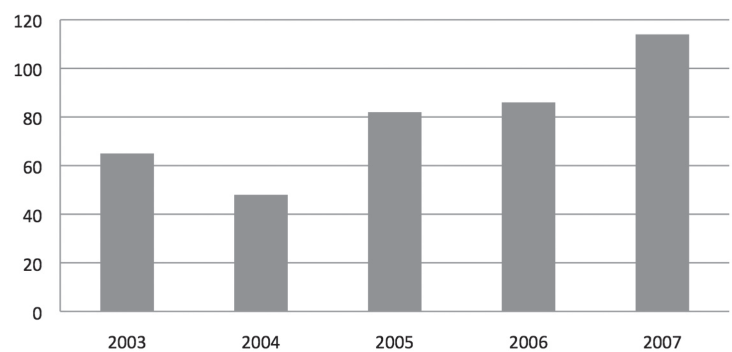


Figure 3. Number of Fatal Crashes Involving Buses

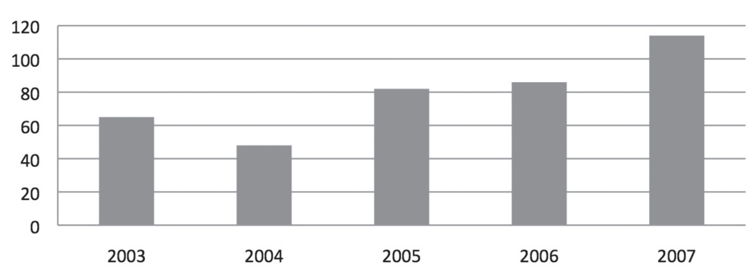


Figure 4. Crashes per 100 Buses Held

Diurnal and Seasonal Variations in the Crashes

To ascertain whether the crashes are dependent on the time of day or are dependent on the seasons during the year, a diurnal and a seasonal analysis was done. Table 6 shows the number of fatal crashes of all vehicles distributed over different months and time of a day. During the day, the variation of traffic on roads is quite pronounced. It is bi-modal, picking up in the morning and then reducing in the noon, then increasing in the evening, and finally tapering off in the night. The traffic pattern on a typical working day is given in Figure 6.[4] Hanowski et al. (2009) found a similar incident to time-of-day relationship.[5]

Table 6. Diurnal and Seasonal Variations of Fatal Crashes

	Month												
Time:Hrs	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
0500-0600							3	1	1				5
0600-0700		2			1	3	1	1		1		2	11
0700-0800		3	1	2	1	1	3	3		1			15
0800-0900	2	5	5	2	1	1	1	3	5	2	4	1	32
0900-1000	4	1	4	1	2	2	3	2		2	3	4	28
1000-1100	3	3	1	1	3		1	2	3	5	2	2	26
1100-1200	2	2		2	1	2		2	1	4	1	2	19
1200-1300		1		1	3	1	1	6		1	3	4	21
1300-1400	1	2		4	1	1	2	2	2	1			16
1400-1500	2		1	3	5		1	3	3	2	1	3	24
1500-1600	3	3	2	1	1	2	2	1	1	4	3	2	25
1600-1700	2	2		1	1	3	4	2	2	3	5		25
1700-1800	2			2	1		4	1	2	5	2		19
1800-1900	4	1	1	3	1	1	5	1	1	1	3	2	24
1900-2000	8	4	2	4	5	3	3	1	5	5	2	2	44
2000-2100	2	2	1	4	1	1	3	1	1	2		4	22
2100-2200	1	1	1	1	5	1	2	4	1		4	3	24
2200-2300						1	3	2	1	1	2		10
2300-2400		2					1		1	2			6
Total	**36**	**34**	**19**	**32**	**33**	**23**	**43**	**38**	**30**	**42**	**35**	**31**	**396**

From Table 6, it is evident that the numbers of fatal crashes is not consistent across the months; thus, there are seasonal variations, but such variations are not significant (mean 33, SD 6.9). Data from Table 6 and Figure 5 show that both the number of crashes and the traffic volume distribution in a day, with respect to time, is bimodal. There are substantial fluctuations in the number of fatal crashes recorded per hour during different times of a day. To compare the vulnerability towards fatal crashes during different time periods of the day, vulnerability factors were calculated by dividing the number of fatal crashes by the average vehicular count during the hour (Figure 6). The factor was set at unity for the time 0600-0700 hours. The vulnerability factor beyond 2100 hours could not be worked out, as the vehicular count was taken up to 2100 hours only. However, the fatality data would indicate that the factor would increase further between 2100 to 2200. The highest (1.3) and lowest (0.52) values were between 1900-2000 and 1300-1400 hours, respectively, with a mean of 0.76 and an SD of 0.22. The relative vulnerability factor was high in the morning between 0600- 0700 hours and again between 0800-0900 hours. This could be due to the relatively low volume of traffic on roads, resulting in higher speeds. However, the values are not significantly different from the mean at 95% confidence levels (Mean +/- 2SD) except for 1900-2000. It is interesting that the two peaks do not coincide. While the crash rate per hour peaks between 0800-0900 hours, the traffic peaks between 0900-1000 hours. Similarly, in the evening, while the crash rate peaks between1900-2100 hours, the traffic peaks between 1700-1800 hours. Also, the crash rate during evening is more than the crash rate in the forenoon. A plausible explanation for this could be that during traffic peak hours, the vehicular speeds are much less and therefore the crash rate also drops. The reason for the more pronounced evening peak crash rate could be the absence of daylight after 1900 hours combined with inadequate street lighting and higher speeds.

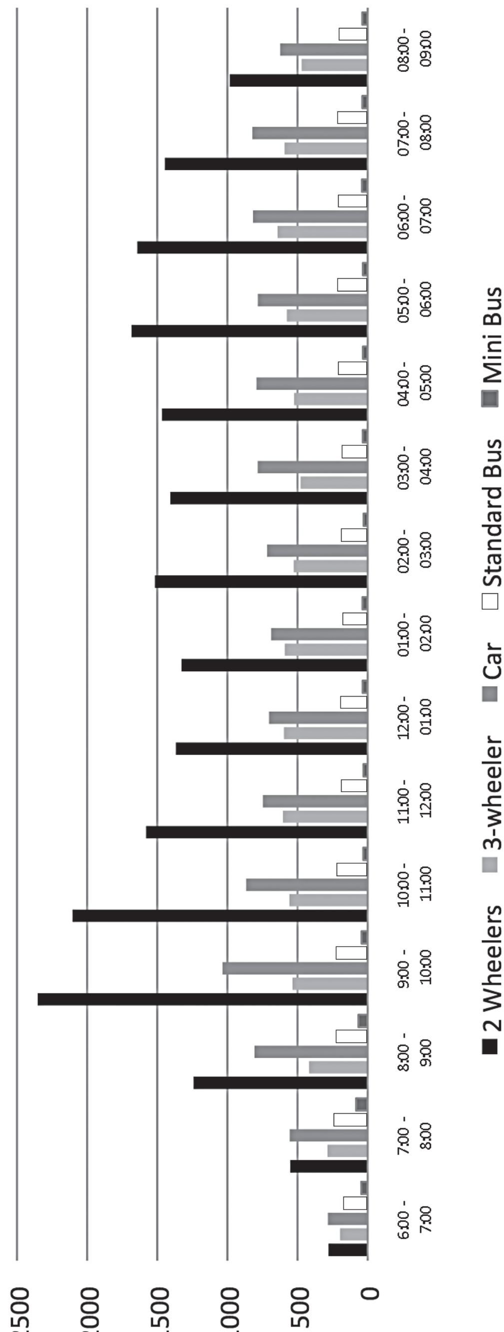


Figure 5. Traffic Distribution During a Day

Analysis of the Mode of Transport of Victims

The risk associated with different modes of transport for being a victim of a fatal crash with buses is different. To analyze this, the modes of travel (of victims) were categorized into six groups: auto rickshaw, cyclist, four-wheeler, two-wheeler, bus passenger, and pedestrian. The mode-wise details of the victims of fatal crashes are given in Table 7. In absolute numbers, motorized two-wheeler riders constitute the largest share of fatalities (40%) and cyclists account for about 10 percent. However, if the probability of a fatal crash is calculated per million km of a particular mode, then the cyclists are about six times more vulnerable compared to motorized two-wheelers. This may be because there are no separate bicycle lanes on arterial roads and bicyclists have to share the left lane with buses.

Table 7. Categorization of Victims

Category of Victim	Impact	Runover	Total	Gross Vehicle km 2003-07 (million km)	Probability of a Fatal Crash per Million km
Auto Rickshaw	5		5	7,606	0.00127
Cyclist	16	16	32	654	0.0949
Four Wheeler	8		8	11,028	0.0014
Passenger	57	26	83	3,075	
Pedestrian	75	32	107		
Grand Total	255	141	396		

**The vehicle kms for the fleet of BMTC buses is readily available (1.17 million km per day). For other modes of transport, it was extrapolated based on the average vehicular count.*

Riders of cars and other four wheelers have a very low risk of being involved in a fatal crash with a public transport bus. These trends can be compared to the trends of fatal crashes in Delhi, Mumbai, and Kota (population 1.5 million), as reported by Mohan et al. (2009) and Tiwari et al. (1998). Buses are associated with nearly 20 percent crashes in Delhi, 12 percent in Mumbai, and 5 percent in Kota. Buses are a smaller component in Kota, which has very limited public bus service. Buses are replaced by jeep taxis (included in the "car" category) and other vehicles transporting passengers as route taxis. The high involvement of buses and trucks has been investigated in a detailed conflict-analysis study (Tiwari et al. 1998). The authors report that these vehicles have to use the curbside lane in the city and often come into conflict with pedestrians, bicyclists, and motorized two-wheelers, as they are present in the same space on the road. This results in frequent involvement of vulnerable road users in fatal crashes because of the absence of dedicated bicycle paths and adequate space for pedestrian movement.

The analysis further revealed that 36 percent of the victims were crushed under the wheels of the buses; Table 8 gives the distribution of these cases according to the position of the wheel. A total of 85 percent of the cases were reported to be crushed by the rear wheels. This indicates that the victim during the crash went under the bus from the sides. This probably was because the side skirting of the bus has a large ground clearance of 700-800mm, which allows the victim to go under.

Table 8. Wheel by Which Victim was Run Over

	FLW	FRW	RLW	RRW	Total
Cyclist	3		10	3	16
Passenger			25	1	26
Pedestrian	5	1	16	10	32
Two wheeler	4	8	35	20	67
Grand Total	12	9	86	34	141

FLW – Front Left Wheel FRW – Front Right Wheel
RLW – Rear Left Wheel RRW – Rear Right Wheel

Details of Fatal Crashes Involving Bus Passengers: Bus passengers account for about 18 percent of the total fatalities, and 92 percent occurred during boarding or alighting. This is because it is possible to do so while the bus is moving (absence of doors) and, in the case of a fall, the bus floor is high enough (~1200 mm) for the possibility of severe injury in head impact with the road.

Direction of Travel of the Victim: Table 9 gives the breakdown of the direction of travel of the victims. Of the total pedestrians killed during a fatal crash with a bus, 73 percent of them were killed while crossing the road. Similarly, of the total two-wheeler fatalities in crashes with buses, 71 percent of them were killed while they were traveling in the same direction as the bus. This underlines the need for provision of safer pedestrian crossings as well as for better traffic management and speed control.

Table 9. Direction of Victim

Victim	Across	Opposite	Same
Auto	1	4	
Cyclist	3	5	24
Four-Wheeler		7	
Pedestrian	78	3	26
Two-Wheeler	8	39	114
Van Driver		1	
Total	90	59	164

Location of Crash Spot

Table 10 shows the distribution of crashes by type of junction and mid-block locations. A total of 89 percent of the fatal crashes were at mid-block, and only 3 percent and 7 percent were at roundabouts and intersections, respectively. This indicates that much more attention needs to be focused on safety at mid-block sections and also the location of bus stops.

Table 10. Location of Crash Spot

Victims	Bus Stand	Roundabout	Intersection	Midblock	Total
Auto				5	5
Cyclist		1		31	32
Four-Wheeler			1	6	7
Passenger	4		7	72	83
Pedestrian		2	10	95	107
Two-Wheeler		7	11	143	161
Van Driver				1	1
Total	4	10	29	353	396

Driver Age and Involvement in Crashes

To arrive at a conclusion about whether the age profile of drivers of buses is linked to the probability of a fatal crash, the age profile of the drivers involved in the fatal crashes was studied. As the numbers of drivers in different age cohorts were different, the figures were adjusted to 100 drivers per cohort for ease of comparison. The distribution of crashes per 100 drivers by age group is given in Table 11. It is evident that the drivers in the younger age group (under 37 years) are more prone to crashes compared to those who are around 45-50 years of age.

