Rural to Urban Intercity Transit User Characteristics Analysis, Demand Estimation and Network Design

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Hongtai Yang
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Abstract

Rural transit always plays a critical role in transporting rural residents, especially the ones who do not have a car, cannot drive, or choose not to drive. Intercity bus (ICB), deviated fixed route transit (DFRT) and demand responsive transit (DRT) are three major modes of rural public transportation. Although there are more DFRT and DRT service providers and services in the US, due to institutional issues, there are much more studies about ICB than DFRT and DRT. Meanwhile, state governments are struggling on how to improve the rural transit system with limited budget. This dissertation is aimed to fill the gap by studying the rural transit rider characteristics, ICB system evaluation method and DFRT route design.

First, surveys were performed to understand who are using the rural DFRT and DRT services and why they use them. It was found out that DFRT and DRT passengers, whose characteristics are similar to ICB riders, are likely to be female, of minority races, have low personal and household income, low number of vehicles in the household and rent the house. 90% of the riders have difficulty finding alternative transportation mode, suggesting they are captive riders, not choice riders. Secondly, a methodology to locate the high ICB demand area and design ICB stops accordingly is proposed. The existing stop locations are compared to the high demand areas and meaningful destinations. It was found out that the ICB stops in Tennessee are well connected to the meaningful destinations but poorly located to cover the high demand areas. Finally, a methodology to find the most cost effective routes is developed. It uses DRT trip records of a local DRT service provider to construct a trip generation model. The model finds that the trip generation rate of a census tract is significantly positively related to the density of population over 16 years old and density of no-vehicle household in the census tract. The method to find the best routes is presented using Tennessee as an example. This dissertation provides useful information to state government on how to evaluate ICB system, improve rural transit and design DFRT network.

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Chapter 1 Introduction and Background

Rural to urban public transit is an important mode of transportation for rural residents. It is essential to rural residents who do not have a car or cannot drive. However, due to the low population density and dispersed origins and destinations, rural transit services usually have a very low fare box recovery rate. Thus, the rural transit is heavily subsidized.

Intercity bus (ICB), deviated fixed route transit (DFRT), and demand responsive transit (DRT) are three major modes of rural public transportation. The definition from the National Transit Database (NTD) [2] establishes DFRT service as "transit service that operates along a fixed alignment or path at generally fixed times, but may deviate from the route alignment to collect or drop off passengers who have requested the deviation". ICB service is defined as "regularly scheduled bus service for the general public, using an over-the-road bus, that operates with limited stops over fixed routes connecting two or more urban areas not in close proximity or connecting one or more rural communities with an urban area not in close proximity; has the capacity for transporting baggage carried by passengers; and makes meaningful connections with scheduled ICB service to points that are more distant". DRT is defined as "a transit mode comprised of passenger cars, vans or small buses operating in response to calls from passengers or their agents to the transit operator, who then dispatches a vehicle to pick up the passengers and transport them to their destinations".

In the 1980s, the deregulation of ICB industry resulted in a large-scale elimination of ICB routes, especially in the rural area, primarily because of low revenue [3]. To meet rural transit needs, federal funds were used to support rural transit. Section 5311 Formula Grants for Other than Urbanized Areas was enacted to provide funding support for the rural transit. One part of Section 5311 is Section 5311 (f) Intercity Bus Program. It requires each state to spend 15 percent of non-urbanized funds on the rural intercity bus services unless the state certifies that the state's ICB needs are adequately met. In order to evaluate this criterion, many states have recently performed ICB studies [4-21]. Because of this, although there are more DFRT and DRT service providers and services, there are many studies about ICB while DFRT and DRT were seldom studied. In the 2010 rural transit report of National Transit Database (NTD) [2], 1180 of the 1751 reported services were DRT services (68%); 57% of the 530 "mode of bus" (include DFRT and

ICB) services were DFRT services; only 43% of the “mode of bus” services were ICB. Although DFRT and DRT are more important than ICB in rural transportation system in terms of number of services, they are much less studied.

Recognizing the lack of literature about DRT and DFRT, this dissertation aims to fill this important gap. But before focusing on DRT and DFRT, a review of the existing rural transit, especially ICB studies is conducted. Those studies, usually in the form of project reports, establish of baseline of ICB passengers’ characteristics, funding opportunities and the ICB infrastructures in the state. However, network planning is seldom studied. As a result, many states are struggling to find the appropriate place to implement the ICB routes. To provide a solution, Chapter 4 of this dissertation develops a methodology to locate the ICB stops and to evaluate the existing locations of the ICB stops.

So far, little information is known about rural DRT and DFRT riders. It is difficult for the government to make appropriate policies or improvement suggestions regarding DRT and DFRT without knowing who are using the service, why they are using the service, and what improvements are valued by existing passengers and potential riders. Chapter 3 explores the trip information, perceptions and especially the personal characteristics of the rural DFRT and DRT riders. A survey was performed to collect demographic and trip information of DFRT and DRT riders in Tennessee. Another survey was performed to collect demographic information of rural residents (i.e., predominantly car drivers) in DFRT and DRT service areas. The trip information and perceptions sections of the survey explore what DFRT and DRT are used for (trip purpose), frequency of the transit use, difficulty level of finding alternative transportation modes, and so on. The demographics of the DFRT and DRT riders are compared to the demographics of rural residents to investigate common or distinct DFRT and DRT rider characteristics. The characteristics can be used to locate the high DFRT and DRT demand areas to help DFRT route planning, thus serving as a good reference for future research.

Due to the low ridership in rural areas, rural transit services are usually heavily subsidized. Determining the most cost effective route under a certain level of operating cost funding is a challenge that government agencies are interested in addressing. Chapter 5 proposes a methodology to find the most cost effective DFRT routes in a state. Tennessee is used as an example to demonstrate the methodology. First, a zero inflated negative binomial regression

model is used to estimate the trip generation of all the census tracts in Tennessee. The model finds that the trip generation rate is positively related to the density of population over 16 years old and the density of no-vehicle households in the census tract. If the census tract is in a big city county, its trip generation rate (from rural transit) is significantly lower. The operation environment of the DFRT is set to be consistent with the existing rural DFRT services in the Tennessee, to only run on interstate and state highways and operate on weekdays and non-holidays with two round trips per day. A methodology to identify all the possible DFRT routes and determine the best routes is presented. All the interstates and state highways are divided into five-mile segments. Since the DFRT serves as a connection between the rural area and the urban areas, the DFRT routes start with the segments intersecting the boundaries of the urban areas. Then one segment connecting to an existing route is added to the route at a time and this process iterates until it meets the user defined stopping criteria (e.g., maximum route-miles). The length of the route, number of passengers served and operating cost per passenger is updated every time one segment is added to the route. This methodology is presented with an example in Tennessee.

This study was originally funded by Tennessee Department of Transportation (TDOT) for the purpose of evaluating Tennessee intercity bus system. All the data used to illustrate the proposed methodology are data from Tennessee. Similar methods can be applied to other states.

Chapter 2

Literature Review

Studies related to ICB are usually performed by states in the form of reports as opposed to peer reviewed papers. The key points in these reviews are riders' demographics, methodology to evaluate the existing network and ways to design routes and networks that serve as a foundation to the research presented later in this dissertation.

Intercity Bus Studies

Since 2007, there have been at least 14 intercity bus studies published. More studies have been performed but their study reports are not accessible to public. These published studies are shown in Table 1.

The most frequent objective of the ICB studies are "to provide the state Department of Transportation with an evaluation of the intercity bus industry in the state so that recommendations concerning 'Governor's certification' of Section 5311(f) funds can be made" [6].

The ICB studies always involve surveys. There are generally five types of survey subjects: representatives from other states that have intercity bus services; representatives from local transit agencies, planning organizations and government agencies; general public and ICB riders; managers of ICB facilities; and ICB service providers. Other state representatives are surveyed to obtain experiences regarding their strategies to meet federal- and state-level requirements [4, 5, 14, 18]. Representatives from local transit agencies, Rural/Metropolitan Planning Organizations are surveyed to elicit information regarding intercity service, local feeder services to ICB services, and unmet transportation needs [9, 10, 14, 17, 18]. ICB facility managers are surveyed and evaluated to determine whether funding should be spent to improve the existing facilities [4, 6, 13]. ICB service providers are often surveyed to obtain their service location and frequency [4-6, 9, 14, 15, 17].

General public and ICB riders are surveyed to get their opinions of the ICB service and deficiency and the demographics of the ICB riders. [4, 7, 9-11, 15, 21] For the general public

surveys, the questionnaires are usually sent to the selected household. For the ICB rider surveys, surveys are usually performed at the ICB stops or on the bus. Only Tennessee sent the questionnaires to the service providers and let the bus driver distribute questionnaires to riders. [21]

Table 1 Intercity Bus Study of States

Year of the Study Report	State	Performing Organization
1993	Texas [4]	Texas Transportation Institute The Texas A & M University System
2001	Illinois [5]	Urban Transportation Center University of Illinois at Chicago
2002	Alabama [6]	University of Alabama
2006	Missouri [7]	Missouri Department of Transportation
2007	California [8]	KFH Group
2007	Ohio [9]	The Lakatos Group
2007	Tennessee [10]	TranSystems Corporation
2009	Michigan [11]	University of Michigan
2009	North Carolina [12]	Institute of Transportation Research and Education North Carolina State University
2009	Alabama [13]	University of Alabama
2009	Indiana [14]	RLS & Associates
2009	Florida [15]	Tindale-Oliver & Associates
2010	Minnesota [22]	KFH Group
2010	Utah [17]	Public Transit Team Utah Department of Transportation
2011	Montana [18]	Western Transportation Institute Montana State University
2011	Vermont [19]	KFH Group
2012	South Carolina [20]	RLS & Associates
2012	Tennessee [21]	University of Tennessee

Except the studies performed by states to evaluate the ICB industry, some other aspects of ICB were also studied. Woldeamanuel [23] compared the competitiveness of various intercity transportation modes in terms of sustainability indicators and found that ICB is "an environmentally-friendly, economically viable and socially-inclusive mode" for intercity travel. Ye [24] found that states that conducted ICB studies to identify routes usually use a RFP(request for proposal)/bid system to award funds. In other states, where funds were awarded using a grantor/grantee system, the determination process has three steps: 1) ICB service providers submit proposals, 2) review and score proposals; and 3) determine funds for projects.

Intercity Bus Rider Demographics

In terms of ICB rider demographics, Greyhound conducted a national survey in 1999. The findings were cited in both the Alabama [6] and Florida [25] reports. Greyhound riders are more likely to have low income (Two-thirds of passengers make less than $35,000 per year), young (53% under 35), single (70%). They are more likely to travel alone (66%) and travel for personal pleasure (73%), for instance visiting family/friends.

Missouri's [7] survey found that people who use ICB service are mostly Hispanic or Amish people, persons released from incarceration, college students and U.S. military personnel. It also reveals that most of the riders were driven by someone else to the bus stop (70%), around 21% of the riders used taxi and the rest of them either took a city bus or drove their own vehicles.

Michigan's [11] survey found out that visiting friends and family was the major trip purpose. Its survey design is similar to ours, making it possible to compare the survey results. The revealed characteristics of bus passengers are from low-income households, having low vehicle ownership and young with age under 35. They are also more likely to travel alone.

Montana [18] conducted an ICB rider survey and found out that the most common trip purpose is visiting family or friends, and the second most common trip purpose is work. Riders are mostly driven by someone else from origin to boarding stop and from alighting stop to destination.

TCRP Report 79 Effective Approaches to Meeting Rural ICB Transportation Needs [3] identified several demographic characteristics of regular-route ICB passengers: "passengers are

more likely to be young or old - more passengers are under age 24 or over age 60 than on other modes; have a low-income - have lower household incomes than those using other intercity modes; and less likely to own a vehicle in operating condition - about 30 percent do not own a vehicle".

Common themes from the above ICB studies are the most common trip purpose is visiting family or friends. Most passengers are driven by someone else from the origin to the boarding stop and from the alighting stop to the destination. The characteristics of ICB passengers are likely to have low personal and household income, have low vehicle ownership, be young and are more likely to travel alone.

The surveys of the studies above are all targeted at ICB service users. Few studies have targeted at DFRT or DRT service users. Although there are more DFRT and DRT services than ICB services in the US, they are less studied. It is not because they are not important but because of institutional issues. The Section 5311 (f) Intercity Bus Program requires each state to spend 15 percent of non-urbanized funds on the rural intercity bus services unless the state certifies that the state's ICB needs are adequately met. In order to evaluate this criteria, many states have recently performed ICB studies [4-21]. However, there is no such requirement for the DFRT and DRT studies. Although DFRT and DRT are less-studied, it by no means indicates they are less important. On the contrary, according to the 2010 rural transit report of National Transit Database (NTD) [2], 1180 of the 1751 reported services were DRT services (68%); 57% of the 530 "mode of bus" (include DFRT and ICB) services were DFRT services; only 43% of the "mode of bus" services were ICB. So there are more rural DFRT and DRT services than ICB services, which to some extent suggest that DFRT and DRT are more important. At the same time, state governments are struggling on how to spend the federal funds to improve rural transit in a cost effective way. This question could not be answered without knowing who are using the rural transit, especially DFRT and DRT, why they are using it, and what are riders' transit service improvement suggestions. Chapter 3 aims to fill this gap by answering these questions and provide useful rural transit trip characteristics and rider demographics information to help state governments make appropriate policies.

Intercity Bus Travel Demand Model and Network Evaluation

A few papers have discussed mode choice modeling for intercity surface travel. Ashiabor, et al. [26] reviewed disaggregate nationwide travel demand modes developed between 1976 and 1990 presented in [27-30]. All four models used versions of National Travel Surveys (NTS) conducted by the Bureau of the Census and the Bureau of Transportation Statistics (BTS). All of these four models included bus as one of the transportation modes. The fifth attempt to model nationwide travel demand was carried out by Ashiabor, et al. [26], who developed a logit model based on 1995 American Travel Survey (ATS). The TCRP 147 Toolkit for Estimating Demand for Rural ICB Services [31], which was subsequently written as [32], describes two models to estimate demand for ICB services on a proposed route. One is a regression model that is developed based on the ridership data of 57 routes. The other one is a trip rate model based on the number of long-distance trips made by rural residents using public transportation modes.

However, those models only focus on trips of 100 miles or more, eliminating intercity trips that are shorter than 100 miles, which include most of the within-state Tennessee ICB trips. Although only Tennessee intercity trips are surveyed and determined to be less than 100 miles, it is reasonable to infer that in other States, there are also many intercity trips that are less than 100 miles because of similar geography, demographics, and travel behavior.

Illinois [5] developed a gravity model to estimate demand for intercity bus. First they inventoried all the city pairs in the state. The city pairs were ranked based on ICB demand calculated by the gravity model and based on supply measured by the level of service of three intercity travel modes: bus, rail, and combined bus and rail. A deficiency analysis indicates routes where existing and additional service is needed if a city pair is ranked more highly on the demand side than on the supply side. The drawback of the method is that it bases the decision on the difference of demand ranking and supply ranking, not the actual “quantity” of demand and supply. For example, if the demand of an area is 5 while its supply is 10. The demand of this area should be met. However, if the demand of this area is ranked highly among all the areas and the supply of this area is ranked low among all the areas, that method could conclude that the demand of this area is not met. So this method could possibly lead to incorrect decision-making.

Yang and Cherry [33] and KFH [8, 16, 19] proposed methods to use the demographics rural ICB riders to locate the high demand area. The coverage of the existing network is compared to the high demand area and the meaningful destinations to evaluate networks. This method was applied in studies of North Carolina, South Carolina, Tennessee and Utah [12, 17, 20, 33]. Chapter 4 described in detail the method and results developed by Yang and Cherry [33].

Deviated Fixed Route Transit Network Design

DFRT has several names. It can be called mobility allowance shuttle transit, flexroute transit or route deviation in different papers. Existing studies related to DFRT are limited. Common themes of those studies are developing a relationship between various design parameters of DFRT to help transit planners to consider the trade-off between parameters or to optimize one specific parameter.

Fu [34] developed an equation for the relationship between various system variables, such as the number of feasible deviations, slack time, zone size and dwell time. Smith and Demetsky [35] explored the relationship between service zone size, which is the area between fixed stops where deviations are permitted, and slack time distribution among zones. Zhao and Dessouky [36] analyzed the relationship between service cycle time, and the length and width of the service area. Those studies serve as a good baseline for DFRT parameter optimization. However, these studies are somehow overlapping. Three studies analyzed the relationship between service area and other parameters. Two studies analyzed the relationship between slack time distribution and other parameters. It would be very helpful if all the parameters could be considered at once. This could be an area of future research.

These studies are focused on the operation of the DFRT. They are usually proposed under an ideal operating environment, such as grid network. So the research products are not ready to be used in an empirical case. On the other hand, state governments are eager to know how to better serve rural residents with limited budget. While many factors could improve the transit service, the route location of DFRT plays an important role in determining ridership (also the number of potential passengers that could be served), fare box recovery rate and operating cost. A well designed route could serve more people with low operating cost. However, no studies have been

performed to answer the question how to design the route. So Chapter 5 will fill this gap by proposing a method to determine the best routes in a state.

Chapter 3

A Description of the Use Characteristics and Demographics of Rural Transit Based on Survey Statistics and Logistic Regression

Introduction

Rural transportation is an important part of the transportation system. Most rural trips are performed by personal transportation mode. A rural resident survey, which will be discussed later, shows that 97% of the reported rural-to-urban trips were performed by personal car, truck and SUV. However, rural transit plays a critical role in transporting rural residents who do not have access to a car or cannot drive, or do not wish to drive. ICB, DFRT and DRT are three major modes of rural transportation.

A DFRT rider survey and DRT rider survey, (discussed later) shows that around 90% of both DFRT and DRT riders found it either "difficult" or "extremely difficult" to find alternative transportation mode, indicating most of DFRT and DRT riders are highly dependent on either DFRT or DRT services. Although DFRT and DRT are more important than ICB in rural transportation system in terms of number of services and dependence of riders, they are much less studied.

This chapter aims to fill this important gap. It focuses on the trip information, perceptions and especially the personal characteristics of the rural DFRT and DRT riders. A survey was performed to collect demographic and trip information of DFRT and DRT riders in Tennessee. Another survey was performed to collect demographic information of rural residents (i.e., predominantly car drivers) in DFRT and DRT service areas.

The trip information and perceptions sections of the survey explore what DFRT and DRT are used for (trip purpose), frequency of the transit use, difficulty level of finding alternative transportation model, and so on. The demographics of the DFRT and DRT riders are compared to the demographics of rural residents to investigate common or distinct DFRT and DRT rider

characteristics. The characteristics can be used to locate the high DFRT and DRT demand areas to help DFRT route planning, thus serving as a good reference for future research.