Table 11. Distribution of Crashes per 100 Drivers by Age Group

Age Group	Number of Crashes	Number of Drivers in Cohort	Number of Crashes per 100 Drivers
25-30	84	1,277	6.58
30-36	111	1,564	7.10
36-42	74	1,581	4.68
42-48	52	1,454	3.58
48-54	26	803	3.24
54-60	6	158	3.80

Driver's Fault

Police reports often show "driver fault" in a majority of the crash investigations without conducting an in-depth scientific analysis (Tiwari 2005). The other attributes analyzed in this study were easily quantifiable, but concluding that a crash was the result of driver's error requires a thorough probe into each crash, and even then it remains opinion rather than fact. Under Indian laws, causing death by a rash and negligent act is an offense punishable with an imprisonment of four years. Thus, each death caused by a crash involving a public bus is followed by a police investigation and then a trial in a court.

Apart from investigation by the police, the public transport company carries out an in-house inquiry. The purpose of this inquiry is to arrive at the extent of the driver's responsibility and inflict administrative punishment. The administrative punishments could be in the nature of a warning, a reduction in salary, or removal from service.[6] The standard of proof required in an in-house inquiry is much lower than that required in a criminal court of law. All these case files were analyzed, and it was determined that in 33 percent of cases, the driver of the bus was "solely at fault," in 44 percent of cases the driver of the bus was "also at fault," and in 23 percent of cases the driver was not at fault. It also was revealed that in 23 percent of cases no punishment was imposed, in 1 percent of the cases the driver was removed from service, and in the rest either the salary of the driver was reduced or his training period was extended.

As observed above, in about 44 percent of the cases the driver was "also at fault." This means that there are other external factors that combined with the driver's fault and led to the crash. These factors include contributory negligence of other road users, faulty infrastructure, etc. Several studies have shown that accidents rarely have a single cause (Rumar 1985; Wegman 2001; Mulhrad 2005). Further, Wegman (2001) has stated that "the circumstances in which

a road user carries out his or her traffic task ('definition of the workplace') partly determine the chances of errors and mistakes." Errors in the design and organization of the workplace are called "latent errors or hidden errors": these have been made long before an accident and are triggered by active errors. Finally, there are the political, cultural, historical, and economic environments that determine the demands made on the traffic environment (workplace). "Driver's fault," as reported in the existing database, remains a contentious issue and requires further research for policy interventions.

Policy Implications

Adequate Right-of-Way for All Modes of Transport

The study clearly brings out that about 25 percent of the victims of fatal crashes involving buses are pedestrians. The analysis has adequately established that pedestrians are the most vulnerable groups on Indian roads, closely followed by cyclists and two-wheelers. The fact that almost all fatal crashes take place on straight stretches of roads and also that most occur when the bus and victim are traveling in the same direction is evidence that road design is forcing conflicts between these road users and is a major cause for concern. Of all traffic fatalities in EU countries, the proportion of pedestrian fatalities is about 17 percent, and the proportion of cyclist fatalities is about 6 percent.[7] Separation of buses from non-motorized road users and provision of safe pedestrian and bicycling facilities on arterial urban roads would be expected to go a long way not only in reducing the number of fatal crashes but also improving access to the public transport system. Studies by Elvik and Vaa (2004) revealed that tracks for walking and cycling reduce pedestrian injuries by 35 percent; construction of pavements reduce crashes involving pedestrians by 5 percent; cycle lanes reduce all types of crashes by 4 percent; and grade-separated crossing facilities reduce crashes involving pedestrians by 82 percent. The addition of bicycle lanes in Davis, California, reduced crashes by 31 percent.[8] In Denmark, bicycle lanes reduced the number of bicycle crashes by 35 percent.[9] In the long run, improved road infrastructure with adequate illumination during night can contribute to substantial reductions in fatal crashes. The effectiveness of such designs has been demonstrated on the BRT corridors in

Bogota (Echeverry 2004) and Delhi (DIMTS 2009), where road traffic fatalities have been reduced by more than 90 percent.

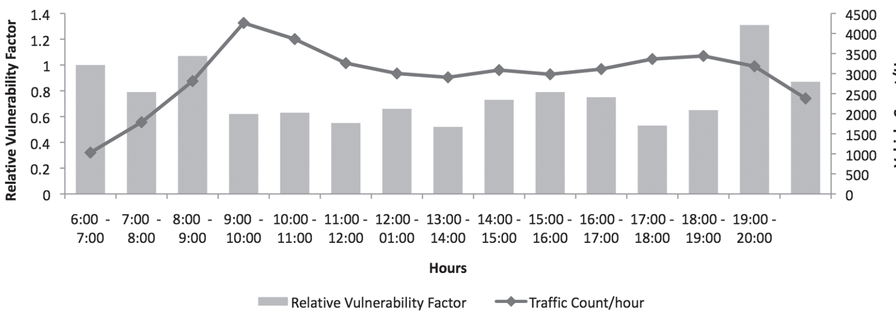


Figure 6. Comparison of Hourly Traffic Count with Relative Vulnerability factor

Installing Automatic Doors

The results of this study show that 92 percent of the bus passengers involved in fatal crashes sustained fatal injuries due to a fall while entering or leaving the bus. Similar results have been reported from a study of DTC[10] operation in Delhi (Mohan 1985). The large number of passenger deaths while boarding and alighting indicates the need for having automatic closing doors and much lower floors in buses. The Motor Vehicles Act 1989 and the Motor Vehicle Rules regulate the manufacture and operation of all transport vehicles. State Governments also are empowered to make rules that all vehicles manufacturers must follow. These rules make various stipulations that are from the point of view of safety of road users as well as others. These rules also lay down some of the critical specifications as well as dimensions of the vehicle. For example, Rule 176 of the Motor Vehicle Rules, 1989 states:

> *176 Width of Doors - (1) Every entrance and exit of a public service vehicle other than a motor cab shall be at least 540 mm in width and of significant height; (2) Every entrance and exit of a stage carriage, not being a stage carriage operating within the limits of a municipal council, municipal corporation or a cantonment board duly constituted or declared under any law for the time being in force, shall be fitted with doors so as to prevent passengers from falling out.*

Most State Governments have similar provisions in their respective Motor Vehicle Rules. These provisions were made in the late 1980s, when the technology of automatic or pneumatic doors was not very popular in India nor were the buses as crowded as they are today. At present, the traffic situation demands that mechanically-operated doors be mandated in city buses. In all high income countries and others such as China, no city buses can operate unless they are equipped with mechanically-operated doors. Several bus transport companies such as the Delhi Transport Corporation (DTC), BMTC, etc. are already fitting buses equipped with pneumatically-operated doors. Therefore, the time has now come to mandate by law (through the Motor Vehicle Rules) that no city bus shall be permitted to operate unless it has mechanically-operated doors. Thus, with this one intervention, fatalities in bus crashes can be brought down by 20 percent and, it would be expected, injuries by a greater number.

Changing the Design of the Bus Body

As shown in Table 7, there is a large number of cases where the victim is run over by the bus. Such crashes could be prevented through better design of buses. At present, most of the buses in Indian cities are fabricated on a chassis that is more suited for trucks. As a result, the bus floor is about 1.0 m above the ground. Such large ground clearances are helpful in negotiating uneven road conditions. Consequently, the side panel of the bus body also is kept at a clearance of about 70 -80 cm from the ground. This leaves a very large opening under the bus, and an inadvertent victim in a crash has a high probability of getting into this opening and getting run over by the wheel. Therefore, there is a strong case for making it compulsory for all buses in cities to have their bodies fabricated in a manner such that the side panels of the bus body are low enough to prevent a person from accidentally or during a crash getting under the bus. Figure 7 show a sketch of an ordinary bus and a modified low-floor bus. This has been made possible by the proposed Automotive Industry Standards Code of Practice for Bus Body Design and Approval (AIS-052), which requires that Automotive Vehicles - Lateral Protection (Side Guards) - Technical Requirements be followed for side under run guards of buses (BIS 1999). This standard mandates that the maximum clearance be limited to 550 mm above road level.

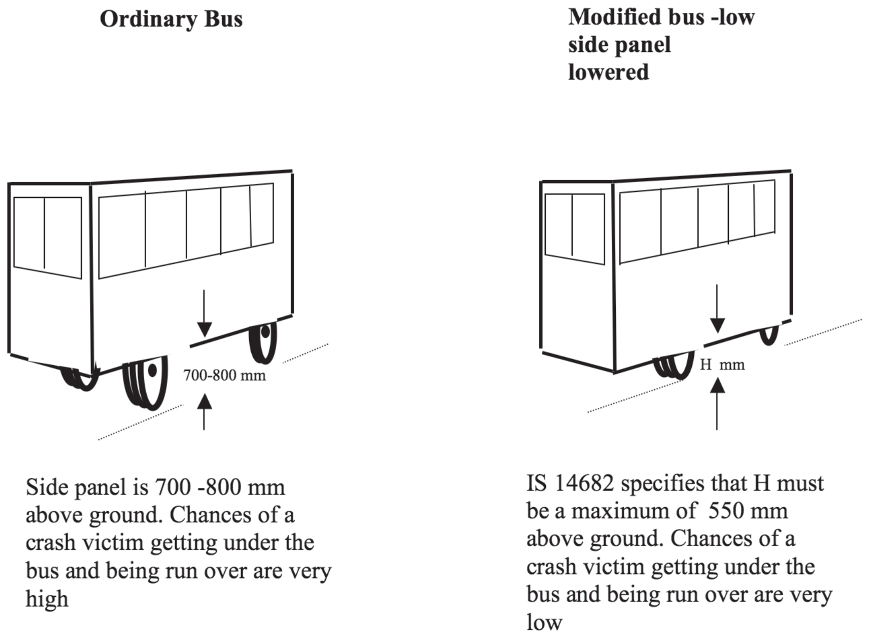


Figure 7. Sketch of ordinary bus and modified low side panel bus model

In a large number of crashes, injuries and fatalities are caused to VRUs (Vulnerable Road Users) in frontal impacts. Research has been done in India and Europe showing that fatalities in such impacts can be reduced significantly by designing safer bus fronts (APROSYS 2004; Chawla et al. 2000; Kajzer et al.1992). It would be appropriate if the recommendations of these reports to set standards for protection of VRUs in impact with buses are put in place as early as possible.

Better Personnel Policies

It has been adequately brought out by the analysis that the risk factor of a driver varies according to his age. As stated earlier, the drivers in the younger age group (under 37 years) are more prone to crashes compared to those who are around 45-50 years of age. This should form an important input in designing the personnel policies of public transport utilities. The public transport organizations in India are government owned, and the general age of recruitment of drivers is 24 years. It also is stipulated in the recruitment rules that to be eligible for consideration as a driver, a candidate should have experience driving a heavy vehicle for at least five years. As the number of drivers in the lower age group are more vulnerable to accidents, efforts should be made to reduce the total number of such drivers. This could be achieved by increasing the minimum age for recruitment or increasing the experience required as a pre-qualification.

The salary structure of the drivers also favors more use of younger drivers. All drivers are on a progressive scale of salary, and their monthly remuneration increases with age. Bus operators have an incentive to use a younger drivers more than relatively senior drivers because the younger drivers cost less per hour. This is especially true when there is a crew shortage and the drivers have to work overtime. This skewed incentive for the bus operators can be corrected by mandating that the overtime rates for all drivers shall be the same.

Another strategy to reduce crashes could be identifying routes that are more prone to crashes. Having done so, only experienced drivers should be deployed on such routes. The study has also brought out that crashes are more probable during certain hours. The reasons for this needs to be investigated further; however, policies for speed control and checking of drivers under the influence of alcohol can be introduced immediately.

Selective but Effective Enforcement of Regulations

The analysis has brought out that, similar to traffic counts, crashes follow a bimodal pattern in a day. The maximum crashes take place between 0800-0900 hrs and again between 1900-2000 hrs. As shown in Fig 6, traffic peaks and crash peaks in a day do not coincide. This has an important policy implication. At present, all enforcement measures are synchronized with traffic peaks. For example, a maximum number of traffic police are deployed during the traffic peak. As a first step, the traffic regulatory authorities should be sensitized towards the reality that hours during which maximum fatal crashes take place deserve equal, if not more, attention as the peak traffic hours. This should be followed by stricter enforcement of traffic rules during such hours. Bus companies also have their own internal regulatory mechanisms for monitoring the behavior of their crews and their compliance with safety rules. These mechanisms should also be scheduled in a manner such that they are most effective during the hours most vulnerable to crashes.

Incentives for Drivers

At present, there is no system for monitoring the performance of bus drivers. The public transport companies should evolve a system under which the drivers are continuously rated based on their performance on the road. All small mistakes on the part of a driver should be recorded, and this database should be used to impart the requisite training; if the drivers do not respond well, they could be removed from service as well.

Structural Changes for an Integrated Approach

Road safety is rarely a high priority for governments in developing and transitioning countries. Typically, resources are underprovided, and responsibility is dispersed among a number of government agencies.[11] Evidence from some highly-motorized countries shows that an integrated approach to road safety produces a marked decline in road deaths and serious injuries, but that the practical realization of the systems approach remains the most important challenge for road safety policy-makers and professionals. The development of traffic safety policy involves a wide range of participants representing a diverse group of interests, such as governments (police, justice, health, planning and education), citizens, industry, NGOs, professionals, and media.[12]

As has been listed in the preceding paragraphs, to reduce fatalities in crashes, changes are required within the bus transport company, but equally essential are changes by other agencies. More importantly, these measures have to be made in a coordinated manner. Lack of an integrated approach to transport in cities also manifests itself in high rate of crashes. At present, there are multiple agencies in a city each having a specific mandate. This fragmented approach is shown in Table 12. These structures were put in place each for a specific purpose, well before the problem of urban transport began to surface in India and, hence, they do not provide for a coordinated approach for transport safety. As a result, each of these organizations is chasing its own objectives and the overall objective of passenger safety is not getting due attention. A long-term solution to high rates of crashes would require several measures, such as proper planning and provisioning of roads, efficient regulation of traffic, better support infrastructure for pedestrians and other complementary modes of transport, managing the demand for public transport, changing laws governing transport safety, etc. For that purpose, it would be necessary that the right structural arrangements are in place. First, the overall responsibility for managing the overall transport systems should be entrusted to the City Governments. Second, the agencies listed in the Table 12 need to be subsumed into an apex body under the city government.

A good management information system is a prerequisite for proper decision making. The shortcomings of the existing data have been brought out in the study. It would be desirable that bus operators have a specially-trained group of professionals who analyze crashes and report directly to the managing director of the company.

Table 12. Illustration of Multiplicity of Authorities Dealing with Transport in indian Cities

1	Overall responsibility for city transport	No specified agency
2	Traffic regulation	Bengaluru city police
3	Registration of vehicles	Motor Vehicles Department of the State Government
4	City planning	Bangalore Development Authority
5	Construction of roads	Municipal Corporation of Bengaluru,
6	Trauma care and ambulance	Hospitals managed by State Government
7	Fiscal and legal environment	Federal and the State Government
8	Transport safety	No specified agency, but to some extent, city police
9	Pollution control	State Pollution Control Board
10	Rescue	State Fire Force
11	Road safety education	No specified agency
12	Providing bus services	Bengaluru Metropolitan Transport Corporation
13	Suburban rail	Indian Railways (Federal Government)

Lessons for City Administrators

The recommendations that have emerged from this study have been known to the researchers for quite some time, but the fact remains that these have not been translated into action and, therefore, the fatalities in road crashes in Indian cities continues to be high. Therefore, as a first step, a detailed study should be carried out in each city to analyze the factors associated with road crashes.

Lowering the side panels of bus and fixing pneumatic doors is not expensive. Cost figures taken from BMTC indicate that both of these could be achieved at a cost of Rs 50,000 per bus (1 US$ =Rs 45). Assuming a future fleet strength of BMTC at 5,000 buses, this entire exercise could be carried out at Rs 250 million. This has the potential of saving about 50 fatalities per year.

As mentioned earlier, road safety is an interdisciplinary subject and requires a coordinated approach. The existence of a large number of agencies at the city level, each being independent of the other, coupled with weak city governments, does not provide the right structural base for either an efficient transport system no a safe transport system. Making fundamental changes in the structure may require legislation and may be time-consuming, but in the interrim a coordination mechanism may be set up under the leadership of the mayor with the ultimate aim of bringing all the independent agencies under the city government. Such changes would require policy advocacy. One of the most effective ways of bringing about these changes could be to carry out studies like as the present one at frequent intervals, with the results be kept in the public domain. A simple step of keeping details about each fatal road crash would go a long way in generating the right public opinion to bring about the requisite change.

Scope for Further Study

Of the total crash fatalities in Bengaluru city, city buses are involved in 12 percent of the total crashes. Low-floor buses are being introduced in large numbers in Indian cities. A study could focus on comparing the fatalities in these buses vìs-a vìs ordinary buses. Another area of research could be analysis of fatalities in crashes of private buses and comparing these with the fatalities involving buses owned by government companies.

Conclusion

This paper, through a micro-analysis of fatal crashes, has attempted to find patterns in the crashes involving public buses. While some of the findings fortify the existing understanding of the causes of crashes, the study has, nonetheless, provided empirical evidence for it. The analysis has provided a very useful input to policy makers who could take corrective steps and consequently reduce the number of such fatal crashes. The paper establishes that change in bus design with low floors, automatically-closing doors, safer bus fronts, and segregated infrastructure for bicycles and pedestrians would go a long way in reducing the number of fatal crashes on city roads involving public buses.

Endnotes

[1] Bengaluru is a metropolitan city in Karnataka, a Southern Province in India. It has a population of about 6.5 million.

[2] Crash rate is defined as the number of crashes per 100 vehicles per year.

[3] The public transport in Bengaluru city is provided by the Bengaluru Metropolitan Transport Corporation (BMTC).

[4] This is based on a traffic count on 10 arterial roads on a working day. The figure gives average number of vehicles. (Average has been obtained of vehicular counts made at 10 different locations in the city.)

[5] Hanowski, R.J., J. S. Hickman, R. L. Olson, and J. Bocanegra, J. (2009), "Evaluating the 2003 revised hours-of-service regulations for truck drivers: The impact of time-on-task on critical incident risk." Accident Analysis & Prevention 41: 268-275.

[6] The crew in public transport companies are appointed on a permanent basis and their conditions of service are governed by a set of rules

[7] http://ec.europa.eu/transport/road_safety/specialist/knowledge/pedestrians/index.htm, retrieved on 1-5-10.

[8] Federal Highway Administration, Bicycle Safety-Related Research Synthesis, 1995. Referenced in http://www.cambridgema.gov/~cdd/et/bike/bike_safety.html#7.

[9] Danish Road Directorate, Safety of Cyclists in Urban Areas, 1994.

[10] DTC-Delhi Transport Corporation.

[11] P. Elsenaar and S. Abouraad (2005), "Road safety best practices: Examples and recommendations," Global Road Safety Partnership.

[12] http://grsproadsafety.org/knowledge-why_do_road_crashes_happen-2.html, retrieved on 1-5-2010.

References

Ackerman, R.O., K . M. Gwilliam, and L. S. Thompson. 1998. The World Bank, transport and the environment. *Japan Railway & Transport Review* 18: 13-39.

APROSYS. 2004. Strategies for enhanced pedestrian and cyclist friendly design (Rep. No. AP-SP-21-0062). Aachen: RWTH.

Bhalla, K. , G. Tiwari, D. Mohan, M. Ezzati, and A. Mahal. 2006. Buses and urban road safety. TRIPP working paper, Indian Institute of Technology Delhi (unpublished).

Bhalla K., M. Ezzati, A. Mahal, J. Salomon, and M. Reich. 2007. A risk-based method for modelling traffic fatalities. *Risk Analysis* 27: 125–36.

Chawla, A., D. Mohan, V. Sharma, and J. Kajzer. 2000. Safer truck front design for pedestrian impacts. *Crash Prevention and Injury Control* 2(1): 33-43.

CRRI, Central Road Research Institute. 2002. Expert committee on auto fuel policy study reports, volume 1. Government of India, August.

DIMTS. 2010. Road accident data on Delhi BRT corridor, 2001-2009. Road accident searches on http://www.dimts.in/

Delhi Traffic Police. 2004. Traffic accidents in Delhi 2003-2004.

Echeverry, J. C., A. M. Ibanez, and L. C. Hillion. 2004. The economics of Transmilenio, a mass transit system for Bogota (Rep. No. CEDE 2004-28). Bogota: CEDE, Universidad de los Andes.

Elsenaar, P., and S. Abouraad. 2005. *Road Safety Best Practices - Examples and Recommendations*. Global Road Safety Partnership.

Elvik, R., and Vaa, T. 2004. The handbook of road safety measures.

Gakenheimer, R. 1999. Urban mobility in the developing world. *Transportation Research Part A* 33: 671-689.

Gakenheimer, R. 2004. Drivers of travel demand in cities of the developing world.

Granados, J. A. T. 1998. Reducing automobile traffic: An urgent policy for health promotion. *Pan Am J Public Health* 3(4).

Gururaj, G. 2006. Road traffic injury prevention in India. Bangalore: National Institute of Mental Health and Neuro Sciences.

Gururaj, G., A. A. Thomas, and M. N. Reddi. 2000. Under-reporting of road traffic injuries in Bangalore: Implications for road safety policies and programmes. *Injury Prevention and Control, Proceedings 5th World Conference*. Delhi: Macmillan India Ltd.

Hanowski, R.J., J. S. Hickman, R. L. Olson, R.L., and J. Bocanegra. 2009. Evaluating the 2003 revised hours-of-service regulations for truck drivers: The impact of time-on-task on critical incident risk. *Accident Analysis & Prevention 41*: 268-275.

Ingram, G.K., and Z. Liu. 1999. Determinants of motorization and road provision. World Bank Policy Research Laboratory, PR/INT/659/2000.

Jacobs, G., and A. Aeron-Thomas. 2000. Africa road safety review - final report. Transportation Research Laboratory, PR/INT/659/2000.

Kajzer, J., Y. K. Yang, and D. Mohan. 1992. Safer bus fronts for pedestrian impact protection in bus-pedestrian accidents. *Proceedings 1992 International IRCOBI Conference on the Biomechanics of Impacts*. IRCOBI, Bron, France.

Koornstra, M., D. Lynam, G. Nilsson, P. Noordzi, H-E. Pettersson, F. Wegman, and P. Wouters. 2002. A comparative study of the development of road safety in Sweden, The United Kingdom and the Netherlands. SWOV Institute of Road Safety Research, SWOV, Leidschendam.

Litman, T. 2004. Integrating public health objectives in transportation decision making. *American Journal of Health Promotion* 18(1): 103-108.

Litman, T., and S. Fitzroy. 2005. Safe travels. Victoria Transport Policy Institute, www.vtpi.org.

Maunder, D. A. C., and T. C. Pearce. 2000, Bus accidents: An additional burden for the poor. CODATU IX Conference, Mexico City, 11-14 April 2000 (also TRL report PA3535/99).

Mirza, S., M. Mirza, H. Chotani, and S. Luby. 1999. Risky behavior of bus commuters and bus drivers in Karachi, Pakistan. *Accident Analysis and Prevention* 31: 329-333.

Mohan, D. 1985. An analysis of road traffic fatalities involving city bus service in Delhi. *Proceeding X Congress of IAATM*. IAATM, Stockholm.

Mohan, D. 2004. The road ahead: Traffic injuries and fatalities in India. World Health Day, 14th April, New Delhi.

Mohan, D., et al. 1997. Delhi on the move 2005: Future traffic management scenarios. Report prepared for CPCB by Transportation Research and Injury Prevention Programme, IIT Delhi.

Mohan, D., and G. Tiwari. 1998. Road safety in low income countries: Issues & concerns. In *Reflections on the Transfer of Traffic Safety Knowledge to Motorising Nations*, Global Traffic Safety Trust, Australia.

Mohan, D., and G. Tiwari. 2000. Road safety in less motorized countries – Relevance of international vehicle and highway safety standards. *Proceedings of the International Conference on Vehicle Safety*, IMechE.

Mohan, D., and G. Tiwari, G. 2000. Road safety in less motorized countries – Relevance of international vehicle and highway safety standards. *Proceedings of the International Congerence on Vehicle Safety*, IMechE.

Mohan, D., O. Tsimhoni, M. Sivak, and M. J. Flannagan. 2009. Road safety in India: Challenges and opportunities.University of Michigan, Transport Research Institute.

Mulhrad, N. 2005. Systems analysis of traffic crashes. In *The Way Forward: Transportation Planning and Road Safety*, eds. Tiwari, G., D. Mohan, and N. Mulhrad. Macmillan India Limited, New Delhi.

Rumar, K. 1985. The role of perceptual and cognitive filters and observed behavior. In Evans, L., and R. C. Schwing, *Human Behaviour and Traffic Safety*. New York: Plenum press.

Sperling, D., and Salon, D., 2002. Transportation in developing countries – An overview of greenhouse gas reduction strategies, Pew Center on Global Climate Change.