This study begins with a description of the DFRT, DRT and rural resident survey developed for the purpose of investigating difference in travel behavior from these groups. The trip information and rider perceptions are discussed. The demographics of DFRT and DRT riders are compared to the car-driving rural residents. A model is constructed to analyze the factors that influence rural residents' mode choice of transit or car. The results are discussed and this chapter closes with a concluding remarks.

Survey Methods and Data Description

A survey approach was used to gather information from DFRT users, DRT users and rural residents who are potential users of the rural transit system. Two main populations were targeted, existing riders of DFRT and DRT services and rural residents in rural transit service areas, and those who are not users of rural transit systems (i.e., car drivers). The surveys were designed in similar ways such that comparisons can be made between populations. Surveys were performed between May 1, 2012 and August 31, 2012. DFRT riders, DRT riders and Tennessee rural car drivers were the survey subjects. Three questionnaires were developed for the three types of survey subjects.

Existing riders of DFRT and DRT The DFRT rider and DRT rider surveys were performed by sending the questionnaires to 10 Human Resource Agencies (HRA) and 1 private DFRT service provider. Survey packages were distributed to the transit agencies and drivers gave the surveys to boarding riders, along with a pencil and mail-back envelope. The 10 HRAs all provide DRT service and 4 of them provided DFRT service. Each agency received 100 questionnaires for each type of service it provides. The collected sample included 45 DFRT rider surveys and 238 DRT rider surveys, representing three DFRT agencies and eight DRT agencies. Since we did not receive any responses from some of the agencies, we assume that they did not distribute the surveys to the riders. In all, we expect that up to 1100 surveys were distributed. The DFRT rider survey response rate is 45/300=15% and DRT rider survey response rate is 238/800=30%. However, we cannot confirm that all 100 surveys were distributed to each type of user.

Rural Resident Survey The rural urban travel survey was conducted to understand rural household travel behavior aimed at non-transit riders. The primary emphasis was exploring how they travel between their residence and nearby cities. Geographic Information Systems data based on census classifications (2010 TIGER/Line data) were used to locate the urban areas in Tennessee. There are two types of urban areas: urbanized areas that contain 50,000 or more people and urban clusters that contain at least 2,500 people, but fewer than 50,000 people. Rural households are the households that are outside of the urban areas. Addresses of 6000 randomly selected rural households were purchased from Survey Sampling International. One survey package was sent to each household and each package contained two identical survey forms, designed to be completed by two adults in the household. If there are not two adults in the household or any other conditions exist that do not allow two adults from that household to complete the survey, completing only one survey and mailing it back is allowed.

Of the 6000 mailed surveys, 247 survey packages were sent back due to incorrect address. There are 844 responses received. Among them, 540 surveys come from households with two or more adults (identified if two surveys were completed by the same household). The other 304 surveys come from one-adult households. There are 7 surveys with the survey ID removed, making it impossible to identify their addresses and whether they come from the same household or not. The response rate ranges between 7.1% (821/(6000-247)/2) to 9.7% (261+2+292+3)/(6000-247), depending on calculation method.

Survey Results

Trip Information The design of the rural resident travel survey queried the information about the most recent trip to a large city by any mode. Nine largest cities were listed as options to choose from. They are Chattanooga, Clarksville, Franklin, Jackson, Johnson City, Knoxville, Memphis, Murfreesboro and Nashville. Nashville responses ranked first (27%), Knoxville second (22%). Chattanooga, Memphis, Jackson, Murfreesboro and Johnson City are the cities that rural residents travel less frequently. Clarksville and Franklin have the lowest trip frequency among the nine cities. According to 2010 US Census data, Memphis has the largest population, 646,889 people; however, it ranked fourth in terms of the frequency residents reported travelling there. It is likely because Memphis is located in the corner of Tennessee and not all the areas around

Memphis are in Tennessee (our sample) and rural areas surrounding Memphis are sparsely populated relative to areas surrounding Nashville and Knoxville.

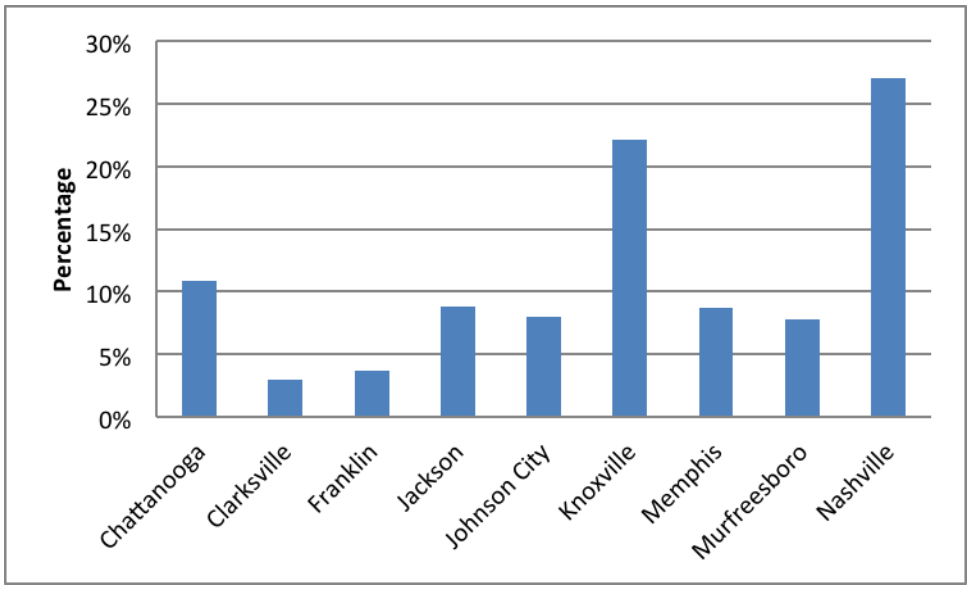


Figure 1 Large City Frequency Distribution of the Most Recent Trip

In the survey, 97% of trips were made by personal car, truck, or SUV. This sample effectively represents car (hereafter "personal car") users allowing for comparison between the other rural transit samples in the following sections.

The trip purposes distribution of the three surveys were plotted in Figure 2. Riders use DFRT and DRT mainly for health care appointments (70% for DFRT riders and 61% for DRT riders), while the most common non-transit trip purpose for personal car travel to go to bigger city is shopping. But it should be noted that the health care appointments and travel are funded by TennCare, Tennessee's low income health care program, thus subsidizing many of the trips for specific health purposes. Trip purposes are more evenly distributed among car travelers, suggesting car is used for trips of multiple purposes. It should be noted that the most frequent trip purpose for ICB riders is visiting families or friends. So the travel modes are divided into three

groups by the major trip purpose: DFRT and DRT for health care appointments, ICB for visiting families and friends and personal car for shopping. The trip purpose distribution of DFRT and DRT are very similar, suggesting they are the same mobility option to users.

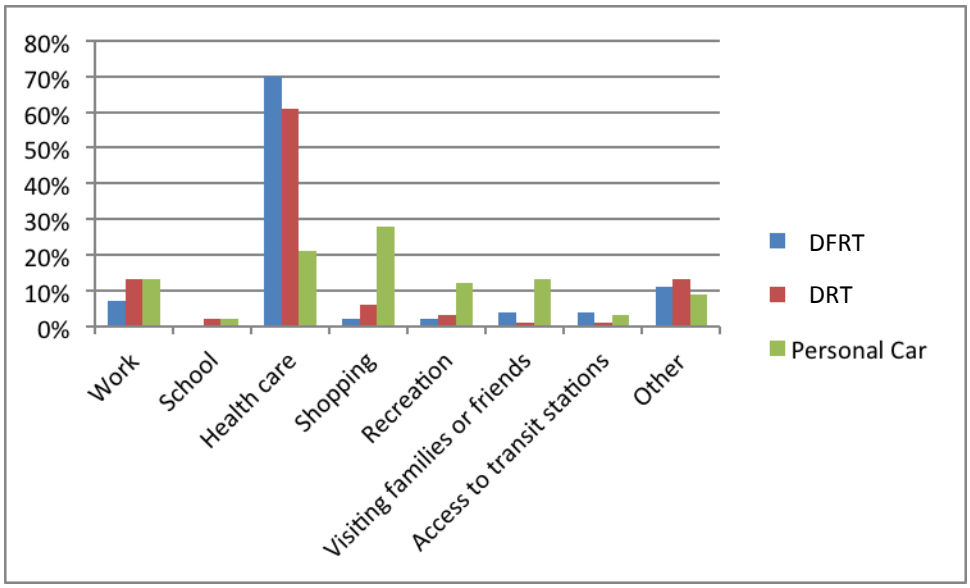


Figure 2 Trip Purpose of DFRT, DRT and Personal Car Trips

Around 78% of DFRT riders and 67% of DRT riders expressed it is "very difficult" to find an alternative method to meet the trip need, and 13% of DFRT riders and 21% of DRT riders expressed it is "difficult". About 90% of the riders have difficulty finding alternative transportation modes, and are highly dependent on the DFRT and/or DRT services. Fewer than 10% expressed it is relatively easy or very easy. These response rates reveal that transit services are very critical transportation methods to those individuals. Recall that around 2/3 of transit riders were using the service to access health care, implying that the DFRT/DRT service is improving accessibility to important health services.

DFRT and DRT riders were asked to report how frequent they used the DFRT or DRT transit service. That frequency is compared to the reported frequency of rural residents visiting

the big city that they reported earlier in the survey, shown in Figure 3. It was found that DFRT and DRT have higher travel frequency. It may be not fair to compare the frequency of rural transit riders to use transit to go anywhere to the frequency of personal car users to use car to go to one place (the reported big city). But the frequency of the rural transit riders use the transit is surprisingly high. 67% of the transit riders use the transit more than once a week. It shows that as long as the transit service area covers the potential riders, they would use the service frequently. The use frequency distributions of DFRT and DRT are very similar, again suggesting DFRT and DRT are the similar mobility option to the users.

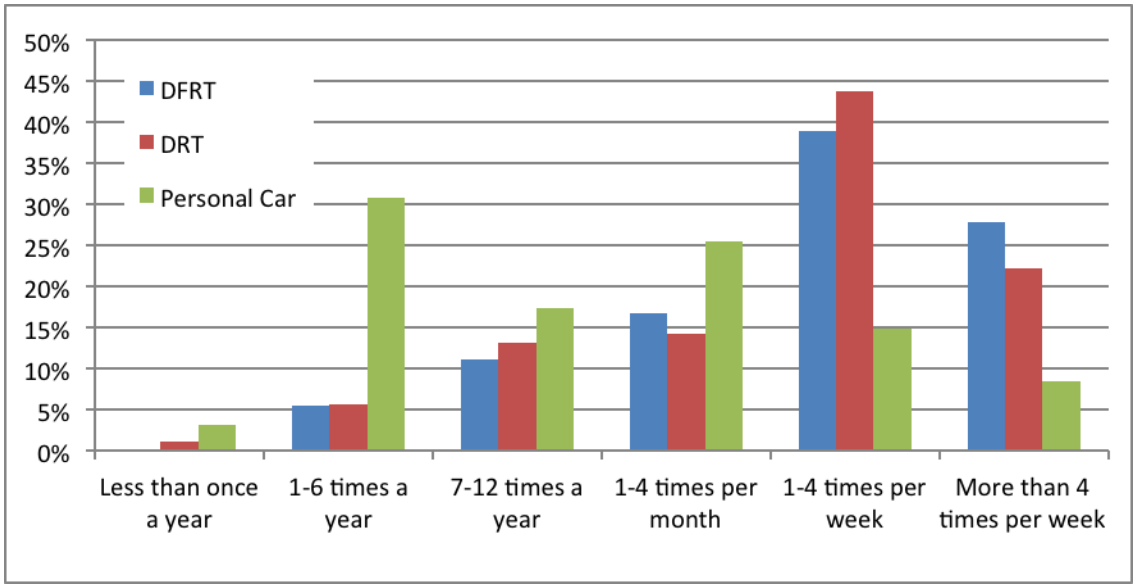


Figure 3 Frequency of DFRT, DRT and Person Car Use

DFRT and DRT riders were asked how they made this trip before the corresponding transit service started and how they would make this trip if the service stops. The most frequent answer is “someone else drove me”. If the service stops, a one third of respondents would not make this trip anymore. Of those who would not make the trip, 54% were using the service to access health care, implying that the DFRT/DRT service is improving accessibility to important health services.

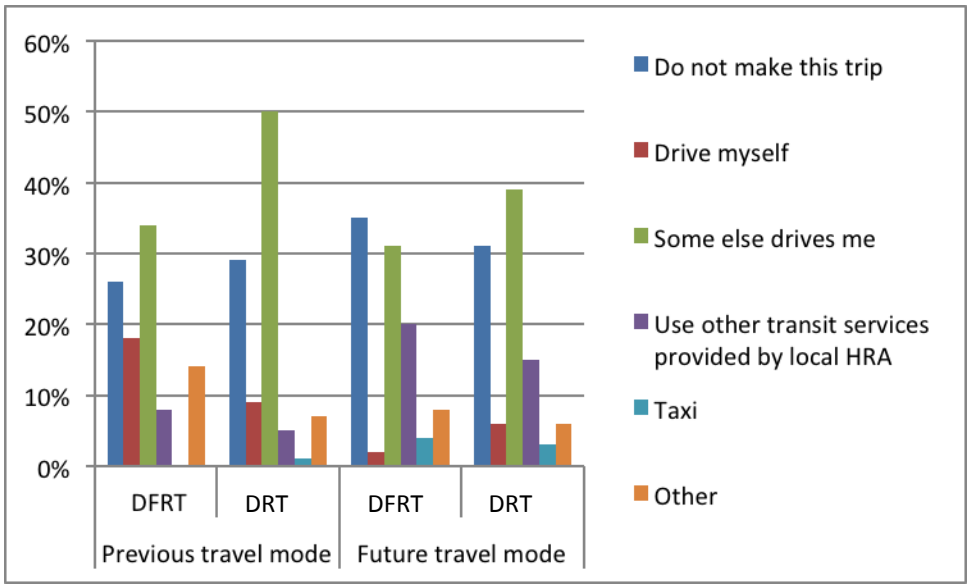


Figure 4 Previous Travel Mode and Future Travel Mode of DFRT and DRT Passengers

To summarize, most of the DFRT and DRT riders use the transit to access health care, while the primary trip purpose for car drivers and ICB users are shopping and visiting families and friends. 90% of the transit riders stated it is difficult to find an alternative way to perform the trip, indicating those people are highly dependent on public transit for critical health care needs. Two thirds of the transit users use the transit service more than once a week, suggesting if the service stops, their mobility would be severely impacted. The trip purpose distribution and use frequency distribution of DFRT and DRT are very similar. It indicates that DFRT and DRT plays the same or very similar role of transportation method to the users.

Demographics The percentage of male DFRT riders, DRT riders and rural-urban household travel survey respondents are 39%, 28% and 49% respectively. Chi-squared test shows that women are more likely to take rural transit than men with p-value less than 0.01. The age distributions of the three surveys' respondents are similar. The median age for DFRT riders, DRT riders and personal car users are 54, 53 and 57 respectively. It shows they are more likely to be

middle aged or old people. This age distribution is different from ICB users, who are more likely to be young.

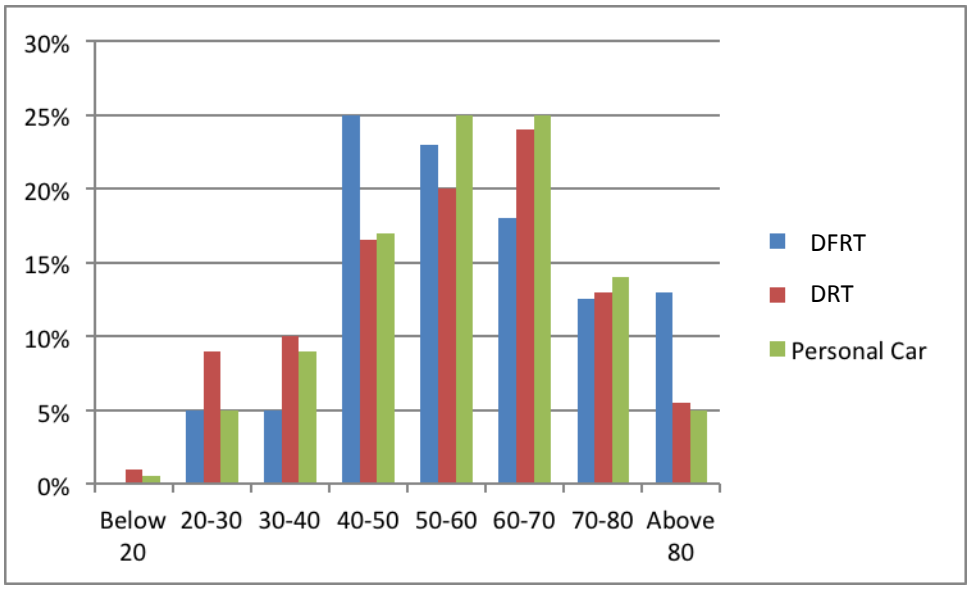


Figure 5 Age Distribution of Respondents of DFRT Riders, DRT Riders and Personal Car Users

Transit riders are more likely to be of minority races. The percentage of white people in DFRT riders, DRT riders and car users are 85%, 75% and 95%, respectively. Figure 6 shows that DFRT and DRT riders also have a higher proportion of unemployed (seven times more likely) and retired compared to the car-driving respondents. The distribution of education level does not have a pattern, and is not shown in this paper. Figure 7 shows that car-driving respondents are twice as likely to be college-educated.