SynthRep Synthesis. 2000. Report on environmentally sustainable transport: Futures, strategies and best practices. Vienna: Austrian Ministry of Agriculture, Forestry, Environment and Water Management.

Tiwari, G. 1994. Safety aspects of public transport vehicles. *Journal of Traffic Medicine* 22: 153-160.

Tiwari, G. 2005. Data recording systems. In *The Way Forward: Transportation Planning and Road Safety*, eds. Tiwari, G., D. Mohan, and N. Mulhrad. New Delhi: Macmillan India Limited.

Tiwari, G., D. Mohan, and R. Muskaug. 1998. Mumbai Urban Transport Project 2: Accident Study. New Delhi, TRIPP, Indian Institute of Technology Delhi. Final Report prepared for the World Bank.

Wegman, F. 2001. A Road safety information system: From concept to implementation. SWOV, The Netherlands. www.swov.nl/ rapport/D-2001-14.pdf.

Wilbur Smith Associates. 2008. Study on traffic and transportation policies and strategies in urban areas in India. Prepared for Ministry of Urban Development. Government of India.

Yong, W., and L. Xiaojiang. 1999. Targeting sustainable development for urban transport. Beijing, CICED., Workshop on Urban Transport and Environment.

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Evaluating the Technical Efficiency of Trolley Buses in Athens, Greece

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Abstract

Efficiency measurement traditionally has been an important approach of evaluating public firm performance. The purpose of this paper is to estimate the technical efficiency of Trolley Buses of the Athens and Piraeus Area (TBAPA) in Greece for the year 2003. The estimation of technical efficiency is based on the Stochastic Frontier Analysis (SFA) and employs the Cobb-Douglas specification of the production function. Meanwhile, an attempt is made to investigate the explanatory power of other factors on the organization's technical efficiency, such as the impact of other competitive means of transportation and the distance of the areas that each line connects. The panel data set consists of the monthly observations of the 20 lines of TBAPA for the year 2003. Finally, our findings are compared with those from Data Envelopment Analysis (DEA), a popular approach in the literature, providing, in general terms, consistent results.

Introduction

TBAPA (Trolley Buses of the Athens and Piraeus Area) was founded in 1970. It is a public Greek company, part of the general Athens Urban Transit Organization (AUTO), responsible for the operation of the trolley bus network. Its main task is to deliver transportation services via electric buses according to schedules and programs that are drafted by AUTO. In 2008, TBAPA had 22 trolley bus lines, which covered more than 350 kilometers in Athens and Piraeus. The fleet consisted of 366 trolley buses, 51 of which were articulated. A total of 12 million passengers use them every year. According to the official TBAPA site, the company has approximately 1,600 employees.

The area of greater Athens, situated on the southern coast of mainland Greece, is 3,200 square kilometers, including the port of Piraeus. It concentrates one third of the population of Greece in about 2.8 percent of the country's total area and is the main urban center of Greece. Athens scores well in almost all "social" indicators, has a very low crime rate in Europe, and has a low income disparity. Business is mainly composed of small- and medium-size enterprises, and the educational level of the Athenian labor force is high (OECD 2004).

Since the late 1990s, the Athens region has benefited from a period of exceptional financing and promotion related to the Olympic Games of 2004 and the EU (European Union) Support Funds (MoF 1998), which boosted investment in infrastructure and a modern region-wide transport network. This included a brand-new international airport; urban highways and ring roads to decrease congestion; upgraded rail links; a new metro; a non-polluting bus fleet; and tramway lines that connect the city center and the suburbs (OECD 2004).

However, Athens still has considerable potential for growth. It needs clear strategic planning to take advantage of the opportunities that globalisation is bringing. In fact, Athens has considerable potential for development in its role as international gateway to Greece, the eastern part of the enlarged European Union, and the Middle East. However, fulfilling this role will require strategic responses from the Greek government and the authorities of Athens and the surrounding region of Attica to a number of specific challenges (OECD 2004).

In this context, it is an important challenge for the economy's authorities to estimate the technical efficiency of TBAPA for each one of its 20 lines for the year 2003. This is a particularly appealing topic for many reasons: (1) Athens is one of the very few European capitals in which trolley buses are used, and (2) trolley buses were one of the main means of transportation in Athens in 2003, when the Athens metro network was still very limited. Besides, in the early 2000s, the Greek Department of Transportation (GDT), in collaboration with the Athens Urban Transit Organization (AUTO), introduced certain reforms in order to promote competition and thus increase efficiency and productivity. One of these reforms was the implementation of Exclusive Bus Lanes.

Review of the Literature

Asensio and Trillas (2006) measured technical efficiency in the Spanish suburban railway for 11 cities in Spain for the 2000-2004 time span, by means of DEA. Furthermore, they measured Total Factor Productivity (TFP) change with a Malmquist index and decomposed it into its various sources. The results indicated the importance that technical change has had as determinant of productivity improvements. While all cities in the sample experienced positive technical change, technical efficiency, on average, decreased in the period under investigation.

Roy and Yvrande-Billon (2007), using a panel data set consisting of 135 different French urban transport networks over the 1995-2002 time span, investigated the impact of ownership structure and contractual choices on technical efficiency in the French urban public transport sector by means of SFA. The empirical results showed that technical efficiency depended on ownership structure and the type of contract governing their transactions. Specifically, private operators outperformed public ones, and operators under cost-plus contracts exhibited a higher level of technical efficiency than operators under fixed-price agreements.

De Borger and Kerstens (2006) provided a theoretical analysis of the performance of bus-transit operators. In fact, they summarized the results about the economic performance of bus-transit operators by focusing on productivity growth and efficiency. More importantly, they reviewed the most relevant technological, environmental, and regulatory determinants of productivity growth and differences in efficiency levels between operators. A first conclusion was that productivity growth of bus-transit operators was either negative or mildly positive. Second, substantial inefficiencies remained among bus operators, although there were huge differences over time and across the countries. Third, an important conclusion was that the ownership structure was not so crucial in explaining differences in efficiency among operators. Finally, although many uncertainties remain, deregulation was likely to improve performance in a number of different respects.

Tsamboulas (2006) presented a comprehensive approach for the ex-ante evaluation and identification of relevant impacts related to the implementation of Exclusive Bus Lanes (EBL). He proposed relevant indicators to measure the impacts related to key stakeholders–public transport operators, taxis, private vehicle drivers, and passengers, as well as society–regarding energy and the environment. The ex-ante evaluation method was based on Cost Benefit Analysis (CBA) and was designed to assist any decision regarding implementation of EBL by determining whether it is beneficial. An empirical application was provided for Athens, where

EBLs were introduced to accommodate traffic for the Olympic Games of 2004. The findings of the study showed that the costs and benefits depend on an area's situation. Also, EBL facilities were found to benefit low-income travelers while imposing costs on high-income travelers.

Walter and Cullmann (2008) analyzed potential gains from hypothetical mergers in local public transport, using DEA with bias corrections by means of bootstrapping in a sample of 41 public transport companies from North Rhine-Westphalia, the most densely populated region in Germany. The mergers were into geographically-meaningful larger units that operated partially on a joint tram network. Merger gains were then decomposed into individual technical efficiency, synergy, and size effects. The findings suggested that the incorporation in rail-bound local public services was necessary, although they would better be analyzed on a case-by-case basis. The impact on the population and network density is not substantial in an already densely populated area. Regarding the merger gains, they must be expected for bus, tram, and light railway mergers and smaller bus mergers, but for larger bus mergers.

Methodological Framework

Stochastic Frontier Analysis

In 1957, Farrell (1957) provided us with the definition of technical efficiency and, until the late 1970s, its empirical application was relatively limited. Aigner et al. (1977), introduced the stochastic frontier production function, and Meeusen and van den Broeck (1977) presented the Cobb-Douglas production function with a composed multiplicative disturbance term. Since then, Farrell's idea became a useful tool for estimating technical (in)efficiency.

There are three main approaches for measuring technical efficiency: parametric (deterministic and stochastic), non-parametric based on Data Envelopment Analysis (DEA), and productivity indices based on growth accounting and index theory principles (Coelli et al. 1998). DEA and SFA are the most widely used methods for calculating the technical efficiency of a firm. The SFA approach requires a functional form to estimate the frontier production function and is based on the idea that the data are contaminated with measurement errors and other noise (Bauer 1990). The DEA approach uses linear programming techniques to estimate a piece-wise frontier that envelops the observations and requires no specific functional form for the production function (Fried et al. 1993).

The specification of the adopted model starts with the assumption that the technology applied in the production process can be described by a twice differentiable production function which relates the flow of output with various inputs of production. In algebraic terms, the stochastic production frontier (SPF) can be expressed as:

$$y = f(X,\beta)exp(\varepsilon),\ \varepsilon = (v-u),\ u>0 \qquad (1)$$

where: y is the observed output quantity; f is the deterministic part of the frontier production function, X is a vector of the input quantities used by the firm, β is a vector of parameters to be estimated, v is a symmetrical random error, and u is a one-sided non-negative random error term representing technical efficiency. It is assumed that f is finite for every X, and continuous for all nonnegative y and X. The elements of v represent the conventional normal distribution of random elements including measurement errors, omitted variables, and other exogenous factors beyond the firm's control. The elements of u indicate shortfalls of the firm's production units from the efficient frontier.

Thus, technical efficiency is measured by the ratio:

$$TE = y / [f(X)exp(v)] = exp(-u)$$

and has a value between 0 and 1, with 1 defining a technically efficient firm. Given a parametric functional form for f and distributional assumptions about u and v, equation (1) can be estimated by Ordinary Least Squares (OLS).

More specifically, equation (1) is written as:

$$ln(y) = ln[f(X)] + v - u \qquad (2a)$$

$$ln(y) = - \mu + ln[f(X)] + (v-u+\mu) \qquad (2b)$$

where: $\mu = E(u)>0$.

The estimation of the SPF by OLS leads to consistent estimators for all the parameters, μ included, under the assumption that v is normally and u is half-normally distributed. The rationale behind normality is simply convenience at the estimation stage, plus the fact that we lack information upon which to base alternative assumptions.

Estimation of equation (2) by OLS gives the residuals e_i, i = 1, 2, ..., N. The second and third central moments of the residuals, $m_2(e)$ *and* $m_3(e)$, respectively, are calculated, as follows:

$$m_2 (e) = [1/(N-k)] \cdot \Sigma e_i^2 \quad (3a)$$

$$m_3 (e) = [1/(N-k)] \cdot \Sigma e_i^3 \quad (3b)$$

where: N is the number of observations and k is the number of regressors, the constant term included. Then, we estimate σ^2_u and σ^2_v using the formulae (Georganta 1993):

$$\sigma^2_u = [(\pi/2)[(\pi/(\pi-4)]m_2(e)]^{2/3} \quad (4a)$$

$$\sigma^2_v = m_2 (e) - [(\pi-2)/\pi)] \sigma^2_u \quad (4b)$$

Following Battese and Coelli (1988), the point measure of technical efficiency is:

$$TE_i=E(exp\{-u_i\}/\varepsilon_i)=[[1-F[\sigma^{\cdot}-(M_i^*/\sigma^{\cdot})]/[1-F^{\cdot}(-M_i^*/\sigma^{\cdot})]exp[-M_i^* + (\sigma^{\cdot 2}/2)] \quad (5)$$

where: $F\cdot$ denotes the distribution function of the standard normal variable. Also:

$$M_i^* = (-\sigma^2_u\varepsilon_i)(\sigma^2_u + \sigma^2_v)-1 \quad (6a)$$

$$\sigma^{\cdot 2} = \sigma^2_u \sigma^2_v (\sigma^2_u + \sigma^2_v)-1 \quad (6b)$$

Data Envelopment Analysis

DEA is an efficiency evaluation method based on mathematical programming techniques (see, for instance, Poitras et al. 1996). In contrast to parametric approaches, DEA optimizes each individual observation with the objective of calculating a discrete piece-wise frontier determined by the set of Pareto efficient Decision Management Units (DMUs). DEA is based on the idea that the efficiency of a DMU is determined by its ability to transform inputs into desired outputs. DEA generalizes the single output/input technical efficiency measure to multiple outputs/inputs by constructing a relative efficiency measure based on a single "virtual" output and a single "virtual" input. The efficient frontier is then determined by selecting DMUs that are most efficient in producing the virtual output from the virtual input. Because DMUs on the efficient frontier have an efficiency score equal to 1, inefficient DMUs are measured relative to the efficient DMUs.

More formally, assume that there are n DMUs to be evaluated. Each DMU_j consumes varying amounts of m different inputs to produce s different outputs. Specifically, DMU_j consumes amounts $X_j = \{x_{ij}\}$ of inputs $(i = 1,..., m)$ and produces amounts $Y_j = \{y_{rj}\}$ of outputs $(r = 1,..., s)$. The $s \times n$ matrix of output measures is denoted by Y, and the $m \times n$ matrix of input measures is denoted by X. Also, assume that $x_{ij}>0$ and $y_{rj}>0$. Consider the problem of evaluating the relative efficiency for any one of the n DMUs, which will be identified as DMU_0. Relative efficiency for DMU_0 is calculated by forming the ratio of a weighted sum of outputs to a weighted sum of inputs, subject to the constraint that no DMU can have a relative efficiency score greater than unity. Algebraically:

$$\max_{u,v} \frac{\sum_r u_r y_{ro}}{\sum_t v_t x_{to}} = \frac{u^T Y_0}{v^T X_0} \tag{7a}$$

where: $u=(u_1,...u_s)^T$, $v=(v_1,...,v_m)^T$

subject to:

$$\frac{u^T Y_j}{v^T X_j} = \frac{\sum_r u_r y_{rj}}{\sum_t v_t x_{tj}} \le 1 \tag{7b}$$

for $j = 1,2,...,n;\; u_r, v_i \ge 0$ *for* $r = 1,2,\dots,s,\; i = 1,2,\dots,n$

where: u_r and v_i are weights assigned to input r and output i, respectively.

For this fractional programming problem with a potentially infinite number of optimal solutions, Charnes et al. (1978) were able to specify an equivalent linear programming problem. This requires introduction of a scalar quantity (θ) to adjust the input and output weights:

$$\theta = \frac{1}{v^T X_0},\; \mu^T = \theta u^T,\; \omega = \theta v^T$$

Appropriate substitutions produce the linear programming problem:

$$\max_{\mu,v} \Lambda_0 = \sum_r \mu_r y_{r0} = \mu^T Y_0 \tag{8a}$$

subject to:

$$\omega^T X_0 = \sum_t \omega_t x_{t0} = 1,\; \sum_r \mu_r y_{rj} - \sum_t \omega_t x_{tj} \le 0,\; \mu_r, \omega_t \ge \in \tag{8b}$$

where the value of Λ_0 is the relative efficiency of DMU_0 and $\in$ is positive constant, called the non-Archimedian infinitesimal, which is introduced to facilitate solving of the linear programming problem. In DEA, this linear programming problem is known as the CCR.

Data and Variables

The panel data set consists of the monthly observations of the 20 lines (see Table 1) of the TBAPA in 2003. The numbering is interrupted because several lines were abolished and new ones created. Table 1 shows that the trolley bus network covers a large surface of Athens and Piraeus, serving areas from the center of Athens to the eastern, western and northern suburbs and Piraeus and its surroundings. However, the network does not serve the southern suburbs of Athens, as those areas became important centers many years after the network was developed.

Table 1. TBAPA Lines in 2003

No.	Line	Route Way
1	Line 1	Attikis Sq.- Moshato
2	Line 2	Kipseli - Pagrati - Kesariani
3	Line 3	Patisia - Girokomio
4	Line 4	Ano Kipseli - St. Artemios
5	Line 5	Lamprini - Koukaki (Gigifies)
6	Line 6	Athens - Kokkinos Milos
7	Line 7	Panepistimiou - Alexandras Av.
8	Line 8	Alexandras Av. - Akadimia
9	Line 9	Ano Kipseli - Zappio
10	Line 11	Koliatsou - N. Pagrati - N. Helvetia
11	Line 12	Zappio - Peristeri - (St. Ierotheos)
12	Line 13	Lamprini - Papadiamantis Sq. - N. Psihiko
13	Line 14	Papadiamanti Sq. - Alexandras Av.- N.Psihiko
14	Line 15	El. Venizelou - Petralona
15	Line 16	Piraeus - St. Ioannis Rentis (ring route)
16	Line 17	Piraeus - St. Georgios (ring route)
17	Line 20	Athens - P. Ralli - Nikea
18	Line 21	Athens - P. Ralli - Nikea
19	Line 24	Zappio - Helion - Petroupoli
20	Line 25	Karaiskakis Sq. - Peristeri - Helion. - Kamatero

The available panel data set consists of four variables. The single output is the total vehicle-kilometers. The inputs are the total labour expanded, the total available vehicles, and the total energy expanded (electricity) by the fleet of the vehicles of each line. Each one of these variables reflects the operational characteristics of each line of the TBAPA.

More precisely, the output of our model reflects the kilometers that are covered by the fleet of the vehicles of each line in total. The total number of the vehicle-kilometers is estimated by the total number of the route ways multiplied with the length of each line. The number of the route ways of each line is scheduled by AUTO. With regard to the independent variables of the model, the energy expanded depends on several factors, such as the number of the passengers carried by the fleet of the vehicles, the number of the vehicles used, their average speed, the traffic situation, and the geographical characteristics of each route. The employees can be drivers, ticket collectors, or stationmasters. Finally, the number of the vehicles of each line is scheduled by the TBAPA and AUTO and depends on the number of the passengers each line serves and on the length of each line.

Moreover, to assess the impact of some other exogenous factors, two dummy variables were introduced (see Table 2). The first dummy variable (d_1) represents the influence of the Athens Metro, while the second dummy variable (d_2) expresses the distance of the areas that each line serves.

Table 2. Dummy Values

Line	Dummy I (d_1)	Dummy II (d_2)
1	1	1
2	1	0
3	1	1
4	1	0
5	1	1
6	1	1
7	0	0
8	0	0
9	1	0
11	1	1
12	1	1
13	1	1
14	1	1
15	1	0
16	1	0
17	1	0
20	1	1
21	1	1
24	1	1
25	1	1

More precisely, passengers prefer to use the Athens Metro, which offers a quicker and more comfortable trip to their destination, and, in this context, we make the assumption that the lines that serve areas directly connected with the Metro are negatively affected. In other words, the dummy takes the value zero (0) when the line connects areas that are served by the Metro, otherwise one (1).

The second dummy variable expresses the distance of the areas connected by a certain line. The lines that connect areas that are both in the center of Athens or Piraeus take the value zero (0); otherwise, lines that connect the center of Athens or Piraeus with the suburbs or a suburban area to another suburban area take the value one (1). This is based on the assumption that the connection of distanced areas directly by one means of transportation, such as a trolley bus line, is expected to increase its passengers.

Empirical Results

From a methodological point of view the question of technical efficiency is examined by using the Cobb-Douglas specification of the production function. Thus, the adopted functional form, corresponding to equation (1), is:

$$lnY = a_o + a_1 lnE + a_2 lnL + a_3 lnK + a_4 d_1 + a_5 d_2 + v - u$$

where: *Y* is a measure of output, *E* is a measure of energy spending, *L* a measure of labour, *K* a measure of the available vehicles, d_1 is the first dummy variable which represents the impact of the Athens Metro, and d_2 is the second dummy variable that represents the impact of the distance between the areas that each line connects.

In the regression results, the variables *K* and *E* were statistically non-significant and had to be removed from the model. As a result, the model had to be re-estimated from scratch. Thus, the Cobb-Douglas production function finally took the form:

$$lnY = a_o + a_2 lnL + a_4 d_1 + a_5 d_2 + v - u$$

The regression results are illustrated in Tables 3 and 4. The R-squared statistic indicates that the model as fitted explains almost 80 percent of the variability in output, which means that the regression analysis provides a very good fit to the data and all the variables are highly significant. Moreover, the significance of the factors that are represented by the two dummy variables is confirmed.

Table 3. Regression Analysis Results

Parameter	Estimate	t-Statistic	P-Value
a_0	4.206	13.664	0.000
a_2	0.823	17.642	0.000
a_4	0.248	3.654	0.000
a_5	0.183	4.969	0.000

Table 4. Analysis of Variance

R-Squared	R-Squared (adj)	D.W.	F-Ratio	P-Value
79.9%	79.1%	1.83	312.33	0.0000

The next step is, through equations (3a, 3b, 4a, 4b), to estimate the second and third central moments, σ^2_u and σ^2_v. After measuring the second and third central moments, σ^2_u and σ^2_v, we are able to estimate the technical efficiency of each line. Table 5 presents the measures of technical efficiency (TE). The results range between 83.91 percent and 94.86 percent, with an average equal to 91.26 percent. Lines 17, 3, and 21 are the most technically efficient in our panel data set, while line 24 is the least efficient one. Lines 7 and 8, which are influenced by the operation of the Athens Metro, are not found to be among to the most efficient ones, a result that is consistent with our assumption expressed through the first dummy.

Table 5. Technical Efficiency Measures (%) and Line Rankings

Line	TE (%)	Ranking	Line
1	92.98	1	17
2	90.90	2	3
3	94.20	3	21
4	90.89	4	5
5	93.76	5	13
6	92.76	6	1
7	90.75	7	20
8	92.59	8	6
9	84.98	9	8
11	88.77	10	15
12	90.79	11	25
13	93.47	12	16
14	87.35	13	2
15	92.48	14	4
16	91.6	15	12
17	94.86	16	7
20	92.77	17	11
21	93.84	18	14
24	83.91	19	9
25	91.63	20	24

Comparison with DEA

In this section, we compare the SFA technical efficiency estimates with the DEA respective results (Kagiantalides 2004) (see Table 6). It is not a strict comparison, because the variables in the two approaches are different, given that DEA is a non-parametric technique that does not specify a production function for the estimation of technical efficiency.

Table 6. SFA and DEA Technical Efficiency Measures

Line	SFA	DEA
1	92.98	95.68
2	90.90	91.05
3	94.20	100.00
4	90.89	91.82
5	93.76	100.00
6	92.76	93.47
7	90.75	67.02
8	92.59	75.76
9	84.98	71.06
11	88.77	90.05
12	90.79	84.29
13	93.47	100.00
14	87.35	82.38
15	92.48	79.34
16	91.6	87.94
17	94.86	98.84
20	92.77	96.01
21	93.84	98.78
24	83.91	71.00
25	91.63	90.93

DEA technical efficiency measures range in relatively high levels, with an average equal to 88.27 percent. As can be inferred from DEA estimates, there are bigger gaps between the technical efficiency measures from line to line in comparison to their SFA counterparts. As we know, conventional DEA attributes the entire distance from the frontier to inefficiency as it cannot discriminate between inefficiency and noise.

To compare the results from the two approaches, we examine the line rankings in both methodologies. The ranking correlation is 84.06 percent, which is particularly high. This implies that regardless of the differences in the estimates between the two approaches, the results are consistent. Indeed, lines 1, 3, 5, 13, 17, 20, and 21 are among the most efficient lines, regardless of the methodology used. Furthermore, lines 2, 4, 6, 16, and 25 ranked in the middle of the sample, while 7, 9, 14, and 24 are among the least efficient lines in both methodologies.

Table 7. Line Rankings

Ranking	SFA	DEA
1	92.98	95.68
1	17	3
2	3	5
3	21	13
4	5	17
5	13	21
6	1	20
7	20	1
8	6	6
9	8	4
10	15	2
11	25	25
12	16	11
13	2	16
14	4	12
15	12	14
16	7	15
17	11	8
18	14	9
19	9	24
20	24	7

Result Analysis and Discussion

As was mentioned before, in 2003, trolley buses were, apart from conventional buses and electric railway, the main public mean of transportation in Athens, since the Metro network was still very limited. The large surface that trolley buses covered, combined with the relatively cheap tickets due to the public character of the company, made this mean very popular among the middle and low income populations in Athens.

Moreover, another fact that affected this mean's performance was the implementation of Exclusive Bus Lanes (EBL). EBL eliminated crosses between public and private means and taxis, making the first faster with fewer delays. As a result, the implementation of EBL improved the reliability of the mean. A very important factor that is also closely related with trolley bus operational performance is the central management of this mean. TBAPA and AUTO allocate vehicles, energy, and labour centrally according to the demand of each line to minimize the waste of inputs. This is obviously reflected to the technical efficiency measures.

Since the operational management of the trolley buses is done by a central authority and the allocation of inputs (e.g., vehicles, energy, and labour) to each line is in accordance to its demand (which is directly connected with the output of our model), it is normal to expect very small differences among the line's technical efficiency measures.

The differences could be explained by several factors. A first factor is the length of each line and the areas that it connects. The SFA results indicated that the length of each line positively affects the line's technical efficiency. Lines 1, 3, 6, 13, 20 and 21, which are among the most efficient, are those that directly connect certain distanced areas. This result is also confirmed by the DEA results.

The second factor has to do with the question of whether (or not) the areas that are connected by trolley buses are also served by other competitive means of transportation, such as the Athens Metro. Our empirical findings indicated that line 7, which serves areas near the center of Athens, is among the least efficient lines in both methodologies.

These factors are crucial for the future performance of the organization. Since 2003, the Athens Metro network has expanded rapidly. In this context, a new strategic planning of the trolley buses network would be relevant, especially now that a tram network also is available in Athens.