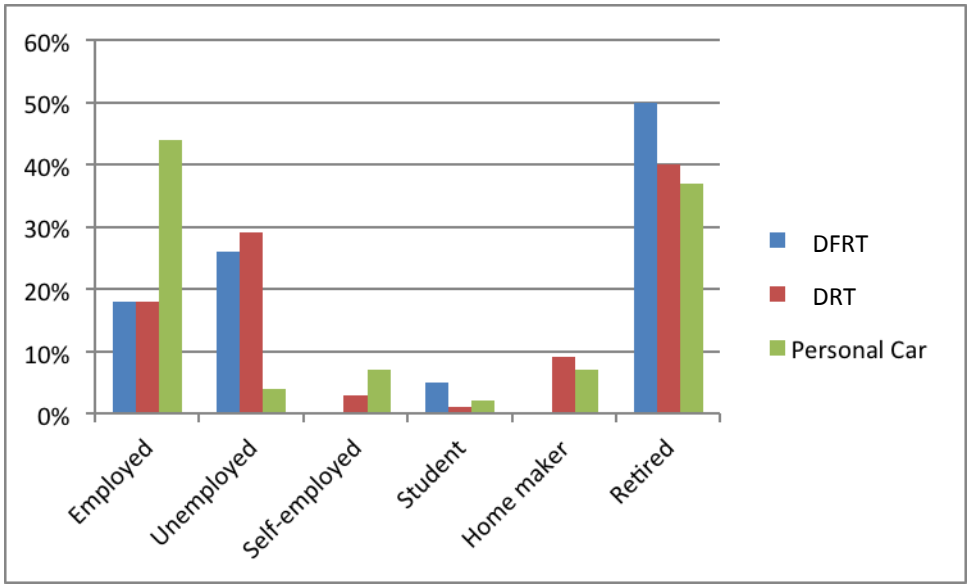


Figure 6 Employment Status of DFRT Riders, DRT Riders and Personal Car Users

The home ownership rate for DFRT riders, DRT riders and rural-urban household travel survey respondents are 38%, 41% and 91%, respectively. The number of automobiles available at home for DFRT riders and DRT riders is lower than rural-urban household travel survey respondents. 95% of DFRT riders and 97% of DRT riders have 2 or fewer cars available at home, compared to the percentage of rural-urban household travel survey respondents 65%. The Chi-square test does not show a significant difference of home ownership rate between DFRT and DRT riders. There are also more non-vehicle households in the DFRT and DRT riders than personal car users.

DFRT and DRT riders have both low personal and household incomes. Their personal annual income is typically below $15,000 and household income below $20,000, while the most common personal income and household income category for rural residents are $50,000 and over and 100,000 and over, respectively.

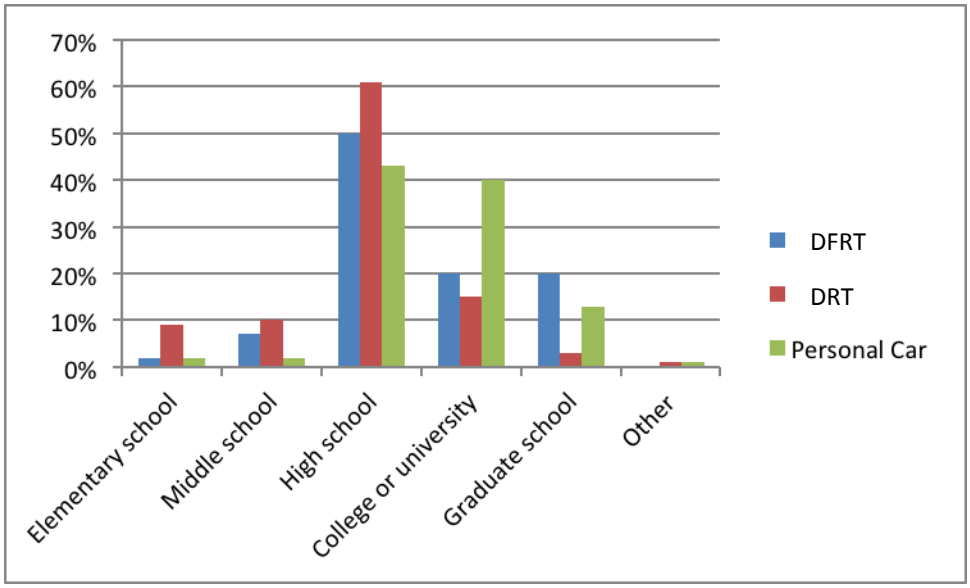


Figure 7 Education of DFRT Riders, DRT Riders and Personal Car Users

Based on the demographics analysis, the transit riders including DFRT riders and DRT riders are more likely to be female, of minority races (non-white), unemployed, rent a house as opposed to own a house, have low automobile ownership, and have low personal and household income. DFRT and DRT riders have generally the same characteristics as ICB riders except the DFRT and DRT passengers were generally not young.

Perceptions DFRT and DRT riders reported the two main reasons that they use the corresponding transit service. The frequency of the reasons reported is shown in Figure 8. The most frequent reason for DFRT riders is the transit fare is subsidized. "I don't have access to a car" is the most frequent reason for DRT riders and the second most frequent reason for DFRT riders. "I don't have driver's license" is the fourth most important reason. It suggests that DRT and DFRT provide important transportation mode to people who do not have access to a car or cannot drive. Another important reason is that the van can pick passengers up from origin and drop them off at destinations. It has an important implication that if the DFRT service is replaced by ICB, which can not deviate to pick up and drop off passengers, the service would become less attractive. The fare of the DFRT and DRT are relatively low. For example, the fare of the DFRT

service from Nashville to Cookeville is only $9.50 one way. While the distance is 81 miles, traveling by car would cost $10.7 if the fuel economy is 25 MPG and fuel price is $3.30 per gallon. For DRT service, it usually charges a fare for in county trip and an additional fare for each county line crossed. The starting fare ranges from $2.00 to $6.00 and the additional fare ranges from $2.00 to $5.00. When the starting fare is high the additional fare is usually low and vice versa. So traveling by DFRT and DRT is cheaper than traveling by personal car. However the low fare is not a leading reason to use the transit. The feature of the transit service (pick up from origin and drop off to destination) and the limitations of the riders (do not have access to a car or cannot drive) are the main reasons of using rural transit. Also when the transit fare is subsidized, it generates a big initiative to use rural transit.

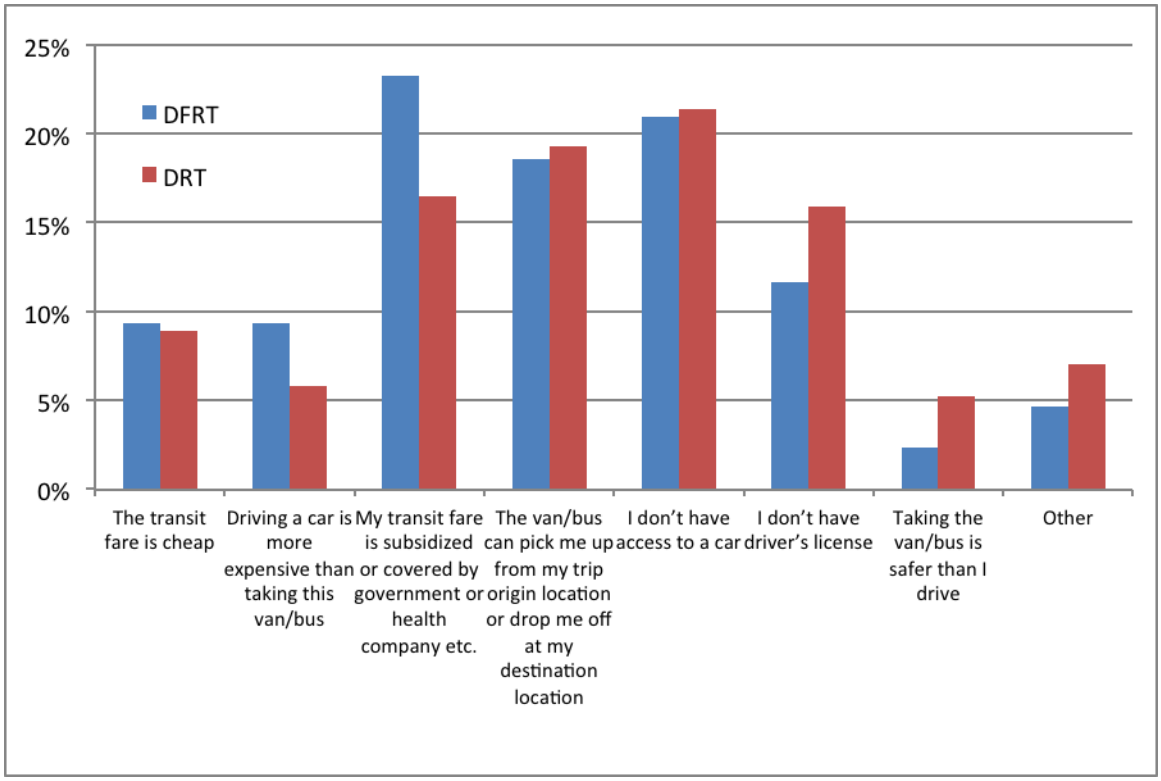


Figure 8 Reasons to Use DFRT and DRT

Rural residents (personal car drivers) were asked their feelings about the following two statements: “I will always dislike the idea of riding intercity bus no matter how good the service is” and “Federal or state money should be used to subsidize intercity transit operating cost”.

Regarding the first statement, 201 respondents said “agree”, 357 said “neutral” and 280 said “disagree”. If only regarding the people who said “disagree” as the people who are open to traveling by ICB, it indicates a significant amount of people (33%) are open to the travel mode of ICB, in contrast to only 5 out of 836 who answered travel method question actually used rural transit to perform the most recent trip. Nearly ¼ of the population are not open to riding ICB. The result indicates although a lot of people are open the idea of using ICB, not many people used it. Again it corresponds to our previous finding that most of the transit riders are captive users, not choice users.

Regarding the second statement, 271, 362 and 194 respondents expressed “agree”, “neutral” and “disagree”, respectively. Only 52% of the people who are open to the travel mode of ICB agree that federal funding should be used to subsidize intercity transit operating cost. Also only 53% of the people who believe federal funds should be used to subsidize intercity transit are open to the mode of ICB. Only 17% of all the respondents both agree that federal funds should be used on intercity transit and are open to travel by ICB.

Respondents of the three surveys were asked to rate on the scale of 1 to 5 that best explains the likelihood that they would use intercity transit if the following changes were made. 1 means “not likely at all” and 5 means “very likely”. The average score of every improvement by three survey respondents are shown in Table 2.

In general, scores of improvements given by DFRT riders are consistent with those given by DRT riders, both of which are much higher than the score given by car-driving rural respondents, either open to using ICB or not. It indicates that DFRT and DRT riders generally value all the improvements more than rural residents, whether they would like to travel by ICB or not.

Table 2 Average Score of Improvements by Survey Respondents

Improvements	Average score by ICB riders	Average score by DRT riders [1]	Average score by rural car-driving travel survey respondents [2]
If it's safer to ride on the transit	4.2	-	3.3 (3.0)
If the transit always arrives and departs on time	4.5	4.3	3.6 (3.2)
If the travel time of transit trip is shorter	4.2	4.2	3.5 (3.2)
If the service is more frequent	4.1		3.5 (3.2)
If the bus stop is closer to my home			3.7 (3.3)
If the fare is less expensive	4.3	4.2	3.6 (3.2)
If the vehicle condition is better with more leg room, wider aisles and more comfortable seats	4.2	4.1	3.4 (3.1)
If the local city public transportation at destination city is more convenient	4.1	3.6	3.7 (3.3)
Auto parking were available near the van/bus station	3.5	-	-
The cost of gasoline were to increase	4.0	4.1	-
The operator of call reservation center or driver was friendlier	4.4	4.0	-
Overall, if intercity transit could pick you up close to your home with a reasonable price and schedule, how likely are you to use it?	-	-	3.7 (3.3)

1. Blank cells mean the question is not applicable to the survey indicated by the column.

2. The value before parenthesis is the answer from rural residents who would consider traveling by intercity bus, while the value in parenthesis is the answer from all the rural residents no matter their answer whether they would consider traveling by ICB.

The improvement with the highest score given by transit riders is “if the transit always arrives and departs on time”. The unreliability of transit arriving and departing time has been the major concern of riders. The improvement of this unreliability has the greatest satisfaction to transit riders. The improvements “If the local city public transportation at destination city is more convenient” and “if the bus stop is closer to my home” get the highest score from rural residents. This generally indicates that easier access to the boarding stop and to the destination from the alighting stop would to the most extent increase the attraction of intercity transit to rural residents. The fact that it may be difficult for potential riders to travel to the bus stop or inconvenient to park at the origin stop and that the local transit is not very convenient will prevent them from riding the intercity transit. The deviation feature of the DFRT could be very attractive to car-driving residents. However, few DFRT service providers give description of this feature on their website. Service providers should put more efforts on marketing, giving more detailed description of the service and highlighting its route-deviation features. That could attract more people to DFRT.

All the improvements scored by rural transit riders are above 4 except two, “if the local city public transportation at destination city is more convenient” and “if auto parking were available near the van/bus station”. Except for those two improvements, all the improvements are scored much higher by transit riders than rural residents, even higher than the score of the last item “overall, if intercity transit could pick you up close to your home with a reasonable price and schedule”. It indicates that the value of any specific improvement to riders is higher than the value of the combination of all the improvements to non-riders.

Riders Characteristics Modeling

The DFRT rider survey, DRT transit survey and personal car travel survey were combined together to perform a case control study. Because the response variable (mode choice of transit or car) is binary, a logistic regression model was constructed to analyze different variables’ influence on the likelihood of a person choosing rural transit. [37]

Correlation Analysis The correlation matrix is shown in Table 3. There is a high correlation between personal income and household income. The household income is highly

positively correlated with the number of cars in the household and number of working adults in the household, with a Pearson Correlation coefficient of 0.49 and 0.45 respectively.

People who own his or her home have an average of 2.13 cars, much higher than people who rent a house, 0.99 cars. White people have, on average, 2.00 cars compared to people of non-white race who have 1.25 cars. Around 80% of white respondents own a house compared to 50% of non-white respondents. The Chi-Square test shows that race is not independent of home ownership type with p-value less than 0.01. So it can be concluded that most of the independent variables (demographic variables) are correlated.

Table 3 Correlation Matrix of Independent Variables

	Personal income	Household income	Number of cars	Number of children	Number of adults	Number of working adults	Number of elderly
Personal income	1.00	0.73**	0.37**	0.05	0.07*	0.29**	-0.12**
Household income		1.00	0.49**	0.14**	0.25**	0.45**	-0.17**
Number of cars			1.00	0.14**	0.36**	0.43**	-0.11**
Number of children				1.00	0.07*	0.24**	-0.33**
Number of adults					1.00	0.51**	0.03
Number of working adults						1.00	-0.45**
Number of elderly							1.00

**significant at 0.01 level; * significant at 0.05 level.

Introduction to Logistic Regression Logistic regression is different from linear regression in that the response variable for logistic regression is categorical. In this case the response variable has two levels (car/transit) so we specify a binary logistic regression.

The event that one chooses intercity transit is denoted by $Y_i = 1$, one chooses car is denoted by $Y_i = 0$. The probability that one chooses intercity transit and car is:

$$P(Y_i = 1) = \pi(x_i)$$

$$P(Y_i = 0) = 1 - \pi(x_i)$$

The binary logistic regression specification is given:

$$log_e\left[\frac{\pi(x)}{1-\pi(x)}\right] = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_j x_j + \cdots + \beta_k x_k$$

where x_i is the value of the *j*th independent variable, β_i is the *j*th coefficient and $\frac{\pi(x)}{1-\pi(x)}$ is the odds.

Since the Y_i observations are independent, their joint probability function is:

$$g(Y_1, \ldots, Y_n) = \prod_{i=1}^{n} \pi(x_i)^{Y_i}[1 - \pi(x_i)]^{1-Y_i}$$

The log likelihood function is obtained by a logarithm transformation of the above function:

$$log_e g(Y_1, \ldots, Y_n) = \sum_{i=1}^{n} [Y_i log_e \frac{\pi(x_i)}{1-\pi(x_i)}] + \sum_{i=1}^{n} log_e [1 - \pi(x_i)]$$

This is the likelihood function of the coefficients to be estimated and one can estimate the coefficients β using maximum likelihood method:

$$log_e L(\beta) = \sum_{i=1}^{n} [Y_i(\beta X)] - \sum_{i=1}^{n} log_e [1 + \exp(\beta X)]$$

The impact of attribute *p* on the mode choice compared to attribute *q* of the *j*th variable can be described by the odds ratio, denoted by OR:

$$OR = \frac{odds_p}{odds_q} = \exp(\beta_j)$$

An odds ratio greater than 1 indicates that attribute *p* increases the probability of choosing intercity transit compared to attribute *q*.

Mode Choice Model and Results Analysis The response variable is mode choice: personal car vs. rural transit. Demographic variables were included in the model and tested. Race, personal income, household income, employment type, education level, type of home ownership, number of cars, children, adults and working adults in household are significant variables at 0.05 level. There are no mode-specific variables because of difficulty estimating cost and performance of different modes for different trips. All the significant variables were included in the model and stepwise selection method was used to select the best model.

Model results are shown in Table 4. Due to the high correlation among independent variables, the variances of the coefficients were overestimated. So the significance of the coefficients was underestimated. This indicates that variables in the model are actually more

significant, instead of less significant. So other variables that are not significant at 0.05 level but at 0.15 level may also be significant due to this underestimation. However, no other variables are significant at 0.15 level when controlling for the current significant variables. So no other variables were analyzed. Although principal component analysis or factor analysis could be used to reduce the multiple highly correlated variables into fewer variables (factors), the reduced variables will lose the ability of interpretation and that is not the aim of this study.

Although the coefficients of the variables in the model can be interpreted as holding other variables constant, what would happen to the odds of the response variable if one independent variable increases by one unit, in reality because of the high correlation between independent variables, when one variable increases by one unit, other variables will also likely change correspondingly. So as personal income increases, the household income would also increase, so does the number of cars in the household. The person is more likely to own a house. So generally speaking, the model result shows that wealthier people (who also generally own more cars and own their home) are less likely to use transit.

It is interesting that all the variables in the model are related to the person's economic status, except for the race. Gender and employment status that were found significantly different between personal car user group and transit user group are not significant in the model after controlling for other variables. It is probably because those variables are correlated with the variables in the model, and do not explain as much variation of the data as the variables directly related to the wealth. It shows again that wealth is dominant factor that influence people's mode choice.

Table 4 Intercity Travel Mode Choice Model (Car vs. Transit) Results

Parameter	Level	Estimate	Odds Ratio
Alternative specific constant		1.67*	
Race	White (base)	-	-
	Non-white	1.23*	3.42
Personal income (unit: $5,000)		-0.27**	0.75
Household income (unit: $10,000)		-0.21*	0.82
Home ownership type	Rent (base)	-	-
	Own	-1.61**	0.21
	Other	0.59**	1.90
Number of cars		-1.29**	0.29

Car is the base mode
** Statistically significant at 1% level; * statistically significant at 5% level;
N= 871; 164 people used intercity transit and 707 people used car.
The -2 Log-likelihood of intercept only model is 1703.8. The -2 Log-likelihood of intercept and covariates model is 1688.2

Combined with previous finding that about 90% of the riders have difficulty finding alternative transportation mode, it suggests that rural transit riders are captive riders, not choice riders. So the rural transit serves a critical transportation role to less wealthy rural residents. It is important that policy makers understand the role of the rural transit plays in the rural transportation system.