Conclusion

The purpose of this paper was the estimation of technical efficiency of the trolley Buses in Athens and the Piraeus area for each of its 20 lines for the year 2003 by means of SFA using panel data. Also, we made an attempt to assess the explanatory power of other factors on the organization's technical efficiency, such as the effect of other competitive means of transportation and the distance of the areas that the trolley bus lines connect, by introducing relevant dummy variables into the model. Furthermore, a comparison between the SFA estimates with the ones measured with the aid of the deterministic approach of DEA was attempted.

The production function provided a very good fit to the data, and the variables included in the model were highly significant. Moreover, the significance of certain exogenous factors, which are represented by the two dummy variables, also was confirmed. As for the estimated technical efficiency measures, they range in high levels. More precisely, technical efficiency has an average equal to 91.26 percent and 88.27 percent with the SFA and DEA methodologies, respectively. The ranking of the lines is, in general terms, consistent when measured with the aid of the two respective methodologies, with the ranking correlation to be equal to 84.06 percent.

In explanation of the estimated technical efficiency measures, the implementation of Exclusive Bus Lanes and the central operational management of the trolley buses in Athens affected positively an already-popular public means of transportation. However, lines that connect directly-distanced areas seem to be more efficient than those that serve areas that are also connected with other competitive means, such as the Athens Metro. No doubt, clear strategic planning is needed to take advantage of the opportunities that the increasing transportation network in Athens is bringing.

References

Asensio, J.. and F. Trillas. 2006. Technical efficiency and productivity measurement of Spanish suburban railways. Unpublished manuscript, http://www.ecap.uab.es/ secretaria/seminaris/asensio-trillas_9ene06.pdf.

Aigner, D., C. A. K. Lovell, and P. Schmidt. 1977. Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics* 6: 21-37.

Battese, G., and T. Coelli. 1988. Prediction of firm level technical efficiency with a generalized frontier production function and panel data. *Journal of Econometrics* 38: 387-399.

Bauer, P. W. 1990. Recent developments in the econometric estimation of frontiers. *Journal of Econometrics* 46: 39-56.

Charnes, A., W. W. Cooper, and E. Rhodes. 1978. Measuring the efficiency of decision making units. *European Journal of Operational Research* 2: 429-444.

Coelli, T.G., D. S. Prasada Rao, and G. Battese. 1998. *An Introduction to Efficiency and Productivity Analysis*. Norwell: Kluwer Academic Publishers.

DeBorger, B., and K. Kerstens. 2006. *The performance of bus-transit operators*. University of Antwerp, CNRS-LEM (UMR 8179), IESEG School of Management, Lille. France.

Farrell, M. J. 1957. The measurement of productivity efficiency. *Journal of the Royal Statistical Society* 120: 253-290.

Fried, H. O., C. A. K. Lovell, and S. S. Schmidt. 1993. *The Measurement of Productive Efficiency—Techniques and Applications*. Oxford: Oxford University Press.

Georganta, Z. 1993. Technical (In)efficiency in the U.S. manufacturing sector, 1977-1982. Discussion Paper. Centre of Planning and Economic Research.

Kagiantalides, N. 2004. Measurement of organizations' technical efficiency by means of data envelopment analysis: The case of the Greek urban public transportation. School of Civil Engineering. National Technical University of Athens, Greece (*in Greek*).

Meeusen, W., and J. van den Broeck. 1977. Efficiency estimation from Cobb-Douglas production functions with composed error. *International Economic Review* 18: 435-444.

Ministry of Finance (MoF) .1998. Current developments and prospects of the Greek and international economy. Athens (*in Greek*).

OECD. 2004. Territorial reviews: Athens, Greece; Paris, France.

Poitras, J., J. Tongzon, and H. Li. 1996. Measuring port efficiency: An application of data envelopment analysis. Department of Economics and Statistics, National University of Singapore.

Roy, W., and A. Yvrande-Billon. 2007. Ownership, contractual practices and technical efficiency: The case of urban public transport in France. *Journal of Transport Economics and Policy* 41(2): 257-282.

Tsamboulas, D. 2006. Ex-ante evaluation of exclusive bus lanes implementation. *Journal of Public Transportation*, BRT Special Edition: 201-217.

Walter, M., and A. Cullmann. 2008. Potential gains from mergers in local public transport: An efficiency analysis applied to Germany. Discussion paper. German Institute for Economic Research / Deutsches Institut für Wirtschaftsforschung.

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Explore: An Attraction Search Tool for Transit Trip Planning

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Abstract

Publishing information about a transit agency's stops, routes, schedules, and status in a variety of formats and delivery methods is an essential part of improving the usability of a transit system and the satisfaction of a system's riders. A key staple of most transit traveler information systems is the trip planner, a tool that serves travelers well if the both origin and destination are known. However, sometimes the availability of transit at a location is more important than the actual destination. Given this premise, we developed an Attractions Search Tool to make use of an underlying trip planner to search online databases of local restaurants, shopping, parks and other amenities based on transit availability from the user's origin. The ability to perform such a search by attraction type rather than specific destination can be a powerful aid to a traveler with a need or desire to use public transportation.

Background

Publishing information about a transit agency's stops, routes, schedules, and status in a variety of formats and delivery methods is an essential part of improving the ease of use of a transit system and the satisfaction of a system's riders. No longer the domain of just simple printed schedules, transit traveler information systems have grown to include route maps and timetables, trip planners, real-time trackers, service alerts, and others tools made available across cell phones, web browsers, and new Internet devices as driven by rider demand (Multisystems 2003).

The primary reason for providing better traveler information as a service to customers is to increase ridership by making transit service easier to use and more convenient. This can be especially true for infrequent transit users and non-peak hour trips, two key markets for improving load factors for many agencies. Transit information appeals most to choice riders and can result in a mode-shift to public transportation (Multisystems 2003). Providing automated user information through trip planners can also reduce the need for call-center representatives to address schedule questions over the phone (Radin et al. 2002).

One of the key staples of most transit traveler information systems is the trip planner. Trip planners use an origin address and destination address to search for a transit vehicle that travels between the two according to the desired time-frame of the traveler. Most trip planners begin with assumptions about walking distance, transfers, and time-frame, requiring a user to enter only two addresses to perform a search. The next step can involve refinements to the initial information provided to narrow or enhance the search for a particular transit trip.

Trip planners have existed for decades, but were used primarily by agencies for in-house call center staff. The first Internet-based transit journey planners were introduced by transit agencies in the 1990s. As of 2002, there were 30 web-based trip planners in the U.S. (Radin et al. 2002). At the time, transit agencies had significant interest in developing online trip planners, with new ones being added at a rate of about one per month. Trip planners were seen as a way to save money, provide better service, and increase ridership, but the agencies lacked the money to implement them and knowledge about GIS, ITS, trip planning vendor terminology, and maintenance of websites (Radin et al. 2002).

Online transit trip planning took a leap forward with the release of Google's transit trip planning lab product in December 2005 and subsequent integration into their Google Maps site in June 2006 as Google Transit. Since the launch of this product, transit agencies of various sizes in 256 cities in 29 countries have provided their data to Google for integration into their system (Google 2009).

Transit Agency Trip Planners Today

Today, the most useful source for pre-trip information is the Internet (Eriksson et al. 2007), especially for younger riders (Farag and Lyons 2008). People typically consult information for a new trip unless their trip has no time constraints, service is frequent, or the journey is local (Farag and Lyons 2008). Among other pre-trip queries by transit customers for occasional trips is "What routes are near my home, work, and other key locations, and what destinations can I reach by transit from these points?" (Multisystems 2003). Table 1 shows the results of our investigation of the trip planners for the 50 transit agencies with the highest unlinked passenger trips in the United States. Trip planners are found on the websites of most of these agencies, either in their own version or through a link to Google. The few agencies without trip planners have provided schedule data to a larger agency in their area.

Although online trip planning has come a long way in the past decade, the current information provided is still considered poor to average in many cases, and there is a desire for higher quality information (Caulfield and Mahony 2007). Efficiency–the ease and speed of accessing and using the site–is the most critical contributor to users' perceptions of a website (Eriksson et al. 2007). In one rating of nine cities based on website performance, static information performance and journey planner performance, Melbourne and London performed the best, but U.S. cities Portland (Oregon) and Washington, D.C. performed well (Currie and Gook 2009).

Recent Enhancements to Trip Planners

The state-of-the-art in trip planning has changed rapidly over the past decade. Beyond the typical trip planner, several transit agencies and third-party developers have added more advanced tools to their trip planners. Recent enhancements include added input capabilities, output capabilities, mapping capabilities, and multi-modal integration.

In addition to the minimal input of an origin address, destination address, and date and time of trip, many trip planners frequently add inputs such as maximum walk distance, maximum number of transfers, need for ADA accessible service, and preferred mode of travel. Rather than just inputting origin and destination by address, some trip planners allow input by intersection, stop or station, landmark, or even by clicking on a map (SEPTA 2009; UTA 2009; Metlink 2009). Cherry et al. (2006) implemented an ArcIMS GIS-based itinerary planner for Sun Tran in Tucson that allows users to select origin and destination on a map in addition to traditional manual address entry or pull-down landmark menus. As they point out, the difficulty in implementing such a feature is in the slow speed of calculation due to the necessity of redrawing the map.

Table 1. Trip Planner Capabilities for the 50 Largest Transit Agencies in the U.S.

	Transit Agency	City	State	2007 UPT	Trip Planner on Website	Google Transit
1	MTA New York City Transit	New York	NY	3,256,977,960	Yes	Yes
2	Chicago Transit Authority	Chicago	IL	499,544,307	Link to Google	Yes
3	Los Angeles Co. MTA	Los Angeles	CA	495,362,403	Yes	Yes*
4	Washington MATA	Washington	DC	411,598,592	Yes	No
5	Massachusetts Bay TA	Boston	MA	357,578,991	Yes	Yes
6	Southeastern Pennsylvania TA	Philadelphia	PA	321,839,783	Yes	Yes*
7	New Jersey Transit Corp.	Newark	NJ	268,289,345	Yes	Yes
8	San Francisco Municipal Rail	San Francisco	CA	206,458,675	Yes	Yes
9	Metro. Atlanta Rapid TA	Atlanta	GA	147,523,544	Yes	Yes
10	King County Metro	Seattle	WA	113,928,156	Yes	Yes
11	Miami-Dade Transit	Miami	FL	111,263,859	Link to Google	Yes
12	MTA Bus Company	New York	NY	110,269,609	MTA NYC	Yes
13	San Francisco Bay Area RTD	Oakland	CA	109,219,470	Yes	Yes
14	Maryland Transit Admin.	Baltimore	MD	108,831,451	Link to Google	Yes
15	MTA Long Island Rail Road	Jamaica	NY	102,143,717	MTA NYC	Yes
16	MTA of Harris County	Houston	TX	100,868,417	Yes	Yes
17	Tri-County MTD	Portland	OR	100,638,004	Yes	Yes
18	Denver RTD	Denver	CO	94,196,136	Yes	Yes
19	Port Authority Trans-Hudson	Jersey City	NJ	82,406,648	NJ Transit	Yes
20	San Diego MTS	San Diego	CA	82,333,186	Yes	Yes
21	MTA Metro-North Railroad	New York	NY	80,324,201	MTA NYC	Yes
22	Metro Transit	Minneapolis	MN	76,966,724	Yes	Yes
23	METRA	Chicago	IL	74,550,584	Link to Google	Yes
24	Dallas Area Rapid Transit	Dallas	TX	73,949,618	Yes	Yes
25	City and Co. of Honolulu DOT	Honolulu	HI	72,557,307	Link to Google	Yes

	Transit Agency	City	State	2007 UPT	Trip Planner on Website	Google Transit
26	Orange County TA	Orange	CA	70,266,572	Yes	Yes
27	Port Authority of Allegheny Co.	Pittsburgh	PA	68,525,198	Yes	Yes
28	Alameda-Contra Costa TD	Oakland	CA	67,414,737	511 SF Bay	Yes
29	RTC of Southern Nevada	Las Vegas	NV	63,733,694	Link to Google	Yes
30	The Greater Cleveland RTA	Cleveland	OH	60,187,823	Yes	Yes
31	Bi-State Development Agency	St. Louis	MO	53,990,802	Yes	Yes*
32	Valley Metro	Phoenix	AZ	50,590,609	Yes	No
33	Milwaukee County Transit	Milwaukee	WI	46,599,318	Link to Google	Yes
34	Santa Clara Valley TA	San Jose	CA	43,434,199	Link to Google	Yes
35	Broward County Office Trans	Pompano Beach	FL	42,442,268	Link to Google	Yes
36	VIA Metropolitan Transit	San Antonio	TX	41,717,688	Yes	Yes*
37	Utah Transit Authority	Salt Lake City	UT	41,349,702	Yes	Yes*
38	Pace - Suburban Bus Division	Arlington Hts	IL	36,590,058	Link to RTA	No
39	City of Detroit DOT	Detroit	MI	35,402,314	Link to Google	Yes
40	Capital MTA	Austin	TX	34,039,638	Yes	Yes
41	MTA Long Island Bus	Garden City	NY	32,440,169	MTA NYC	Yes
42	Sacramento RTD	Sacramento	CA	32,261,658	Yes	Yes
43	Westchester County Bee-Line	Mount Vernon	NY	31,079,433	Link Trips123	No
44	DOT and Public Works	San Juan	PR	30,491,313	No	No
45	City of Los Angeles DOT	Los Angeles	CA	30,205,735	On LA Metro	No
46	Ride-On Montgomery Co. Transit	Rockville	MD	28,302,019	On WMATA	Yes**
47	Long Beach Transit	Long Beach	CA	26,636,190	Link LA Metro	Yes**
48	Southwest Ohio RTA	Cincinnati	OH	26,146,916	Yes	No
49	Central Florida RTA	Orlando	FL	26,078,255	Yes	No
50	Niagara Frontier TA	Buffalo	NY	24,145,786	Yes	Yes

** Added between April 2009 (research initially conducted) and July 2009 (paper submission).*

*** Added since July 2009.*

Using this input, trip planners output at least one potential route in response to the input constraints. These output routes typically include detailed walk, transit, and transfer directions with times of trips, as well the potential to investigate earlier or later trips, fare information, links to schedules, and route maps. This information appears on the screen, but more recent enhancements allow results to be printed, e-mailed, or downloaded to a PDA (Dadnab 2009; MTA 2009). Many agencies now include a button to quickly plan the return trip as well. In addition to mobile tools, BART in San Francisco has one of the best website trip planners in terms of output, with maps of walk and transit components and information such as detailed station information, carbon saved by using public transportation, fare information, and station advisories, all on one output screen (BART 2009).

A critical component of the future of transit trip planning is the ability to integrate trip planners across agencies and across modes. Regional trip planners such as Goroo, the trip planner found on the Chicago area RTA website, typically work through obtaining a feed from all agencies involved in the trip planner (RTA 2009). Regularity of feed data through standards such as the General Transit Feed Specification and the JourneyWeb protocol allow integration of multiple trip planners (Fingerle and Lock 1999). Others have attempted the integration of two completely independent trip planners using a broker that divides the trip between the two systems and assembles the answer for the user. One system was developed and tested for the trip planners in greater Waukesha and Milwaukee, Wisconsin (Peng and Kim 2008).

In addition to integration across agencies, integration across modes is a critical future direction for trip planning. The Google transit trip planner began as an enhancement to its online roadway directions. Multi-modal trip planners have been developed by others prior to Google's work (Chen et al. 1999). More recently, several regions, including greater Chicago, Atlanta, London, and Athens, have developed multimodal trip planners. The Regional Transportation Authority's Goroo trip planner includes the option to obtain directions for train, bus, driving, and drive to bus, comparing the distance, time, cost, and carbon output of the trip for the modes queried (RTA 2009). The A-Train in Atlanta and Transport for London already include cycling and walking routes in their transit trip planners; however, driving is not an option (Citizens for Progressive Transit 2009; Transport for London 2009). In Athens, an urban trip planner has been combined with country-wide coach, air, and ferry service (Zografos 2008).

Beyond the Single Trip Origin/Destination Planner

To aid commuters in their individual transit planning, several agencies have added trip planner tools that go beyond a single origin to destination trip. MTA in New York, MUNI in San Francisco, Seattle's King County Metro, and Minneapolis all have added point-to-point schedules to their websites to allow users to obtain personalized schedules over a range of times between any two locations on the same route.

Many agencies have added "service in area" searches to allow a user to search for routes in the area of a landmark or address. This type of search appeals to someone who is new to a location or new to transit and trying to investigate routes available to one location. However, without consulting maps for each of the routes, these "service in area" tools cannot provide information about potential destinations along the reachable routes.

In addition to these agency trip planners, Google Maps has implemented a Search Nearby tool that allows users to enter an address and then search for attractions nearby by entering a category (doctor, park, etc.). Although users can then click on any of the resulting nearby attractions to find transit directions, it may require several tries before an easily-reachable destination is found.

OneBusAway Explore Tool

Typical online trip planners work well if the destination is known. However, sometimes the availability of transit at a location is more important than the actual destination. For example:

1. A transit-dependent elderly woman needs to find a new doctor's office for regular visits. Although the quality of the care is important, several doctors would be acceptable for her situation. The ability to search for a doctor that is easily reachable via transit can help make her routine trip to the doctor easier on her.
2. A group of college roommates wants to go out drinking and are concerned about getting home without needing to drive. Although some bars are more popular, many would be welcome choices. By having the ability to search a website for easily-reachable bars, the group finds using transit preferable to driving intoxicated.

3. A new mom with a desire to limit her carbon output is looking for activities to entertain her toddler. She is willing to go to any number of local parks or community centers, but would enjoy traveling without her car. Using a reachable attractions search tool allows her to pick a location for their daytrip and travel car-free.

For those looking for a new destination, infrequent riders, or those new to an area, the required questions can be difficult to answer. Such a search would require looking up and typing in multiple destinations into a trip planner and might not be worth the effort. Given this premise, we developed the Explore Attractions Search Tool to make use of an underlying trip planner to search online databases of local restaurants, shopping, and other amenities.

In the first iteration of the Explore tool, a website was created that searched a four-table Microsoft SQL Server database. The user would input a route number and an attraction type (doctor, bar, park, etc.). The program would then search an ordered pattern stop table to translate the route to a list of stops along the route. Using the longitude and latitude of the stops, the program would search a destinations table for the particular category and output a list of possible destinations. The main problem with this approach was that all the data were static GIS data stored locally on a computer and would have had to be maintained by the authors. Therefore, it was decided that the next iteration should rely entirely on data updated by other parties, such as King County Metro, Google, or Yahoo. As the process of redoing the Explore tool began, the authors brainstormed features and interviewed users from different demographic categories to gain input for format and features.

In the current version of Explore, the user specifies his starting point along with what he is interested in searching for. Optionally, a start time and date, a maximum trip length, a maximum number of transfers, and a maximum walking distance may be specified. A screen shot of the introductory data entry screen is shown in Figure 1.

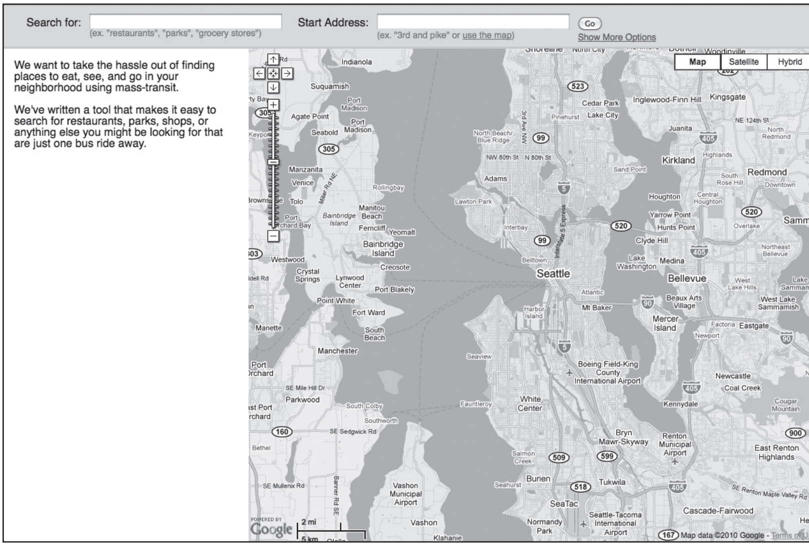

Figure 1. Explore Introductory Data Entry Screen

When the search is submitted, the program executes the search in two steps, as described below. The first step involves computing the total area reachable by transit, given a starting point and any constraints supplied by the user. The second step involves conducting a local search within the reachable transit area for the amenities specified by the user.

Finding the Area Reachable by Transit

To find the total area reachable by transit, we search for the specific set of all transit stops reachable from the user-specified starting location in the specified amount of time along with any additional constraints, such as the number of transfers or max walking distance. This search problem is fundamentally different than the search task undertaken by a typical trip planner. In the typical case, the search is between a known source and destination, so directed search algorithms such as A-Star search can be leveraged to efficiently find paths between the two points. In our case, we have no fixed destination. Instead, we are looking for efficient paths to ALL potential stops and destinations reachable within the constraints specified by the user.

To compute this set of stops, we employ what is essentially Dijkstra's graph search algorithm on a memory-resident street/sidewalk and transit network graph, with a number of optimizations to limit the search space. Effectively, we simulate all potential trips taken by a rider from the starting location, advancing each trip in parallel through time. As each trip reaches a new stop, we note if it was the first trip to reach the stop. If so, we continue modeling the trip. If not, we prune the trip from further consideration, since any travel from this stop going forward would be made using the first trip that had already reached the stop. We stop searching when the length of the longest trips in the current search reach the time window specified by the user.

As an optimization, we pre-compute offline the full set of potential transit transfer points in the transit network graph. Since we are computing the fastest times to reachable stops, as opposed to the set of all points on the street/sidewalk network, our graph search can avoid having to search the street/sidewalk network for potential destinations and transfers and can instead only consider transfer points between stops in the pre-computed set. This optimization dramatically reduces the search space of potential trip itineraries.

Through the careful optimization and pruning in the graph search described above, combined with keeping the entire transit network graph in-memory for fast access, we can usually compute in under 200 ms the set of all reachable stops for a typical time window (20 minutes). This response time is good enough for use in a web application where quick responses to webpage requests are essential for user satisfaction.

Finding Amenities Within in the Area Reachable By Transit

Once the set of reachable stops is computed, the second step of the search begins as we discretize the reachable area into a half-mile grid, including a grid cell if it contains one of the reachable stops. We then start searching for local businesses and amenities as specified by the user within the activated grid cells of the reachable area. The beta version of One Bus Away Explore uses the Yelp (*http://yelp.com*) online database of reviews, but we could just as easily integrate another local search database such as Google Local or Yahoo Local. Once results have been returned, we check them against our street/sidewalk network to ensure that there is a path from a nearby stop to the search result and that the total travel time is still under the specified limit. We wish to avoid search results that are close to a reachable stop, but that are separated by non-walkable barrier such as a major highway or a body of water.

Figure 2 shows the resulting screen from the initial search. In this example, the user has searched for nearby parks within 30 minutes by transit from his home with no transfers. The display of results includes the name of the park, the average rating for that park, and the minimum travel time to that park, along with a display of all the results on a map.

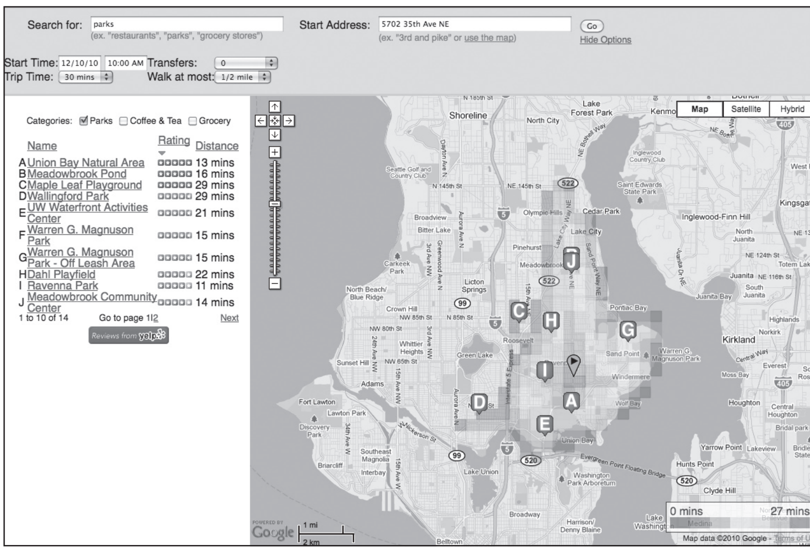

Figure 2. Parks Less Than 30 minutes by Bus from a Seattle Residence

Once a user has settled on a particular park, he can select it for more information, including location and up to three transit trip plans that will get them to their destination at the selected time frame, as shown in Figure 3. By clicking on the individual trip number, the walk and transit paths are explained and shown on the map.