Discussion and Conclusion

Rural transportation is an important component of the transportation system. Although most of rural resident travel by cars, rural transit plays an important role in transporting people

who cannot drive or do not have access to a car. ICB, DFRT and DRT are the three main modes of rural public transportation. Although there are more DFRT and DRT services than ICB services, ICB are studied much more frequently than either DFRT or DRT. Little information is known about the rural DFRT and DRT trips or rider characteristics. Policies regarding DFRT and DRT and improvement suggestions are hard to make without knowing who are using the service, why they are using the service and what improvement is valued. This paper summarizes three surveys: DFRT rider survey, DRT rider survey and rural car-driving residential survey and tries to answer these questions.

DFRT and DRT are mainly used for health care appointments, in part because the fare is subsidized under health programs. To compare, there is no leading trip purpose for car users. Personal cars are used for multiple trip purposes while fixed route and schedule rural transit, ICB, is mainly used for visiting families and friends. In general DFRT/DRT, personal car and ICB are three different groups of mode choices. The trip purpose distribution and travel frequency distribution of DFRT and DRT are very similar, suggesting they are the same mobility option to users.

It is important to realize how critical the DFRT and DRT are to the users. Over 90% of the DFRT and DRT riders reported it is difficult to find alternative transportation method, indicating rural transit riders are mostly captive users instead of choice users. More than two thirds of the riders use the transit at least once a week. If the transit services are stopped, it would severely impact the mobility and welfare of the users.

In terms of improvement, the unreliability of the transit is the biggest concern for transit riders. To personal car users (choice riders), on the other hand, they are more attracted to transit if the bus stop could be closer to their house or the local transit would be more convenient at the destination city. Improving transit in the destination city could increase the ridership of rural transit.

The demographics of DFRT and DRT riders are very similar. They are more likely female, of minority races (non-white), unemployed, rent a house as opposed to own a house, have low automobile ownership, and have low personal and household income. Those characteristics are similar to ICB riders, but different from car users. It indicates that the rural transit service is

mainly used by less wealthy people. It is important for policy makers to understand to make equitable policies. After controlling for other variables in the logistic regression model, only the variables that are directly related to the wealth and race are significant. It again suggests that wealth is the main factor that determines a person's mode choice.

Although the rural transit fare is cheap compared to the car travel, it is not the main reason that riders use it. The feature of the transit service (pick up from origin and drop off to destination) and the limitations of the riders (do not have access to a car or cannot drive) are the main reasons of using rural transit.

This paper gives an overview of the DFRT and DRT trip characteristics and rider demographics and compares those to riders of ICB and personal car users. It is one of the first studies that focuses on the rural transit in general, not only ICB. It also points out the number of existing studies related to rural DFRT and DRT do not match its importance in rural transportation system. Future work should focus on the planning of DFRT routes and optimization of DFRT and DRT services.

Chapter 4

Rural-Urban Bus Travel Demand and Network Evaluation

Introduction

US cities lost one third of the scheduled ICB service between 1960 and 1980 and more than half of the remaining service between 1980 and early 2006 [38]. But with rising travel demand, escalating fuel price, and the Federal Transit Administration (FTA) 5311 (f) funding to support ICB agencies to provide or continue their service; the ICB industry is beginning to see more ridership. It has been rated as the fastest growing mode of intercity transportation, outpacing air and rail transportation in 2010 [39]. In Tennessee, an ICB Demonstration Program was implemented in 2008 in response to the growing public intercity travel need. There is a growing number of fixed route, scheduled ICB service in the state. In the context of this study, we focus on ICB operating within the state of Tennessee, and not directly connecting to different states (though they do feed interstate bus terminals). In general, the ICB services described in this paper are short-haul buses that connect rural regions with urban centers.

While some studies have investigated interstate bus trips, such as Greyhound trips [26-30, 40], little research has been directed to the within-state ICB services, particularly in the context of recent demographic changes and growth in demand. This paper is aimed at exploring the rider and trip characteristics of ICB, estimate high demand regions, and evaluate the existing ICB network.

Literature Review

Intercity Travel Demand Model Review A few papers have discussed mode choice modeling for intercity surface travel. Ashiabor, et al. [26] reviewed disaggregate nationwide travel demand modes developed between 1976 and 1990 (Stopher and Prashker 1976; Grayson 1981; Morrison and Winston 1985; Koppelman 1989). All four models used versions of National Travel Surveys (NTS) conducted by the Bureau of the Census and the Bureau of Transportation Statistics (BTS). All of these four models included bus as one of the transportation modes. The

fifth attempt to model nationwide travel demand was carried out by Ashiabor, et al., who developed a logit model based on 1995 American Travel Survey (ATS). However, both 1977 NTS and ATS only collected information on trips of 100 miles or more, leaving the intercity trips that are shorter than 100 miles pre-eliminated from these studies, which include most of the within-state Tennessee ICB trips. Although only Tennessee intercity trips are surveyed and determined to be less than 100 miles, it's reasonable to infer that in other States, there are also many intercity trips that are less than 100 miles because of similar state dimension and people's travel behavior.

Fravel, et al. [41] wrote TCRP Report 147 introducing the toolkit for estimating demand for rural ICB services. An application example of the tools is the Minnesota ICB network study [22, 40] which chose five transit-dependent population characteristics to profile persons who rely on transit. Potential ICB needs were identified by comparing the locations served by the current network with the locations in Minnesota that have concentrations of persons more likely to rely on public transportation. It serves as a good reference to this paper. We improve the method by comparing Tennessee ICB riders characteristics to general travelers to get the specific characterizes of Tennessee riders and introduces methods to evaluate the connection of bus network to potential riders and destinations.

ICB Riders Characteristics Review An earlier Tennessee ICB Study [42] performed an ICB passenger interview survey to develop a profile of passengers. It was conducted for 24-hour period at several bus terminal locations. The survey result shows that a typical ICB passenger is aged 16 to 25, uses the bus once a year to visit friend and/or relatives, travels over ten miles by auto to get to and from the terminals, and has an annual income of between $7,501 and $15,000. Data also indicates some variance in automobile ownership between cities. In Chattanooga, Memphis, and Nashville most respondents indicated that they owned one automobile, while in Jackson and Knoxville most respondents indicated that they did not own an automobile.

The BTS's 1995 American Travel Survey [43] concludes that the ICB riders are more likely to be persons 65 years old and over, female, minority, less educated, to live in households with low income and no personal use vehicle available. Although it's a good description of long

distance ICB riders' characteristics, these characteristics parallel the scope of the ATS, people who travel more than 100 miles.

Although the studies above have given a comprehensive view of intercity travel mode choice modeling and ICB riders' characteristics, no published study has been performed to analyze the within-state long distance bus travelers' characteristics, particularly linking rural areas with urban centers. As a result, to get information about intrastate long distance travelers is crucial to determine these individuals' characteristics and identify the area with such demand. This paper will begin to fill this gap and test how ICB rider population demographics are different from overall intercity traveling population.

Survey Method

A questionnaire was developed for each of the ICB route that is supported by FTA 5311 (f) funds. This included 5 transit companies (3 Human Resource Agencies and 2 private service providers) providing 756 route-miles of service in Tennessee. The surveys were conducted between May 1, 2010 and August 21 2010. ICB passengers were asked about their trip and personal information, such as trip purpose, boarding and alighting stops, rider age, gender, annual household income, and so on.

Two survey methodologies were considered. The first one is an intercept survey. Researchers intercepted passengers at different ICB stops in different locations throughout the state and ride the bus to survey passengers on bus. This type of survey has a high response rate; a high quality of data collected and allows surveyors to collect other information, including open-ended observations from the riders. However, a big drawback of this survey method is that it has high cost for interviewers, particularly given low bus service frequency, dispersed locations of bus stops, and relatively small number of riders on the bus. A pilot survey was performed to test the survey method. During the two-day pilot survey, only 27 riders were interviewed.

Another survey method distributed questionnaires to bus riders with the help of the driver. Survey packages were distributed to the transit agencies and drivers gave the surveys to boarding riders, along with a pencil and mail-back envelope. This survey method had a relatively low response rate and survey quality, but it greatly increased the cost-effectiveness of the data

collection. Using this method, 446 questionnaires were sent out and 92 were returned (21% response rate). The true response rate is somewhat uncertain because we were unable to confirm that all surveys were distributed to passengers.

Statistical Analysis

Considering the low number of ICB trips recorded in the 2009 NHTS nationwide, only 48 trips are made by ICB compared to 62,920 trips made over 30 miles by other modes, it is difficult to model ICB travel from this dataset. Indeed, the NHTS does not record any trips in Tennessee that are made by ICB. As such, an alternative method is adopted to estimate ICB rider characteristics. All intercity trips made in Tennessee are extracted from NHTS. ICB riders' and trips' characteristics are summarized by comparing data in our survey and the dataset extracted from NHTS. ICB riders' attributes will serve as a reference to determine the number of potential ICB riders in each census tract in Tennessee, which will be converted to estimate likely ICB rider population density. The density will help to determine the areas with higher ICB demand.

Attributes Comparison ICB riders and trips characteristics were summarized from the survey responses and compared with the riders and trips characteristics of intercity car trips with same travel distance, extracted from 2010 NHTS. From our survey, trip length ranges from 6 miles to 162.5 miles. There are only two trips shorter than 30 miles, the existence of which might be due to the misunderstanding or writing error, the shortest length of intercity trip is set as 30 miles. The upper limit of intercity trip length is rounded to 170 miles. ICB trip distance includes three parts: distance from origin to boarding bus stop, travel distance on the bus, and distance from alighting stop to destination. Moreover, a geographic criterion was also used to filter the data from NHTS--only trips made in Tennessee were selected. Considering the fact that the trip origin and destination are unknown for the NHTS data, the State of household location of survey responders was adopted as an alternative way to select the trips made in Tennessee.

The filtered NHTS dataset includes 1116 intercity trips distributed among modes shown in Figure 9. As shown, 1095 trips are made by non-public transportation and no trips are made by ICB. Of these trips, 129 were made by private vans, which could include commuter vanpools.

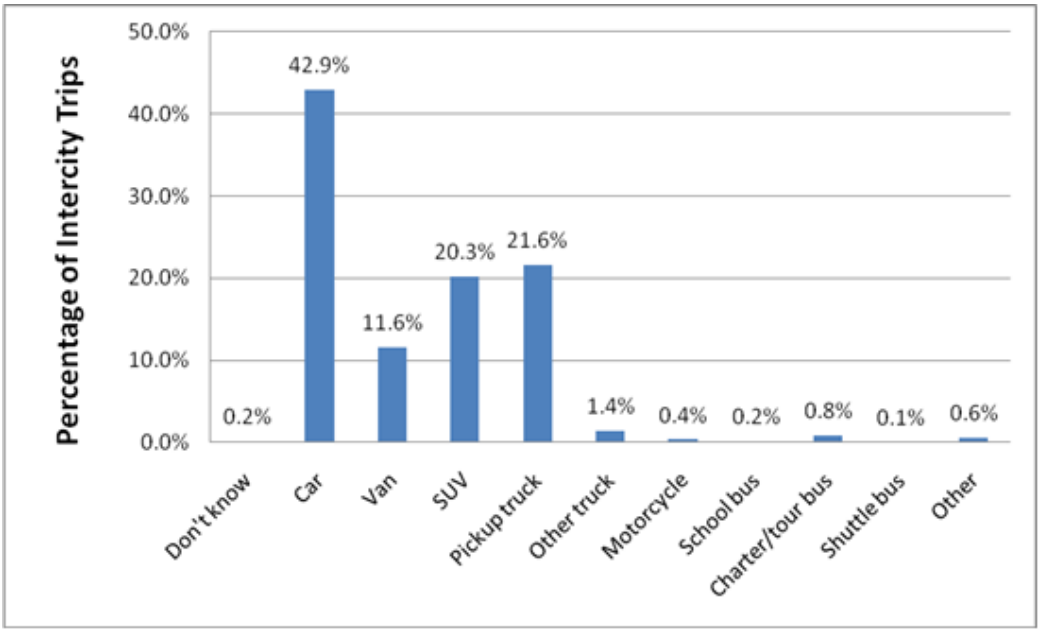


Figure 9 Transportation Mode Choice Percentage of NHTS Intercity Trips

In addition to transportation mode choice, 11 trip and rider characteristics are compared, including traveler's race, gender, age, employment status, ability to drive, household annual income, household size, number of vehicles available in household, education level, trip purpose, and trip distance. We assume these 11 characteristics influence traveler's mode choice and are included in both the NHTS and our survey.

Our analysis focuses on supplementing the NHTS with our survey data and applying findings from the NHTS to our dataset. We compare the differences in the variables to identify if the variable in each survey dataset has the same distribution.

Results Comparing both the NHTS (mostly personal auto) intercity trips in Tennessee with our dataset reveals significant differences in all variables with the exception of gender, as shown in

Table 5.

The results obtained here are different from what have been observed in other studies, which shows the importance to perform this test and comparison. Most results follow intuition. Key results are summarized as follows.

Although age between private vehicle users and ICB riders are significantly different, there is no special trend to characterize ICB riders' age.

ICB riders are more likely to be non-white races.

ICB riders are more likely to be unemployed.

ICB riders are more likely to be unable to drive.

ICB riders are more likely to be from low-income household. Nearly 70% ICB riders' annual household income is under $27,499 compared to 21% of non-ICB riders.

ICB riders are more likely to have larger number of household members, especially equal to or above seven.

ICB riders are more likely to have smaller number of vehicles in the household, usually two or fewer. Combined with the high number of people per household results in higher reliance on transit service.

Table 5 Demographic Comparison between NHTS Trips and ICB Trips

Variable Name	Category	NHTS Percentage	Survey Percentage	P-value
Race	White	94	86	0.0079
Sex	Male	56	53	0.6357
Employment status	Employed	63	46	0.0014
Capability to drive	Able	97	91	0.0036
Household income	Under $15,000	12	49	<0.0001
	$15,000-$27,499	9	20	
	$27,500-$52,499	27	8	
	$52,500-$89,999	32	8	
	$90,000 and over	20	14	
Household size	1	6	31	<0.0001
	2	50	28	
	3	17	9	
	4	18	16	
	5	6	8	
	6	2	0	
	7 and more	2	9	
Household vehicle Count	0	0	1	<0.0001
	1	9	40	
	2	37	30	
	3	34	22	
	4	11	7	
	5 and more	9	1	
Education level	Less than high school	7	63	<0.0001
	High school or GE	32	0	
	Some college or vocational degree	32	0	
	Bachelor's degree	16	30	
	Graduate or professional degree	13	7	
Age	Below 15	4	0	0.0122
	15-24	6	14	
	25-34	10	13	
	35-44	17	9	
	45-54	20	21	
	55-64	22	27	
	Equal to or above 65	21	15	
Trip purpose	Work/school	27	24	<0.0001
	Religious activity	4	2	
	Medical/dental services	4	39	

Table 5 Demographic Comparison between NHTS Trips and ICB Trips-Continued

Variable Name	Category	NHTS Percentage	Survey Percentage	P-value
Trip Purpose	Shopping/errands	20	1	<0.0001
	Social/recreational	14	10	
Trip length (miles)	Mean value	53.8	75.5	<0.0001

Note: All p-values were estimated using the Chi Squared test with the exception of trip length, evaluated with Wilcoxon Rank Sum test.

ICB riders in our sample are likely to take the trip for medical purpose. This could be because of a bias in the sampling approach, i.e., many of the bus services we surveyed fed regional medical centers.

ICB riders are more likely to travel for longer distance.

Among the eight characteristics, six of them are household- or individual-level: race, employment status, ability to drive, household income, household size, and number of vehicles in household. In order to use these characteristics to identify the areas with high ICB demand, the demographic data related to these six attributes were downloaded for the Tennessee at census tract level from the American Community Survey (ACS). The ACS does not contain any information about the capability to drive (or license status), so only five variables are used to locate the area where residents with a higher demand of ICB live.

Geographic Analysis

High Demand Census Tract The number of people that satisfy each of the selection criteria was determined. Five measures are determined for each census tract in Tennessee, and then divided by census tract area to get the density of that variable. The five measures are non-white population density, unemployed population density, poverty-level household density, large-size household density and low vehicle count household density. Five ratings are given to each census tract according to the five measures. Each rating is given by ranking all the census tracts by one measure. For example, the first rating is given according to the variable Race. All census tracts are ranked by non-white density. The higher the non-white population density is, the higher

the census tract's ranking is. The five ratings are summed to get a total rating for each census tract.

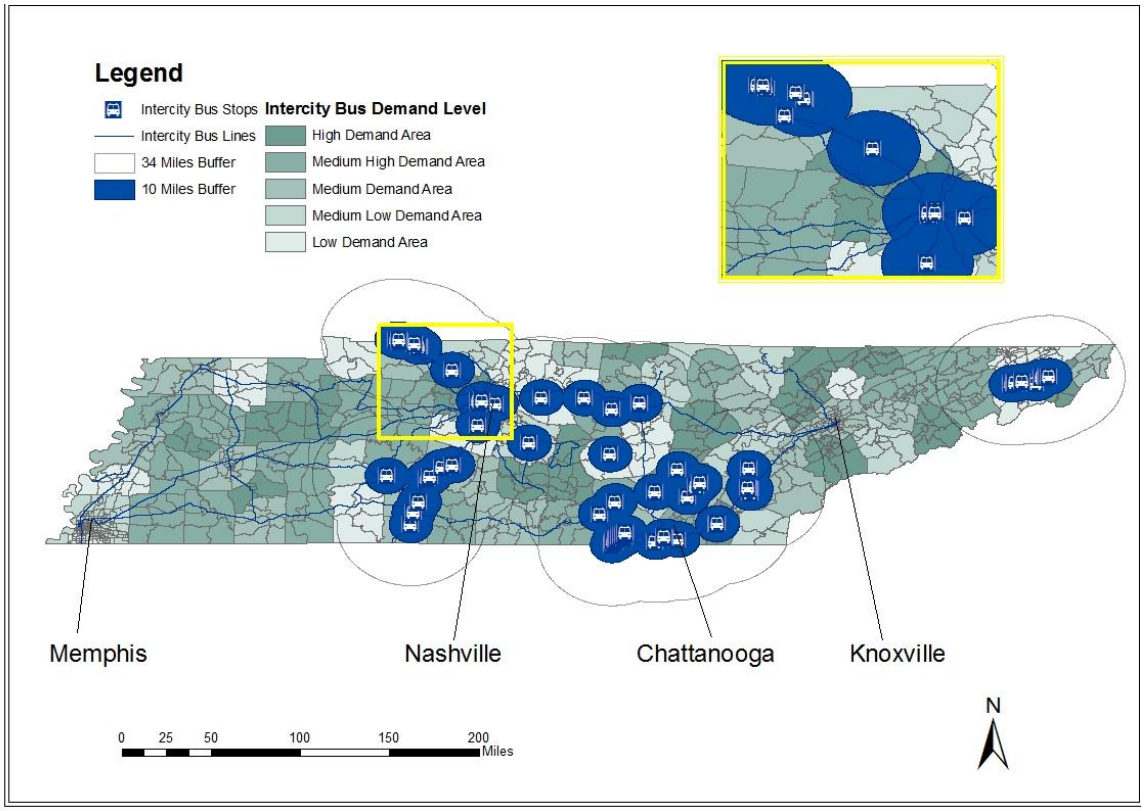


Figure 10 Tennessee ICB Demand Map

The ICB demand is divided into five levels using ArcGIS--high, medium high, medium, medium low and low (based on demographic rating). This grouping level could change depending on analysis purpose or government's goal of ICB service coverage. Out of 1261 census tracts, 228 were identified as the high ICB demand area, with a total area of 7684 square miles and 973795 residents, around 18% of Tennessee's area and 16% of Tennessee's population. The next highest category, medium high demand areas, included 296 census tracts, with an area of 12254 square miles and 1362653 people, around 29% of Tennessee area and 22% of Tennessee's

population. Figure 10 shows that census tracts with the similar demand levels are usually located adjacent to each other, enabling potential ICB corridors.

Spatial Analysis There are six agencies providing ICB services within Tennessee. Altogether 15 routes are running in addition to interstate Greyhound routes that connect all the Greyhound stations in Tennessee. This system serves 87 stops.

The access shed, defined as the access and egress distance, is summarized based on our survey dataset. For the access distance, the mean is 10.1 miles and maximum value is 34.0 miles. For the egress distance, almost all trips were destined for location of the bus stop (usually a major trip generator) with a mean distance of 1.2 miles and 90 percentile distance of 9.2 miles. Average egress distance is shorter than access distance because some ICB agencies provide stop-to-door service, i.e., transport passengers to the destinations, even though they are not bus stops; and while it's not likely that passengers' origin is exactly the starting stop, in most cases, their destination is one of the stops. In these cases, their egress distance is zero.

The function of one bus stop is two-fold: connect to potential riders and connect to meaningful destinations. As a result, we evaluate bus stops by these two functions. To evaluate how well bus stops connect to riders, we use two methods: 1, determine how much high demand area is covered by ICB stops service area and 2, count how many stops are within the high ICB demand area and medium high demand area.

Two buffers are made around each bus stop, one with radius of mean access distance value, 10 miles, and the other with a radius of maximum value, 34 miles, as shown in Figure 10. Considering that 34 miles is the largest distance from the origin to boarding stop, the aim of the buffer with this radius is to cover all the high and medium-high demand area in Tennessee. The 10 mile radius buffer is meant to cover the high demand area.

Combining the buffers with the demographic distribution, 1222 square miles of the 7684 square miles high demand areas (around 16%) are covered by the small buffer and 9875 square miles of 19938 square miles medium-high and high demand areas (50%) are covered by the large (34 miles) buffer. Looking at Figure 10 another way, the total area of the small buffer is 8735 square miles, compared to 7684 square miles of high demand area. Similarly, total area of the

large buffer is 33618 square miles, compared to 19938 square miles of high and medium-high demand areas. It may imply that the bus stops are not well located to cover the high and medium high demand area.

Another way to assess the bus stops' connection to riders is to explore the percentage of stops that are within the high and medium high demand area and compare to the percentage of these demand area to total state area. 14 stops are within the high demand area and 8 stops are within the medium high demand area. Since the high and medium high demand area covers around 18% and 29% of Tennessee area, the number of stops within these two areas should be at least proportional to the two percentages. 17% of stops are within the high demand area , which is proportional to the high demand area percentage. However, only 9% of the stops are within medium high demand areas, which is lower than the medium high demand area percentage, indicating an inappropriate orientation of the bus stops. The two analysis results above show that bus stops are not well located on the origin side.

Since bus stops are not only designed to connect to riders (origins) but also connect to activity center (destinations), which are usually not areas with high number of people matching ICB rider demographics, we need to explore how well these stops connect to activity centers to evaluate the orientation of bus stops. Depending on purpose of ICB program, the destinations stops should connect to different types of places, such as hospitals, universities, airports, military bases, large employers and so on. In this paper, we focus on ICB programs that provide rural residents access to opportunities in urban area, but not include job access. So hospitals, universities, airports and military bases are regarded as meaningful destinations. They are shown in Figure 10.

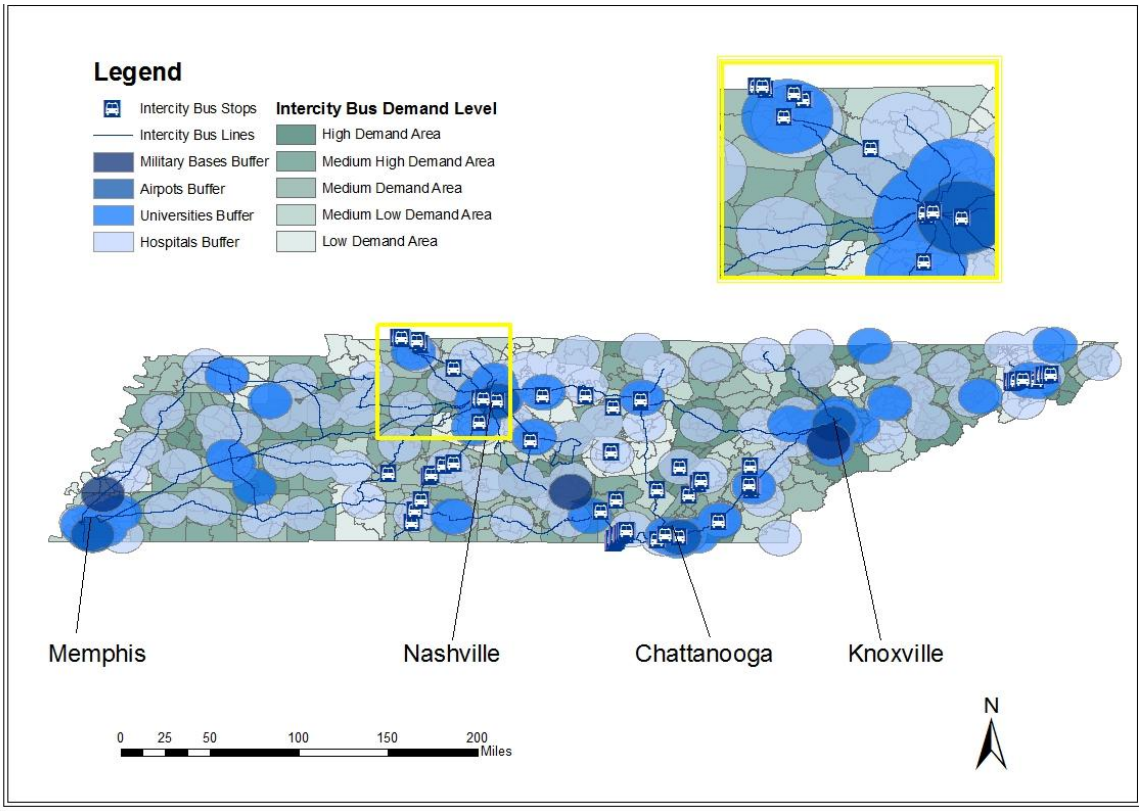


Figure 11 Tennessee Meaningful Destinations Map

Stops located within 10 miles of the meaningful destinations are regarded as connecting to them. All the airports, hospitals, military bases and universities in Tennessee are inventoried. There are 4 airports, 156 hospitals, 3 military bases and 67 universities and research institutes. Spatial analysis was used to determine how many stops are within the 1.2 miles buffer of these meaningful destinations. We found out that 8 stops connect to airports, 70 stops connects to hospitals, 0 stops connect to military bases and 49 stops connect to universities and research institutes. Some of the stops connect to two or more destinations. Only 15 stops (17%) do not connect to any meaningful destinations. It indicates the bus stops are well connected to the destinations.

To make the ICB program successful, changes need to be made on the stop locations to better connect to origins. There are 13 stops that are not located within high or medium high

demand area and not connected to any meaningful destinations. They could be relocated to better connect to potential riders. The identified high demand area and meaningful destinations could serve as reference for where these stops should be relocated to.

There are several issues that need to be further studied. A more complete inventory of all possible destinations may be needed to give a more detailed study. The distance by which whether bus stops are connected to a meaningful destination should be studies carefully because it has great impact on bus stations' accessibility level. A sensitivity analysis may be needed to have a general understanding of how distance changes will affect bus stations' connectivity level.

Conclusion

The ICB (particularly those publicly subsidized) in Tennessee that connect rural areas to urban areas usually only travels within Tennessee and serve urban centers. ICB riders' characteristics and trip characteristics are different from car-based intercity or interstate trips, say traveling more than 200 miles. A survey was performed to attain Tennessee ICB rider characteristics. NHTS data are filtered based on the trip distance that satisfies the intercity and intrastate travel requirement to correlate with the types of trips that ICB service provides. We compared ICB survey responses and the NHTS responses and found significant difference between mostly car drivers and bus riders among almost all variables we observed. Several ICB characteristics are identified and used to locate where these populations, whose demographics correlate with ICB riders, live based on ACS data. Bus stations have two service functions: connecting to potential riders and connecting to potential destinations. To evaluate how stations connect to riders, we place existing ICB stops on a GIS map, buffering their service areas to determine the proportion of the high demand census tracts that are served by the bus stops and proportion of bus stops within high demand area compared to proportion of high demand area to total state area. These buffers are viewed as bus service area and compared with high demand areas. The result shows that there are enough ICB stops to cover all the high demand area in Tennessee, but only half of ICB high demand area is covered. While the medium high demand area covers 29% of the state area, only 9% of the stops are within high demand area. These results suggest that the location of these stops should be investigated to better connect to potential riders. On the destinations side, 81 airports, 156 hospitals, 3 military bases and 67 universities and research institutes are inventoried and regarded as popular destinations. 72 stops connect to the

meaningful destinations. It shows that the bus network are well connected to destinations but poorly connected to potential riders. 13 stops are found neither connecting to potential riders nor connecting to destinations. So relocation of these stops to better connect to high demand area should be considered. This research provides solid methodology of evaluating the current ICB network. It also introduces ways to identify the bus stops that do not have good connectivity to either origins or destinations, and methods to relocate them.

This paper has several limitations. First, because ICB service and ridership is low in Tennessee, data volume and quality are challenges toward developing robust transportation demand models. The data collection method possibly introduces some self-selection bias, that is, we survey existing bus riders on existing routes that are not ubiquitous or randomly distributed across Tennessee. Still, this paper has begun to fill a research gap on a mode of transportation that is beginning to grow after decades of decline. The methods applied here could be applied to other states to identify their ICB riders' characteristics and to evaluate their existing ICB network.

Chapter 5

Rural to Urban Intercity Deviated Fixed Route Design -An Application in Tennessee

Introduction

DFRT is an important type of rural transit, maintain characteristics of fixed route transit (ICB) and fully demand responsive transit (DRT). It "operates along a fixed alignment or path at generally fixed times, but may deviate from the route alignment to collect or drop off passengers who have requested the deviation" [2]. Its flexibility could make it more suitable to serve the rural area than fixed route counterparts because of dispersed rural population. In late 1980s, the deregulation of ICB industry has resulted in abandonment of many ICB routes, especially in rural areas, because of the low revenue generation from rural riders [31]. Service cuts negatively impacted the mobility of bus-riding rural residents. DFRT has been playing an increasingly important role in meeting rural residents' transportation needs. According to National Transit Database (NTD) [2], in 2010 there were 302 rural DFRT operators in the US, providing around 22 million passenger trips with total revenue miles around $65 million. Although the DFRT services have been implemented across US, there are few standards to which transit service providers can turn when designing service. [44]

The existing literature related to DFRT focuses on optimizing various service parameters of DFRT and while constraining other parameters. No studies have focused on the route planning of DFRT using existing networks and heterogeneous demand. Recognizing the lack of literature about DFRT demand analysis and empirical network design, this chapter aims to fill this important gap by proposing a methodology to estimate demand and plan DFRT routes.

The two-part planning methodology is presented using Tennessee as an example. First travel demand of each census tract in Tennessee is estimated using a trip generation model. This model is estimated using a DRT ridership dataset as input, relating trip generation with census-level demographic data. DRT riders share common characteristics to DFRT riders (see Chapter 3), we assume DRT trip generation serves as an effective proxy to DFRT trip generation. Using available ridership data from one DRT operator is available a model is constructed to estimate

trip generation of census tracts as a function of available demographic data, and estimate ridership in census tracts surrounding cities that are not in the operator's service area. Second, after estimating trip generation of all census tracts in Tennessee, all the interstates and highways in Tennessee are divided into 5-mile segments and analyzed as potential route segments, radiating from Tennessee's five largest urban areas. The service areas of all the segments are overlaid with trip generation to estimate the trip generation served by each segment. Segments are linked to form routes and all routes are evaluated for cost effectiveness as they extend away from urban areas. Most cost-effective routes are prioritized and presented. Last, suggestions about how to use this methodology and its limitations are discussed.

Literature Review

DFRT can also be referred to as mobility allowance shuttle transit [36, 45], flexroute transit [34] or route deviation transit [46, 47] in different papers. Existing studies related to DFRT are limited.

For studies directly related to DFRT, the common theme the development of relationship between various design parameters of DFRT to help transit planners consider the trade-offs between parameters or to optimize one specific parameter. They are usually proposed under an ideal or hypothetical operating environment, such as grid network [34-36].

Fu [34] developed an equation for the relationship between various system variables, such as the number of feasible deviations, slack time, zone size and dwell time, based on a grid network. Smith and Demetsky [35] explored the relationship between service zone size, which is the area between fixed stops where deviations are permitted, and slack time distribution among zones. Zhao and Dessouky [36] analyzed the relationship between service cycle time, and the length and width of the service area. Those studies serve as a good foundation for DFRT parameter optimization, yet provide little practical or empirical approaches to service planning or network design.

Other articles do not study DFRT directly but focus on flexible transportation services, which include "all types of hybrid services that are not pure DRT or fixed-route service" [44]. Most of the flexible transportation services are implemented in rural and small urban areas [47].

Koffman studied the flexible transportation services operated by 24 transit systems and acknowledged that there are few standards that transit service providers can use when designing service. Potts et al. [48] analyzed features of small, medium and large urban and rural transit agencies and described the appropriate flexible transportation services strategies for each of them. All these studies acknowledge the need for studies that look at the planning and operation of flexible transportation services. In summary, studies on flexible transportation services all state there is a need to look at the planning and operation of flexible transportation services. The existing DFRT studies focus on operations of existing or hypothetical DFRT service, but do not provide guidance on network planning. Important challenges of how to design efficient DFRT networks or where to implement the deviated fixed routes remain unanswered. This chapter will address these challenges by proposing a method to plan DFRT routes in a state. It begins with constructing a trip generation model to estimate the trip generation of all census tracts in Tennessee. Next all the interstates and highways in Tennessee will be divided into five-mile segments and overlaid with the trip generation to estimate the trip generation of each route segment. Different combinations of linked route segments will be analyzed to find the best routes for different budget constraints.

Trip Generation Modeling

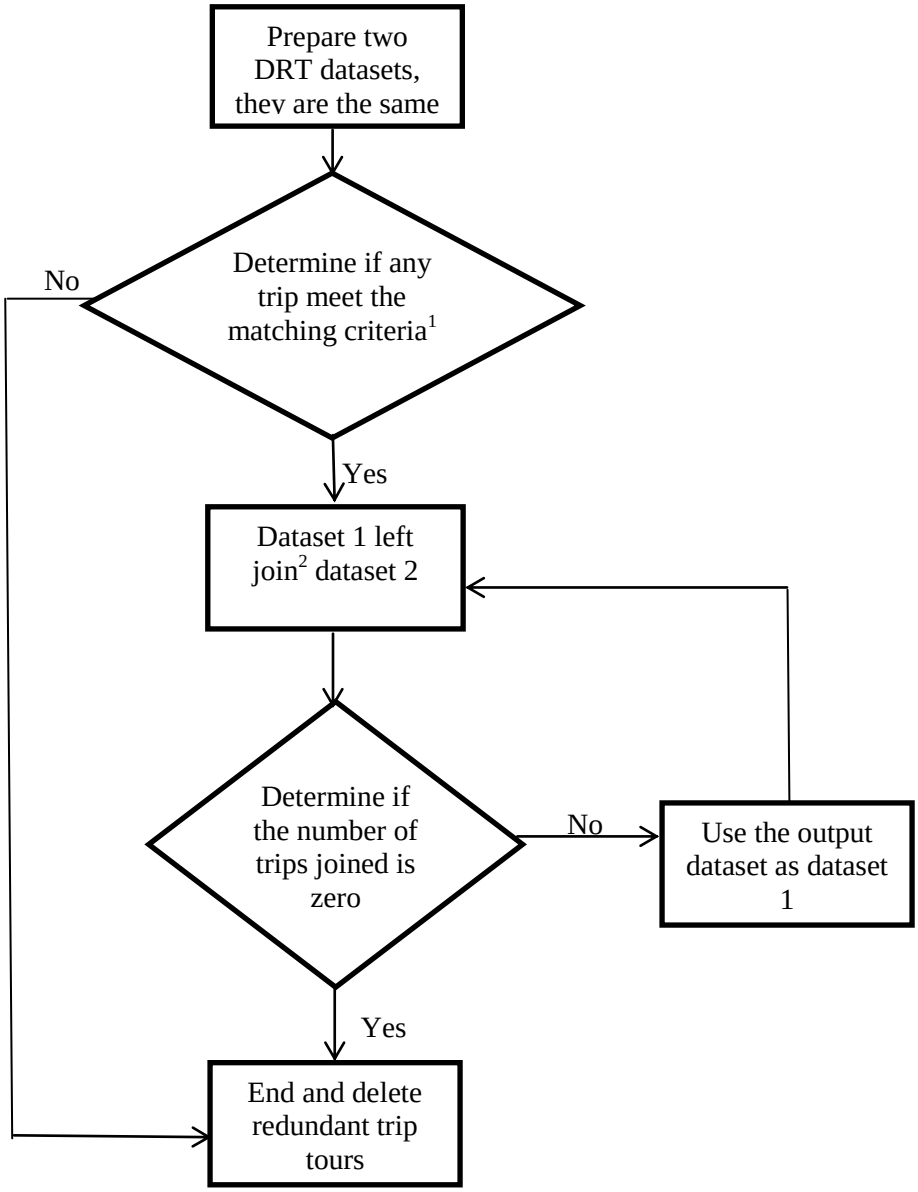
This section describes a trip generation model used to estimate trip generation rate of all census tracts in Tennessee. This model is constructed based on a DRT ridership dataset in one part of the state and applied to areas without ridership data estimate the trip generation of those areas based on demographics in the census data.