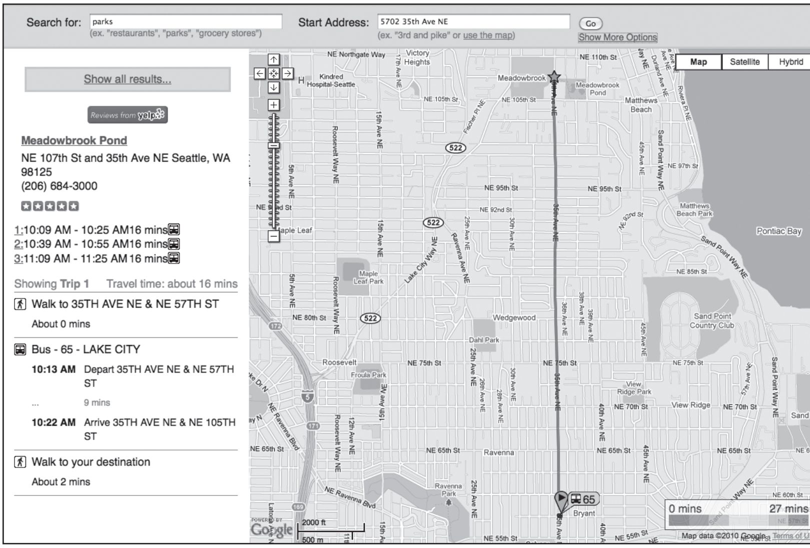

Figure 3. Trip Plan Results for a Specific Park using Explore

A second example search is shown in Figure 4 and Figure 5. In this example, the user has searched for a chiropractor from a local retirement community. The user does not wish to walk very far, so he has opted for a maximum of ¼ mile walk, but is allowing one transfer during the trip. Several choices are available, and a chiropractor close to the university is chosen.

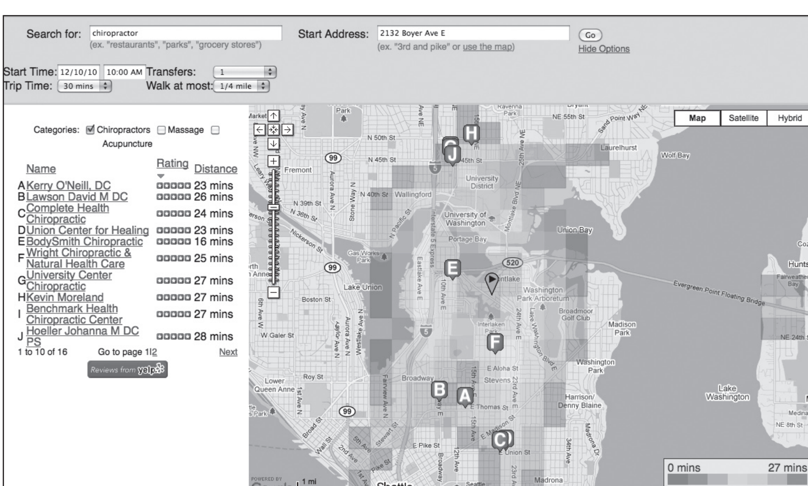

Figure 4. Chiropractors Less Than 30 Minutes by Bus from a Retirement Community

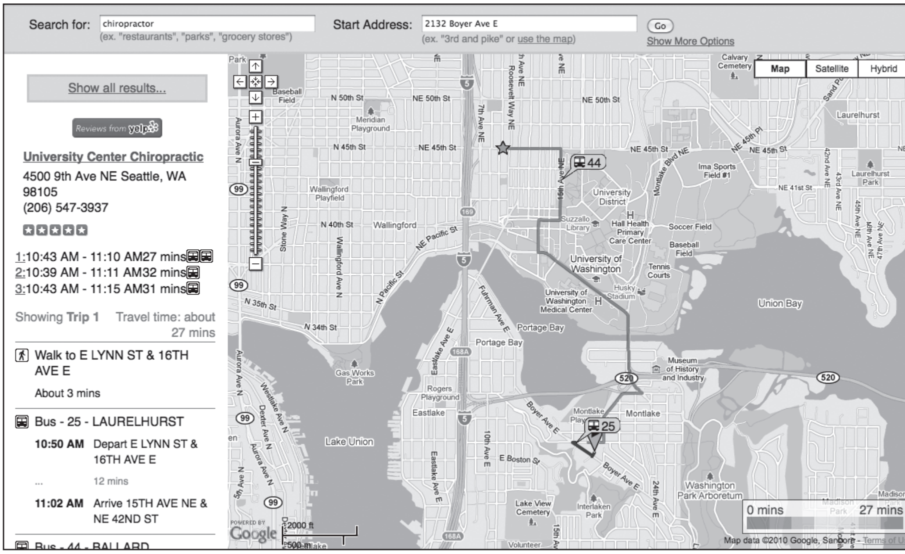

Figure 5. Trip Plan Results for a Specific Chiropractor using Explore

This beta version of Explore has been implemented on the OneBusAway website at *http://onebusaway.org/explore/onebusaway/* using data from King County Metro, an underlying OpenStreetMap transportation network (*www.openstreetmap.org*) and the Yelp online database of reviews (*www.yelp.com*) for a comprehensive list of attractions. Although Yelp is fairly thorough and offers user ratings for its listing, the site is used by a predominantly younger demographic. Future versions may explore the use of another local search database such as Google Local or Yahoo Local to overcome this barrier. All of these local search databases are provided free of charge and are updated by companies other than transit agencies, thus ensuring minimal cost and effort for a program such as Explore. The addition of more transit agencies to the Explore program requires only agency schedule data in the format of the General Transit Feed Spec (GTFS), about one day worth of programming on the part of the developer and adequate server resources.

Next Steps for Explore

The Explore tool is still under development by the OneBusAway project team. Several enhancements and smaller bugs have to be addressed, including the ability to stop a search once an acceptable destination has been shown. One enhancement would add details about the bus frequency and return trip frequency and exceptions (weekdays only or only until 10 p.m.), so that a user does not get stuck at his destination. As mentioned previously, there are some drawbacks to the use of Yelp, especially with the searching of categories in which the word must only appear somewhere in the write-up. Therefore a restaurant near a park may get listed with a "park" category search. We would, therefore, like to add support for Yahoo and Google Search as well. We would like to add features such as a print button to make it easier for the user to print all the needed information. In addition, the user should have the ability to store a search to repeat it or alter it slightly from the last time the site was used. Finally, we think the user should be able to have an option to connect a trip to the original one searched. With this ability to add a second destination, a user could plan an evening including dinner and then a movie, all with the stipulation that the locations would be easily reachable via transit.

In addition to these Explore enhancements, another missing element of the Explore tool is a link to the real-time information that is the cornerstone of OneBusAway (Ferris et al. 2009, 2010). One goal of OneBusAway is to develop many rider information tools, including more tools that build on underlying trip planners, and to add more transit agencies to the system so that the tools can be used outside the metro Seattle area. Our hope is to integrate an open-source trip planner with real-time arrival information and real-time service alerts to create a network of linked transit rider tools. To this end, we are currently working with Tri-Met's Open Trip Planner project as well as undergoing a value-sensitive design process to identify the most needed rider tools and enhancements to the existing OneBusAway tools.

Implications and Future Research

The ability to perform such a search by attraction type rather than specific destination can be a powerful aid to a traveler with a need or desire to use public transportation. Explore allows riders to choose their destinations based on transit availability, which can encourage transit use. The only other existing attraction search tool has been implemented by Google Maps. Although their Search Nearby tool allows users to enter an address and then search for attractions nearby by entering a category (doctor, park, etc.), users interested in determining the transit availability at the destinations may have to try clicking several results before an easily-reachable destination is found.

The Explore tool is one of many possible online search tools to make transit more easily reachable to current and potential riders. In addition to our work at OneBusAway, the WalkScore developers are currently implementing a TransitScore algorithm to inform potential homebuyers and renters about which locations are the most transit-friendly. Their initial efforts are found at *www.walkscore.com/transit-map.php*. By helping riders choose transit-friendly properties in the first place, programs such as TransitScore can complement tools such as Explore, which allow riders to choose destinations based on the easiest journey from their home location.

The goal of the OneBusAway project is to implement tools that will make transit easier to use and better able to compete with non-public modes. OneBusAway is being developed as an open-source transit traveler information system to allow transit agencies to access the code and use it themselves. In addition, the open-source model allows other developers to make use of the code or the data to create further transit traveler information tools such as those described. The source code for the deployment is available at *http://code.google.com/p/onebusaway/* under an open-source license.

The development of this type of program is possible only with the aid of transit agencies that are willing to make their data available for free. The leader in this type of data exchange between a transit agency and transit software developers for the past two years has been the Bay Area Rapid Transit agency. BART has partnered with the developer community and makes its schedule data, real time data, and service alert data easily available for other websites and tools. Tri-Met and MBTA more recently have implemented similar programs, and other agencies are following suit. King County Metro in greater Seattle has graciously partnered with One Bus Away to provide the data for this project.

Acknowledgements

Thanks to King County Metro for the continued use of their data. Thanks to Alan Borning, Nokia Research, the U.S. DOT Eisenhower Fellowship, and the National Science Foundation under Grant IIS-0705898 for financially helping to support this project. Thanks to Evan Siroky and Carl Langford for helping with the original Explore OBA vision. Finally, thank you to our friends at UW and beyond and several anonymous reviewers for their feedback and suggestions.

References

BART. 2009. Quick planner. Retrieved May 18 from http://www.bart.gov/.

Caulfield, B., and M. Mahony. 2007. An examination of the public transport information requirements of users. *IEEE Transactions on Intelligent Transportation Systems* 8(1): 21-30.

Chen, C., R. Kitamura, et al. 1999. Multimodal daily itinerary planner: Interactive programming aroach. *Transportation Research Record* 1676: 37-43.

Cherry, C. R., M. D. Hickman, et al. 2006. Design of a map-based transit itinerary planner. *Journal of Public Transportation* 9(2): 45-68.

Citizens for Progressive Transit. 2009. A-Train Atlanta transit/bike/walk trip planner. Retrieved May 19 from http://trip.atltransit.com/.

Currie, G., and M. Gook. 2009. Measuring the performance of transit passenger information web sites. Transportation Research Board Annual Meeting, 09-1363.

Dadnab. 2009. Retrieved May 18 from http://www.dadnab.com/.

Eriksson, L., M. Friman, et al. 2007. Electronic service quality: Public transport information on the Internet. *Journal of Public Transportation* 10(3): 35-46.

Farag, S., and G. Lyons. 2008. What affects use of pretrip public transport information? Empirical results of a qualitative study. *Transportation Research Record* 2069: 85-92.

Fingerle, G. P., and A. C. Lock. 1999. Practical issues in prototyping national public transport journey planning system using JourneyWeb protocol. *Transportation Research Record* 1669: 46-52.

Ferris, B., K. Watkins, and A. Borning. 2010. Location-aware tools for improving the usability of public rransit. *IEEE Pervasive Computing* 9(1): p.13-19.

Ferris, B., K. Watkins, and A. Borning (2009). OneBusAway: A transit traveller information system. International Conference on Mobile Computing, Applications and Services (MobiCase).

Google. 2009. Google Transit Partner Program. Retrieved April 12 from http://maps.google.com/help/maps/transit/partners/faq.html.

Metlink. 2009. Viclink journey planner. Retrieved May 17 from http://jp.metlinkmelbourne.com.au/metlink/XSLT_TRIP_REQUEST2.

MTA. 2009. Mobile trip planner. Retrieved May 18 from http://trilanner.mta.info/trilannerPDA.aspx.

Multisystems. 2003. Strategies for improved traveler information. *Transit Cooperative Research Program Report* 92, Transportation Research Board.

Peng, Z.-R., and E. Kim. 2008. A standard-based integration framework for distributed transit trip planning systems. *Journal of Intelligent Transportation Systems* 12(1): 13-28.

Radin, S., D. Jackson, et al. 2002. Trip planning state of the practice, Volpe National Transportation Systems Center, Federal Transit Administration, Federal Highway Administration.

RTA. 2009. Goroo, learn more. Retrieved May 16 from http://www.goroo.com/goroo/showLearnMore.htm.

SEPTA. 2009. Trip planner. Retrieved May 18 from http://airs1.septa.org/bin/query.exe/en?

Transport for London. 2009. Journey planner. Retrieved May 18 from http://journeyplanner.tfl.gov.uk/user/XSLT_TRIP_REQUEST2?language=en.

UTA. 2009. Trip planner/advanced. Retrieved May 18 from http://www.rideuta.com/ridingUTA/trilanner/default.aspx.

Zografos, K. G., V. Spitadakis, et al. 2008. Integrated passenger information system for multimodal trip planning. *Transportation Research Record* 2072: 20-29.

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