Data Description Mid-Cumberland Human Resource Agency (MCHRA) keeps a record of all the demand responsive trips it provided. A two-year dataset (July 1, 2009-June 30, 2011; fiscal year 2009-2010) was obtained from MCHRA. The dataset contains an anonymous but unique passenger ID number, trip date, pick up address, pick up time, drop off address, drop off time, trip mileage, fare, passenger age, gender and trip purpose of all the trips. There were 169112 trips in fiscal year 2009 and 180488 trips in fiscal year 2010. This dataset is used to construct a model to estimate trip generation based on known census data (e.g., population density, no-vehicle household density) and applied to other places in Tennessee without direct demand data. Because the trips in the dataset are unlinked passenger trips, where a trip is

originally produced (i.e., home) is unknown. If a pickup location is regarded as a trip producing zone, then the urban area would have the highest trip generation rate because most riders go there and return from there. To address this, trips are linked into trip tours and assigned to the origin of the original trip link in the rural area.

Trip Linking In each trip tour there could be many trips. Only the origin of the first trip is the trip producing location. The origins of other trips in this trip tour are actually intermediate destinations of the traveler. Confusing them could lead to incorrect estimation of trip generation. An examination of the data reveals that the connecting trips in a trip tour are usually performed within ten hours while two different trip tours are usually more than ten hours apart. A criteria to link trips into trip tours was developed: trips performed by the same person (indicated by matching rider ID) within ten hours, with the drop off address matching the pick up address of the following trip are linked together. The trip linking was performed using SAS PROC SQL [1]. The trip linking process is shown in Figure 12.

In total, 349600 trips in the dataset are linked into 190914 trip tours. Among the 190914 trip tours, 148500 tours are composed of two trips, 4134 tours are composed of three trips and 965 tours are composed of four trips. Number of trip tours generating from each census tract were counted as input of the trip generation model.



1. Criteria are: 1) rider ID in dataset 1 = rider ID in dataset 2; and 2) drop off address in dataset 1 = pick up address in dataset 2; and 3) pick up time in dataset 2 is between the drop off time in dataset 1 and the drop off time in dataset 1 + 10 hours; and 4) the first pick up address in dataset 1 ≠ the last drop off address in dataset 1
2. "Left join" is a term used in SQL [1].

Figure 12 Trip Linking Procedure

Model Selection Because only trip tour count data in the MCHRA service area are available (other service providers either do not keep a record of individual trips they provided or are reluctant to offer that information), a model was constructed to estimate the trip generation of census tracts in Tennessee outside of MCHRA's service area relying on relationships between trip generation and demographics. To estimate the model parameters, first, the number of trip tours generating from each census tract were counted from the last section. The trip generation rate (unit is trip tours per square mile) of each census tract is the dependent variable of the trip generation model. The trip generation rate of census tracts in MCHRA service area is shown in Figure 13. For illustration, trip generation rate is divided into five quintile levels (0-0.17, 0.17-0.66, 0.66-6.03, 6.03-20.87, 20.87-449.7 trip tours per square mile per year). In the figure, Davidson County is highlighted as the political boundary of the urban area (Nashville), which has lower (or zero) rural transit trips. This is important when developing the model. This model is applied to areas outside MCHRA's service area to estimate trip generation in all of Tennessee's census tracts.

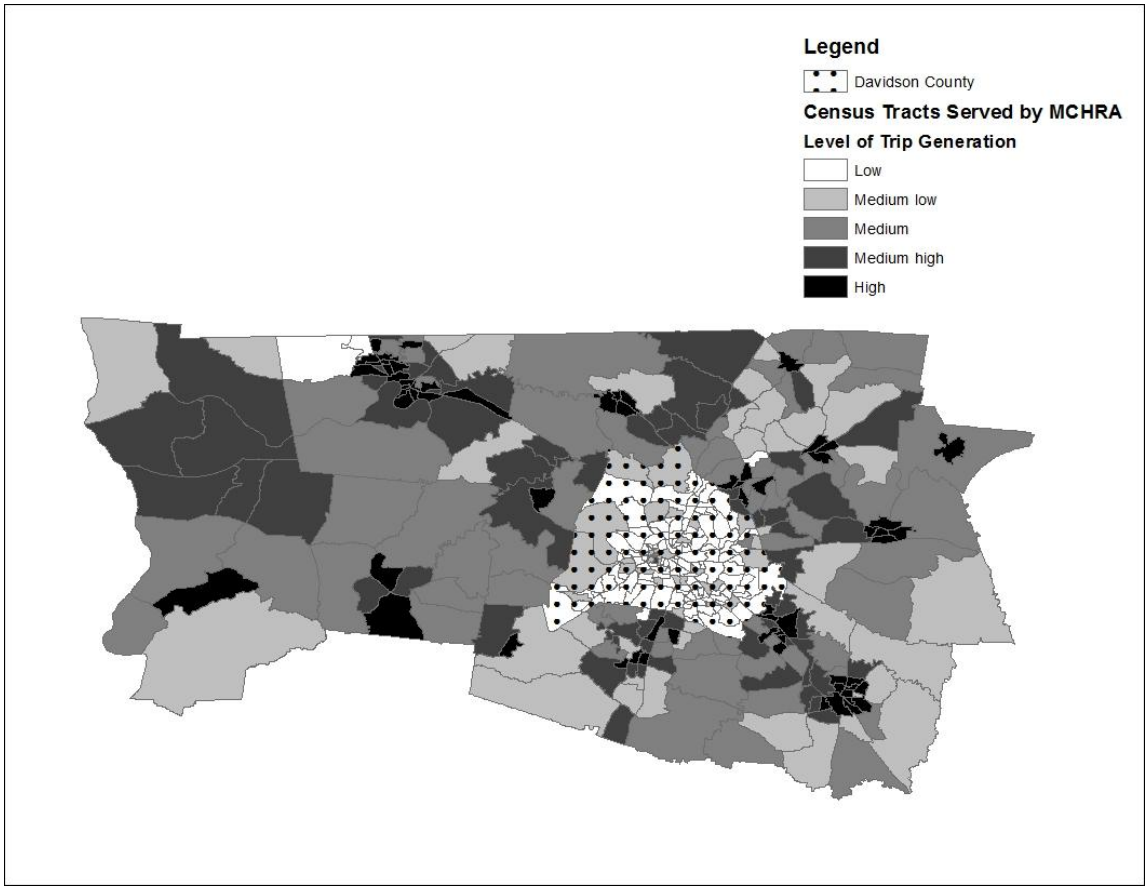


Figure 13 Trip Generation of Census Tracts in MCHRA Service Area

The trip generation rate is represented as count data (number of passenger trip tours) divided by the area of the census tract. Poisson regression and negative binomial regression models are usually used to model count data. The less restrictive NB model is more widely used than Poisson regression because it does not assume the variance of the responsive variable is equal to the mean. In this dataset, the variance of the responsive variable is larger than the mean so the NB model is used. Often when analyzing count data, the number of exogenous zeroes may seem large, which is the case of this study. Davidson County (or generally the county where a large city is located) is served with urban transit, paratransit, and taxi service, so people in those urban counties are not likely to use rural DRT, It is reasonable to assume that this pattern also applies to other large urban areas. So when this model is used to estimate the trip generation of

urban census tracts, the true trip generation rate should be much lower than predicted by the model. As shown in Figure 13, census tracts in Davidson County usually have the lowest trip generation. In fact, many of census tracts have zero trip generation. Thus, the number of zeroes may be inflated and a standard NB model would not be appropriate to model these data. A zero-inflated negative binomial (ZINB) model allows for excess exogenous zeros is most appropriate.

In this case, a ZINB model [49] assumes that zero outcome is due to two different processes: 1) whether a census tract is in an urban county; 2) if in the urban county, the outcome is zero. If not in the urban county, trip generation is estimated as a count process. The two parts of a ZINB model are a binary model, usually a binary logit model and a count model, in this case, a standard NB model. The expected count is function of the two processes. In this study, the expected trip generation rate is defined as follows:

$$E(trip\ generation\ rate)$$

$$= P(trip\ generation\ rate\ is\ zero) * 0 + P(trip\ generation\ rate\ is\ not\ zero) * E(trip\ generation\ rate | trip\ generation\ rate\ is\ not\ zero)$$

The probability whether the trip generation rate is zero, *p* is modeled by a logistic regression, with the form:

$$log\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1\, x_1 + \beta_2\, x_2 + \cdots$$

β's are the parameters that will be estimated. x's are the features of a census tract, such as population density, no-vehicle household density, and its distance from the Davidson County.

The expected trip generation rate given it is not zero is modeled using NB regression. Its form is:

$$log(trip\ generation\ rate | trip\ generation\ rate\ is\ not\ zero) = \alpha_0 + \alpha_1\ x_1 + \alpha_2\ x_2 + \cdots$$

α's are the parameters that will be estimated and again, x's are features of the census tract.

SAS 9.3 [50] was used to construct the model. There are 397 census tracts in the MCHRA service area. 300 observations were randomly chosen as the training sample and the other 97 observations are used as validation sample. The data were tested to show that there are excess zeros in the data with p-value less than 0.01, which means ZINB is required rather than standard NB. The density of total population, population of age 16 and over, population of age 65 and over, people without employment, not in labor force, females, unemployed, total households, households with no vehicles available and households with income below poverty level served as the predictors of the trip generation model. A dummy variable indicating whether the census tract is located within the five urban counties also serve as an independent variable. A stepwise variable selection procedure was used to select the best model.

Before settling on the best model, several different specifications were tried. Trip generation, defined as number of trip tours generating from each census tract, and number of trip tours per thousand people were used as dependent variables. None of these models have as good fit as when trip generation rate (tours per square mile per year) is used as the dependent variable. The model specification was selected using trip generation rate as the dependent variable.

Model Results The best model has an R-square of 0.54 for the training sample and R-square of 0.42 for the validation sample. The model contains three variables: a dummy variable whether the census tract is in the large urban area county boundary, the log transformation of the density of no vehicle households in the census tract and the log transformation of the density of population aged 16 and above in the census tract. Then all the observations including both training sample and validation sample were used to estimate the parameters of the three variables and the intercept. The results are shown in Table 6.

Distance of a census tract away from the Davidson County, calculated from the centroid of the census tract to the centroid of the Davidson County, was expected to have an effect on the trip generation rate of this census tract. Distance was included in the model and it does improve

the predictive power. However, contrary to intuition, the distance parameter is positive, which means the farther away the census tract is from Davidson County, the higher trip generation rate when controlling other variables. This is an interesting finding that is worth exploring. One possible reason could be that it is easier for people living closer to Davidson County to get a ride to the county (or Nashville) from friends or families than for people living farther away. Thus census tracts closer to the Davidson County have lower trip generation rate. However this pattern would ultimately fail at some point. If this pattern always holds, it would predict, for example, a census tract in New York city have a much higher demand to go to Nashville than any census tract in Tennessee, which is not true. It is unknown when this pattern would fail and how transferable this pattern is when applied to a larger area (Tennessee or region). If the distance is included in the model, when the distance goes up, it always becomes a dominant factor that determines the trip generation rate. A census tract far away from large urban county will always be predicted to have high trip generation rate, regardless values of other variables. To try to control for this increasing, then diminishing effect of distance, one specification included distance interacted with a dummy variable to "turn off" the distance effect after an arbitrary distance is exceeded. This limited dataset does not allow estimation of this threshold because the geographic distribution of the data are relatively small. However, choosing a threshold of the approximate radius of MCHRA's service from Davidson County (75 miles) reveals that, within the range of 0-75 miles, distance still has a positive and significant effect on DFRT demand. The distance effect is worthy of future exploration, but because of the challenges with the specification, the distance variable is not included in the model to avoid a biased estimate.

The fitted model was used to estimate the trip generation of other census tracts in Tennessee. The trip generation map is shown in Figure 14. For the most part, trip generation rates are high surrounding the large urban areas (labeled in white) primarily because of higher densities.

Table 6 Trip Generation Model Results

Negative binomial regression part			**Logistic regression part**		
Variable	Coefficient	S.E.	**Variable**	Coefficient	S.E.
Intercept	-0.18	0.31	**Intercept**	-24.68*	0.28
If in the urban county	-5.56*	0.29	**If in the urban county**	25.28	0.00
Log of no vehicle household density	0.97*	0.12	**-**	-	-
Log of population aged 16 and above density	1.37*	0.29	**-**	-	-

1. Dependent variable is log of trip tours per square mile
2. * indicates significant at 0.05 level.

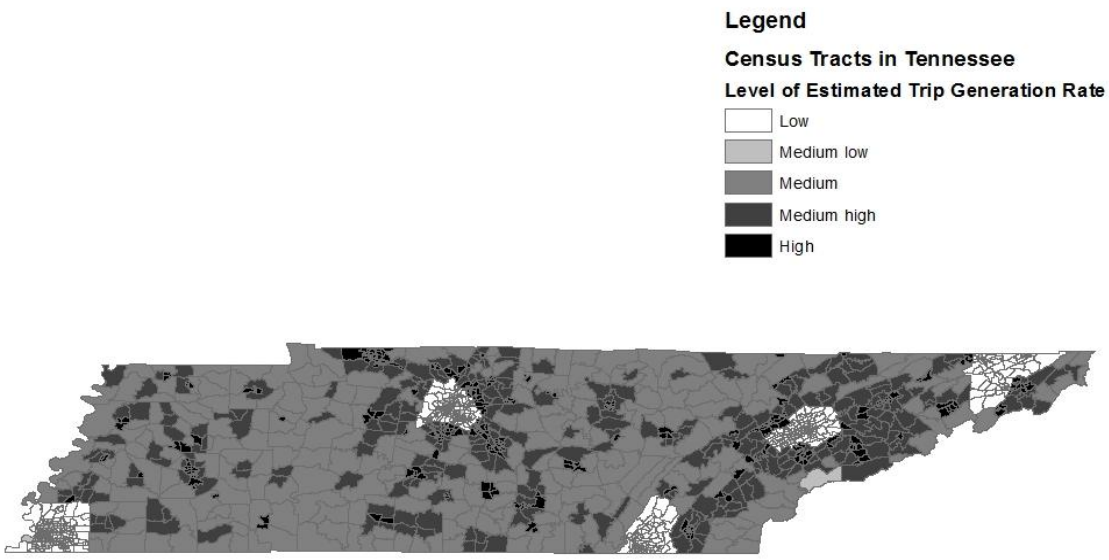


Figure 14 Tennessee Trip Generation Map

Routes Development

After the trip generation rate map is developed, all the interstates and highways are divided into five-mile segments. The segments are surrounded by 0.75-mile, 5-mile and 10-mile buffers and are used as proxies for service areas (see Chapter 4). The centroids of five-mile

segments and buffers are shown in Figure 15. Trip generation of a segment is defined as the trip generation of its service area. Routes are developed by radially extending five-mile segments from urban county boundaries. The cost effectiveness of the routes is evaluated each time they are extended and optimum routes are identified as those who generate the most ridership per distance of service.

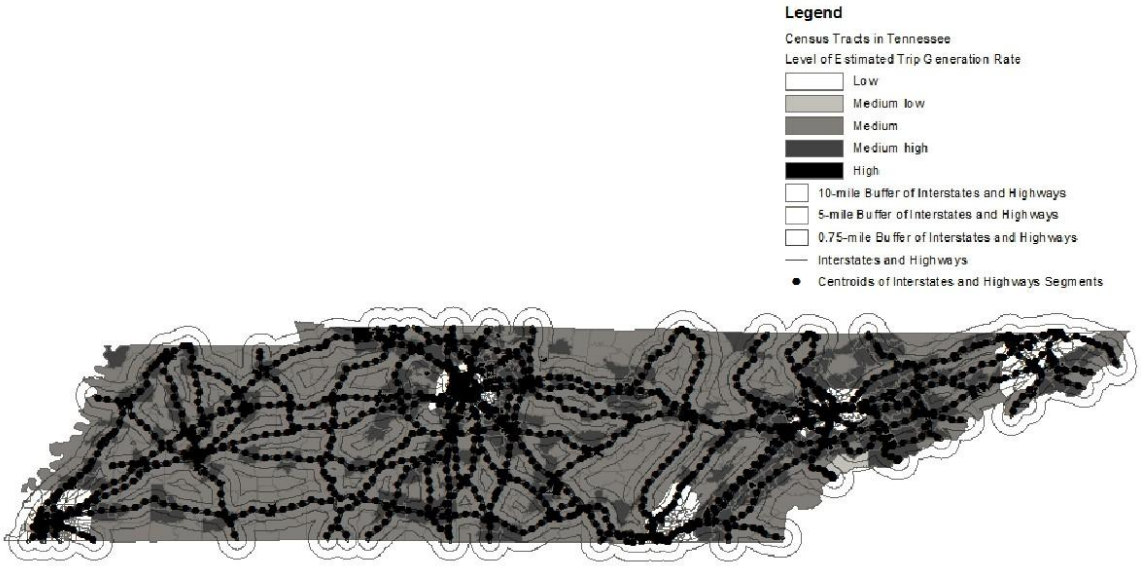
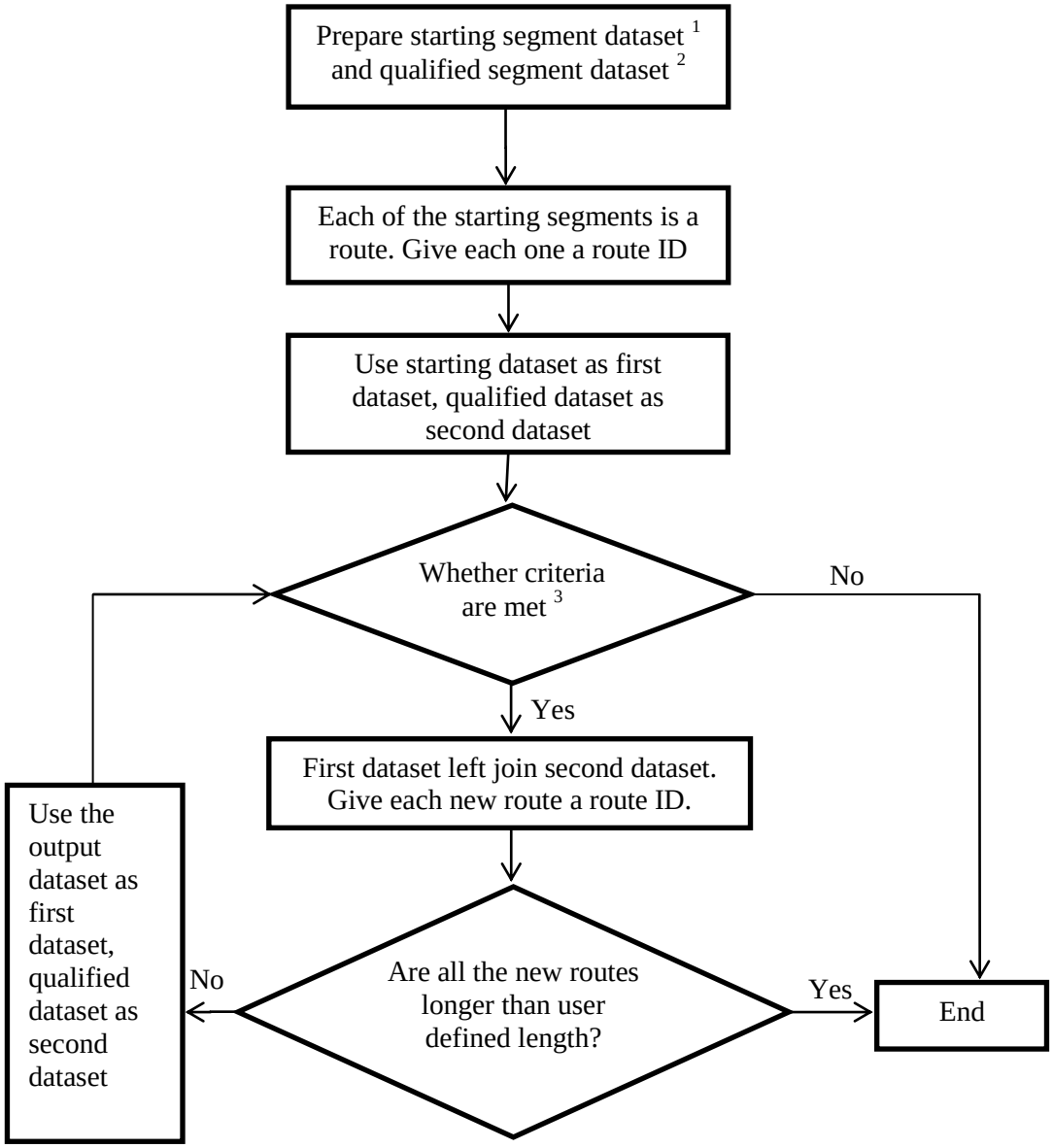


Figure 15 Centroids of Interstates and Highways Segments and Buffers

Route Development Methodology Since rural to urban DFRT usually run for long distances, we eliminate the use of local streets as main bus routes, limiting mainline service to interstates and state highways. Each interstate and highway outside of the urban area counties are divided into five-mile segments (some segments are shorter). Those segments are used to build routes. Five large urban area counties are identified as destinations because they contain major activity centers (e.g., hospitals) and operate urban public transportation systems. The DFRT routes radiate from these five cities.

The route segment linking procedure is performed using SAS PROC SQL [1] and is shown in Figure 16.



1. Starting segment dataset: composed of the segments with one end in the big city county and the other end outside.
2. Qualified segment dataset: composed of the segments with at least one end outside of the urban county.
3. Criteria: x, y coordinates of one end in second dataset are equal to the x, y coordinates of one end in first dataset, and the segment in second dataset has not appeared in route before,

Figure 16 Route Development Procedure

Cost and Ridership Calculation Each developed route has an associated cost (based on vehicle miles) and ridership (based on demand estimate) yielding a relative cost effectiveness value. It is important to note that the demand estimates are most likely accurate relative to other census tracts, rather than absolute. As such, the cost effectiveness estimates are appropriate for ranking and comparison of routes. In this study the operating cost is assumed to only be related to the annual vehicle miles provided by the service. Operating cost is calculated as follows.

$$\text{Operating cost} = \text{Route length} \times \text{Service days in a year} \times \text{Number of round trips per day} \times 2 \times \text{Average operating cost per annual vehicle mile}$$

Since most rural DFRT services provide two round trips per day and do not run on Saturdays, Sundays, or major holidays, the proposed DFRT service uses the same level of service. There are 254 service days, with two round trips per year. The average operating cost per annual vehicle mile of DFRT service for three years (2008-2010) is obtained from the National Transit Database (NTD) [51]. The mean of 324 systems (if one system appear twice in different years, it counts as two) in 50 states is $2.88 per vehicle mile traveled.

The service area of each segment is a ribbon. TCRP Synthesis 53 [52] states most DFRT service providers allow a maximum deviation distance of 0.75 miles. But the service area is wider than 1.5 miles (2*0.75) because people who live nearby the 0.75 buffer area could access to the closest point in the buffer area and get DFRT service. To understand how different width of the service area could influence the route locations and what percent of riders could be served under different service area assumptions, three service area widths are considered: 1.5 miles, 10 miles and 20 miles. Three buffers, 0.75-mile, 5-mile and 10-mile buffers, are made around each segment to represent the three service areas. Those buffers are overlaid on the trip generation map to assess the trip generation potential. So each segment has three trip generation (demand) potentials corresponding to three buffers. After segments are linked to become routes, the length and demand potential of all the routes are determined. The demand potential is the sum of the potential of each segment in the route. Since the operating cost is calculated, the cost effectiveness, measured by operating cost per trip tour could be calculated. Routes with the

lowest operating cost per trip tour are defined as the optimum route for that class. So the optimum route has the following quality: given the length of the route, the optimum route has the lowest operating cost per passenger, or stated another way, the highest potential demand per route mile.

Proposed Route Locations

All possible routes were developed radiating out of each city. A dataset was developed containing all the routes and the associated cost effectiveness. The stopping criterion is when all routes exceed 70 miles. Figure 14 shows the five aggregated urban counties in Tennessee (five light color areas). From left to right, the urban counties and associated metropolitan areas are: Shelby County (Memphis), Davidson County (Nashville), Hamilton County (Chattanooga), Knox County (Knoxville) and Washington-and-Sullivan County (Kingsport).

Table 7 shows the number of routes of different length categories for each urban county. Memphis has fewer routes compared to other cities because the surrounding interstate and highway network less complex, so there are not many combinations of segments to form different routes. Also, this study only considers routes within the state and ignores routes extending into other states. This is important for Memphis (bordering Arkansas), Chattanooga (bordering Georgia), and Kingsport (bordering Virginia).

Table 7 Number of Routes of Different Length Categories

	40-50 Miles	50-60 Miles	60-70 Miles	Above 70 Miles
Chattanooga	68	110	188	231
Kingsport	28	68	145	539
Knoxville	613	945	964	1393
Memphis	7	18	75	154
Nashville	1771	3536	4036	6885

The cost effectiveness of all routes are calculated and the best route connecting to each urban county is picked for each distance category, which reflects budget availability. Considering a 0.75-mile buffer, the best routes of length 40 to 50 miles, 50 to 60 miles, 60 to 70 miles and

above 70 miles are shown in Figure 17, Figure 18, Figure 19 and Figure 20. The figures reveal that the best routes of different lengths are sometimes serving different locations, indicating the best route location is sensitive to its design length and the demand density distribution served. Even given a demand density map, it could be hard for a transit planner to choose corridors with the most potential ridership. These maps illustrate the value of this route-finding methodology to find the best routes for different distance (budget) categories.

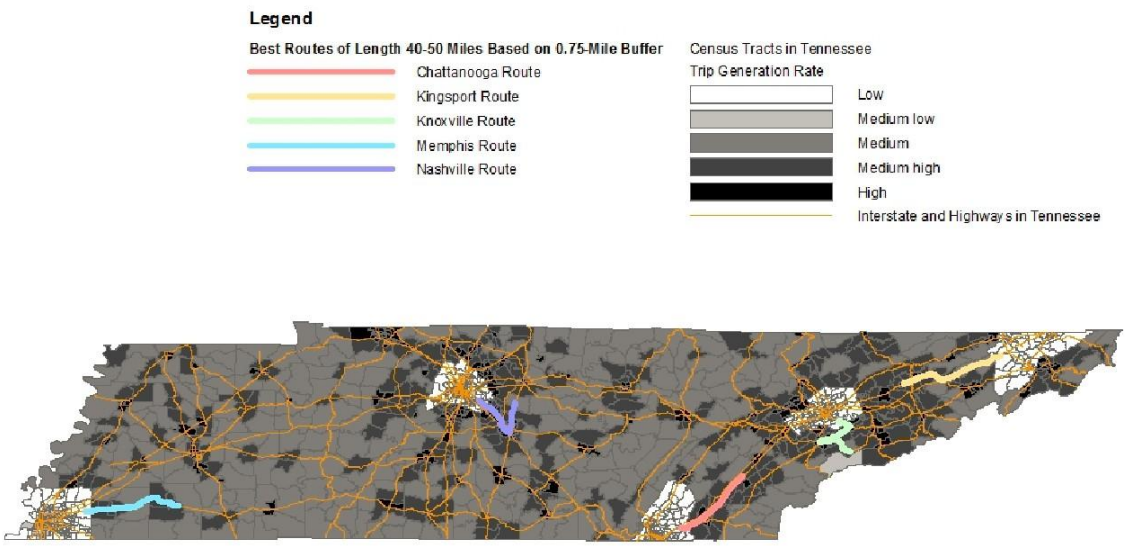


Figure 17 Best Routes of Length between 40 and 50 Miles Based on 0.75-Mile Buffer

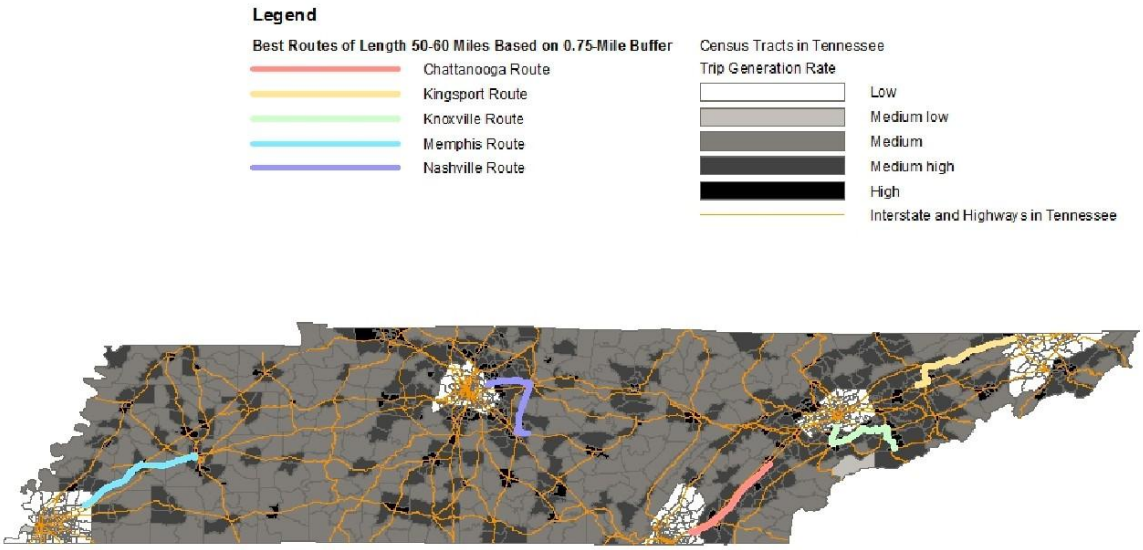


Figure 18 Best Routes of Length between 50 and 60 Miles Based on 0.75-Mile Buffer

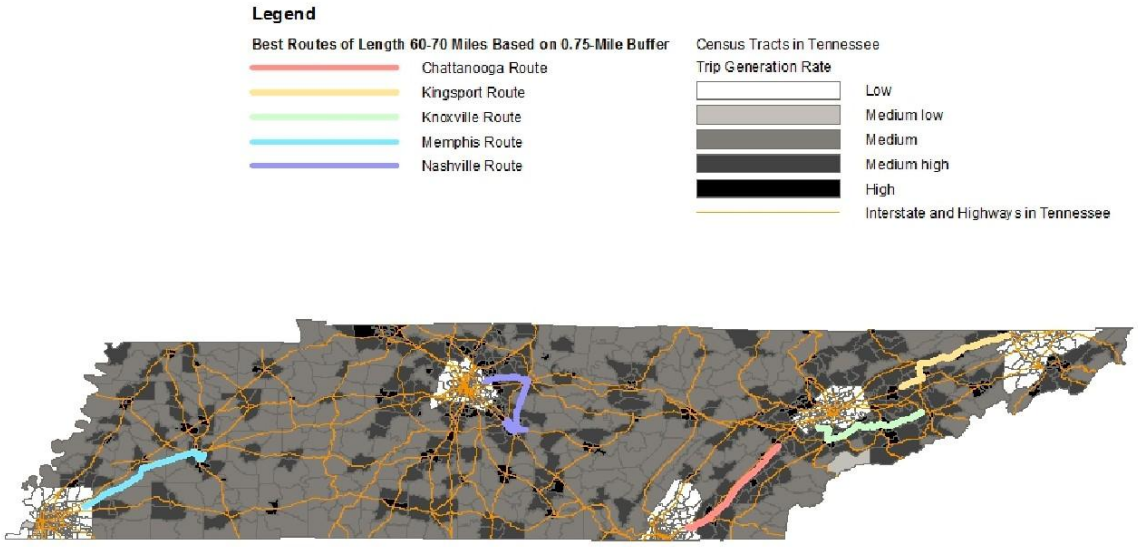


Figure 19 Best Routes of Length between 60 and 70 Miles Based on 0.75-Mile Buffer

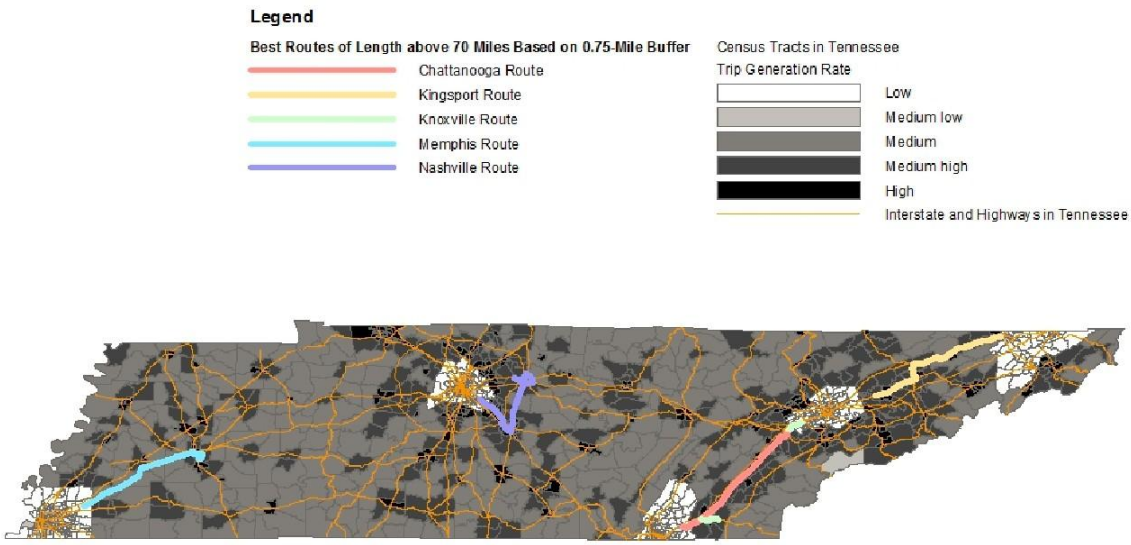


Figure 20 Best Routes of Length above 70 Miles Based on 0.75-Mile Buffer

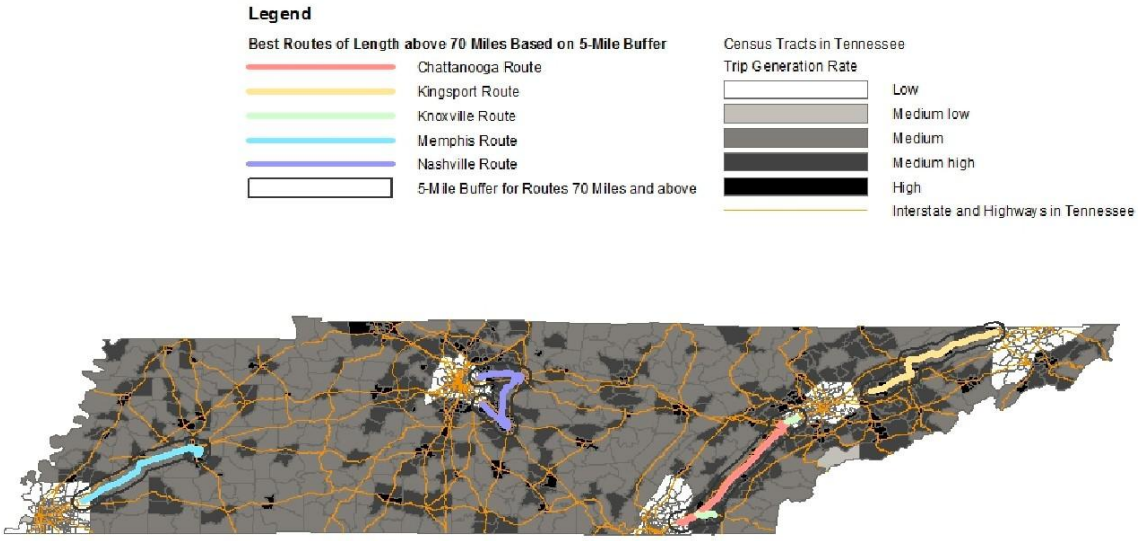


Figure 21 Best Routes of Length above 70 Miles Based on 5-Mile Buffer

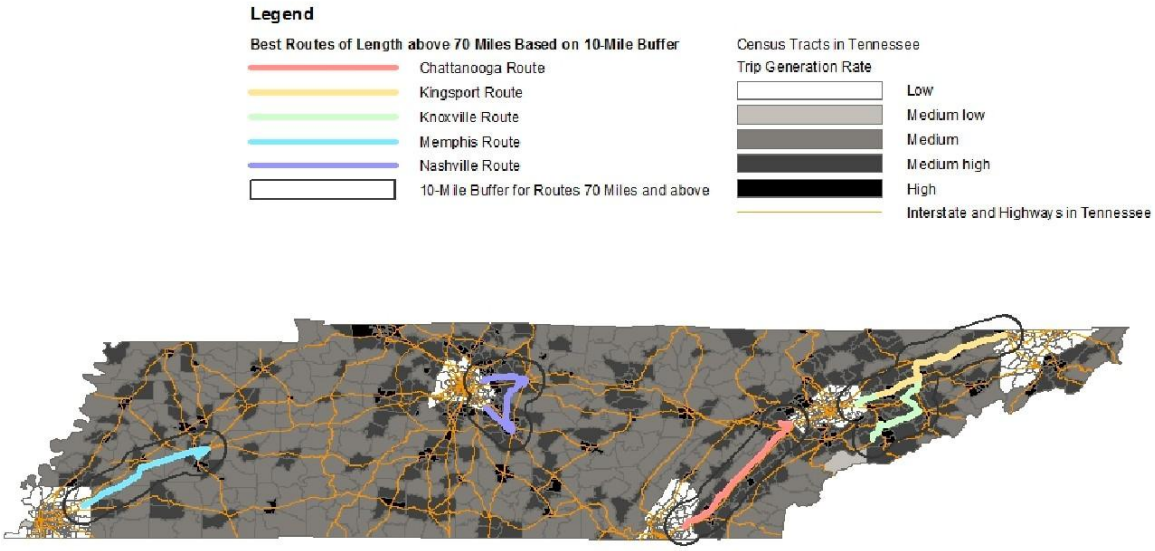


Figure 22 Best Routes of Length above 70 Miles Based on 10-Mile Buffer

Figure 21 and Figure 22 show the best routes greater than 70 miles long that are chosen based on 5-mile buffer and 10-mile buffer. Compared the routes above 70 miles based on 0.75-mile, 5-mile and 10-mile buffers, their locations can be different, particularly Knoxville. It suggests the route locations can be influenced by the width of the buffer. The strength of influence is determined by the demand distribution and the width of the service area. If the route is located in a wide high demand area, after increasing the service area width, the service is still in the high demand area. The best routes could still be the best routes. But if the service area width is increased too much or the high demand area is narrow, after increasing the service area width, some parts of the service area will fall out of the high demand area. The locations of the best routes may change.

Table 8 shows the lowest operating cost per trip tour (OCPTT, unit is dollar per trip tour) of the routes picked based on the 0.75-mile buffer. It shows that there is not a simple pattern between route length and OCPTT. For Chattanooga, the lowest OCPTT is the optimum route in the 40 to 50 mile category. For Memphis, the lowest OCPTT is the optimum route in the >70 mile category. This is because of the different distribution of high trip generation areas surrounding each city. The OCPTT of Knoxville routes that correspond to the four lowest

OCPTT in Table 8 are presented in Figure 23. It shows some routes have the lowest cost per passenger for one range but very high cost per passenger for other ranges, extending up the y-axis in figures. For example, the route that is the most cost effective for the 40-50 miles category is least cost effective when its length is around 25 miles, as circled in Figure 23.

Table 8 Lowest Operating Cost per Trip Tour (0.75-mile deviation, Dollar)

Range (miles)	Chattanooga	Kingsport	Knoxville	Memphis	Nashville
40-50	68.5	90.0	43.3	244.5	39.1
50-60	78.8	59.9	51.7	177.1	40.6
60-70	86.0	60.0	62.5	74.8	41.5
>70	79.3	62.6	67.4	65.7	49.3

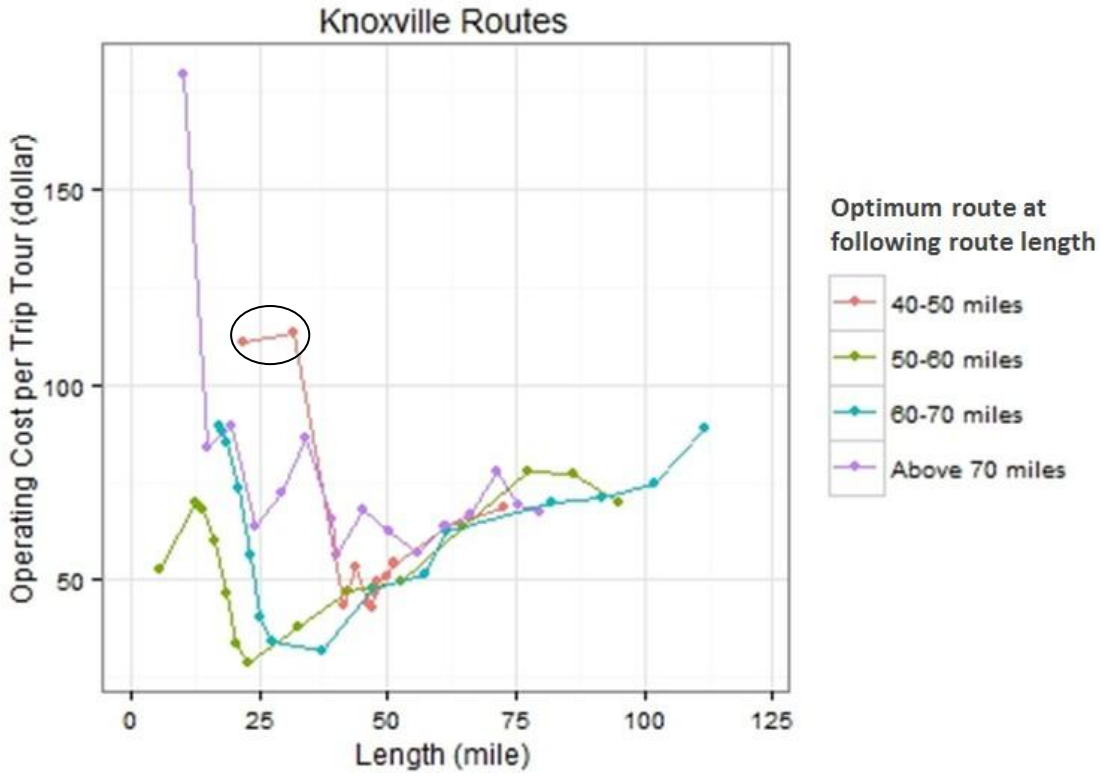


Figure 23 OCPTT of Best Knoxville Routes of Different Lengths (0.75-mile deviation)

In general, Nashvilles routes have the lowest cost per passenger, followed by routes serving Knoxville and Kingsport. Routes serving Memphis have the highest cost per passenger. This is probably because rural areas surrounding Memphis are sparsely populated relative to areas surrounding other cities and the interstates and highways are sparsely located, making it less likely to cover the high demand areas. When the route of Memphis is longer than 60 miles, it reaches a higher trip generation area, and its OCPTT goes down.

The percent of Tennessee area covered estimated demand by the service area of proposed routes is calculated and shown in Table 9. The column "Trip Gen" shows the percentages of the estimated trip generation or demand covered by the service area. The column "Area" shows the percentage of Tennessee area covered by the service area. It should be noted that the best routes of some length ranges are close to each other or overlap. Then their buffers overlap, making the total buffer areas smaller. This is why the percent of area and estimated riders covered by routes above 70 miles is lower than those covered by routes between 60 and 70 miles. The column "Ratio" is calculated by dividing trip generation percentage by area percentage. This indicates the percent of trip generation covered by unit percent of area. If this proposed method to find the best routes ends up being completely random then, on average, the percent of trip generation covered should equal to the percent of area covered and the value of the ratio will be about 1:1. However, all the ratio values in the table are above one, with the highest value above 4, indicating with 1% of the area coverage, the proposed routes covers more than 4% of the trip generation potential. It shows this method can discover high demand areas and the good routes. Another usage of the ratio is that it can be compared to other ratios to find out which routes are more effective in terms of covering more trip tours within a unit service area. For example, a policy objective could be to provide the highest amount of coverage, regardless of which city is served. This policy would likely eliminate the Memphis route in favor of more or longer Nashville routes. For routes proposed, based on 0.75-mile buffer, the routes in the 60-70 mile category and >70 mile category have the highest ratios. It suggests that the routes of 60-70 mile category and >70 mile category could serve more trip tours per unit service area. So while not considering the budget constraint, longer routes are preferred to shorter routes.

Table 9 Percent of Area and Estimated Riders Covered in Tennessee

Dist. Range (mile)	0.75-mile Buffer			5-mile Buffer			10-mile Buffer		
	Trip Gen	Area	Ratio	Trip Gen	Area	Ratio	Trip Gen	Area	Ratio
40-50	2.1%	0.6%	3.67	11.0%	5.0%	2.20	18.2%	11.7%	1.55
50-60	3.6%	0.9%	4.09	15.5%	6.5%	2.37	23.6%	13.7%	1.72
60-70	4.4%	1.0%	4.31	17.4%	7.5%	2.32	25.6%	15.2%	1.69
Above 70	4.2%	1.0%	4.31	15.4%	6.7%	2.28	25.4%	15.6%	1.63

Conclusion

In this study, a method of inventorying all the possible DFRT routes and picking the best route based on the lowest operating cost per passenger is proposed. The design methodology is as follows. The input is the ridership dataset of DRT services, in this case, a record of all the DRT trips by MCHRA from July 1, 2009 to June 30, 2011. Unlinked trips were linked into trip tours apply the trip production to the census tract where the trip tour originated. A trip generation model was constructed to understand the relationship between trip generation and demographic predictors. In the absence of state or location specific ridership data, the trip generation model developed here could cautiously be transferred to other areas. Since we do not know the trip generation of areas other than MCHRA service areas, the trip generation model was used to estimate trip generation in all census tracts in Tennessee. The trip generation rate is positively related to the density of population above 16 years old and no-vehicle households. If the census tract is in a large urban area county, its trip generation rate is significantly lower.

All the interstates and highways in Tennessee were analyzed as potential route segments, radiating from Tennessee's five largest urban areas. The service area of all the segments were overlaid with the trip generation map to estimate the trip generation rate of each segment and all routes were evaluated for cost effectiveness as they extend away from urban areas. Three service area buffers were considered: 0.75-, 5- and 10-mile buffers. The cost effectiveness of routes is compared at four ranges: 40-50 miles, 50-60 miles, 60-70 miles and above 70 miles. The routes with the lowest cost per passenger were chosen to present here. Government agencies could use the result of this study to determine the best route network under budget constraints or policy objectives. The private sector could use these results for service planning and revenue estimation.

There are several assumptions and approximations used in this study. First, because the DFRT serves to transport rural residents to urban centers, all the routes start from the urban centers. There are many ways to define the boundary of the urban centers. In this chapter, the county border where the urban center located in is used to define the boundary. An alternative way is to use the urban transit network coverage to define this boundary. This approach would assist in the development of a multimodal transportation system and avoid redundant service. However, in the scope of a statewide study, it is assumed that the main county boundaries are appropriate approximations of urban cores. Next, since the input data for the trip generation model is the DRT ridership data, it is assumed that people who use the DRT service will also use rural DFRT service when it is used to replace the DRT service. It is unclear if DFRT will have higher ridership since it introduces some schedule constraints but also requires less advance planning (i.e., scheduling pickups in advance). The trip generation model should be used to assist in relative rank and prioritization. Based on expected (low) trip generation, the cost effectivenss of the services is much lower than the national average, $22 per passenger trip tour. There is no apparent reason that cost effectiveness in Tennessee should be that much lower than neighboring states or national average. The results should be used cautiously and are best applied as a relative ranking tool than an absolute ridership estimation tool. Despite its limitations, this study provides much new information and proposes methodologies to evaluate and design rural transit. The methodology proposed in this study is also applicable to other states.

Chapter 6

Conclusion

This study examined the trip information and riders' personal characteristics of rural DFRT and DRT; proposed a method to locate the high ICB demand area, identified existing ICB network gaps; designed an framework to design ICB network and proposed an method to design compared the proposed the method to design rural DFRT network.

To study the characteristics of rural DFRT and DRT passengers, surveys were distributed to rural DFRT riders, DRT riders and rural residents to understand needs of rural intercity transit users (and potential users) and their opinion about intercity transit. It was found that rural DFRT and DRT riders are more likely to be female, of minority races (non-white), rent a house as opposed own a house, have low automobile ownership, and have low personal and household income. Most of the users express they are highly dependent on rural transit to travel around the state. Their characteristics are different from ICB passengers.

The identified demographics of rural transit users were used to locate where people with those demographics live. Areas with a high population density with those sets of demographics are regarded as high demand areas. It was suggested that ICB stops should be located in these identified high demand areas. After comparing the existing stop locations to the high demand areas and meaningful destinations, it was found out that the existing ICB network was able to connect to the meaningful destination but not well designed to cover all the high demand areas. The meaningful destinations include airports, interstate bus and train stations, hospitals, military bases, and universities. Eight stops are found neither connected to high demand areas, nor connected to any meaningful destinations. Suggestions were made to move the eight stops into the high demand areas.

Finally, a new method of designing the optimum rural DFRT network was proposed. A DRT trip dataset was used to construct a trip generation model. This model was used to estimate the trip generation of all the census tracts in Tennessee. All the interstates and highways serve as

potential routes. They were divided into 5-mile segments and were overlaid with trip generation map to estimate the trip generation rate of each segment. All the routes radiate from Tennessee's five largest urban areas. All the possible routes were inventoried and evaluated for cost effectiveness as they extend away from urban areas. The best route has the quality that its service area has the highest trip generation rate (also the highest cost effectiveness).The best routes of four ranges of route length (40-50 miles, 50-60 miles, 60-70 miles and above 70 miles) are presented on the map. Under different service area width, the best route locations are different. The route locations of three widths of service area were examined: 1.5-mile, 10-mile and 20-mile. Government agencies could use the result of this study to determine the best routes under budget constraints or policy objectives. The private sector could use these results for service planning and revenue estimation.

The cost effectiveness of the best rural DFRT routes was compared to the rural DFRT service in NTD. It was found out that the OCPTT is higher than the median OCPTT of services in the NTD. However, its cost effectiveness is comparable to that of DRT services in NTD. It indicates that the DRT service could be replaced by the proposed DFRT service without compromising the cost effectiveness.

The study provides much new information and proposes methodologies to evaluate and design rural transit. Useful information includes a new demographic profile of rural transit riders and non-riders in Tennessee. Methodologies include evaluating the existing ICB network, designing the optimum deviated fixed route network and comparing the cost efficiency of deviated fixed route service with demand responsive service to determine whether to replace one by another. Those methodologies are also applicable to other states.

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Appendix

Appendix A. ICB Rider Survey Questionnaire (Front Page)

First Tennessee Human Resource Agency | TENNESSEE DEPARTMENT OF TRANSPORTATION | University of Tennessee

Intercity Transit Rider Survey

Dear Riders,

I am Hongtai Yang, a third-year doctoral student of the Civil and Environmental Engineering Department at the University of Tennessee at Knoxville. Thank you for your support of transit services in Tennessee. I am doing research on ways to improve the intercity transit service in Tennessee for my dissertation. I need your help to get input for my research project as well as my dissertation. Please help me out by completing this survey. I appreciate your help.

This survey is designed to give you the opportunity to provide input on the Tennessee transit service you use to travel between cities, also called intercity transit. The van/bus you are riding is an example of intercity transit. Your feedback will help us make better planning decisions for future rural and urban intercity transit service.

This survey is administered by Tennessee Department of Transportation and University of Tennessee. Please complete the survey only if you are over 18 years old. This survey is anonymous.

There is a pencil in the attached envelope. Please return the completed survey to the van/bus driver when you leave the van/bus, or put the survey in the postage-paid envelop and mail it back. I am grateful for your participation in the survey.

Hongtai Yang

Hongtai Yang

1. Please indicate the time you got on the van/bus and the time you get off the van/bus:

Getting on:_____am/pm

Getting off:_____am/pm

2. Where did your current trip start? (This is called "trip origin")

Description:_____

(example: Home, work place, medical center)

Zip Code:_____

Address or nearest intersection:

_____

3. Did this van/bus pick you up from your trip origin?

☐1 Yes

☐2 No

4. If not, how far is your trip origin from the place where you boarded this van/bus (in miles)?

_____miles

5. How did you travel to the boarding place from your trip origin?

☐1 Walked

☐2 Drove myself

☐3 Someone else drove me

☐4 This van/bus picked me up directly at my trip origin location.

☐5 City bus

☐6 Used other transit services provided by local Human Resource Agencies

☐7 Taxi

☐8 Airplane

☐9 Other, please specify_____

6. Where will your current trip end? (this is called your "destination")

Description:_____

(example: Home, work, medical center)

Zip Code:_____

Address or nearest intersection:

_____

7. Will this van/bus drop you off at your trip destination location?

☐1 Yes

☐2 No

8. If not, how far is your destination from the place where you get off this van/bus (in miles)?

_____ **miles**

9. How will you travel to your destination after riding this van/bus?

☐1 Walk

☐2 Drive myself

☐3 Someone else will pick me up

☐4 The van/bus will drop me off directly at my trip destination location.

☐5 City bus

☐6 Use other transit services provided by local Human Resource Agencies

☐7 Taxi

☐8 Airplane

☐9 Other, please specify_____

_____

10. What is the main purpose of this trip?

☐1 Work

☐2 School

☐3 Health care

☐4 Shopping

☐5 Recreation

☐6 Visiting families or friends

☐7 Access to airport, Greyhound station or other transit stations.

☐8 Other, please specify _____

_____

11. How often do you use this intercity transit?

☐1 Less frequently than once a year

☐2 1-6 times a year

☐3 7-12 times a year

☐4 1-4 times per month

☐5 1-4 times per week

☐6 More than 4 times per week

☐7 I don't know

12. Do you have a regularly scheduled time or day to use this intercity transit? (example: every Thursday at 8am)

☐1 Yes, it's _____

☐2 No, it's not regularly scheduled.

13. Before this intercity transit service was available to you, how did you make this trip?

☐1 Did not make this trip

☐2 Drove myself

☐3 Someone else drove me

☐4 Used other transit services provided by local Human Resource Agencies

☐5 Taxi

☐6 Airplane

☐7 Other, please specify_____

Appendix B. ICB Rider Survey Questionnaire (Back Page)

First Tennessee Human Resource Agency | TENNESSEE DEPARTMENT OF TRANSPORTATION | University of Tennessee

14. If this intercity transit service were not available anymore, how would you make this trip?

- ☐1 Will not make this trip
- ☐2 Drive myself
- ☐3 Someone else drives me
- ☐4 Use other transit services provided by local Human Resource Agencies
- ☐5 Taxi
- ☐6 Airplane
- ☐7 Other, please specify_____

15. How difficult would it be to find alternative transportation if this service was not provided?

- ☐1 Very difficult
- ☐2 Difficult
- ☐3 Neutral
- ☐4 Easy
- ☐5 Very easy

16. What are the TWO main reasons that you use this transit service?

- ☐1 The transit fare is cheap
- ☐2 Driving a car is more expensive than taking this van/bus
- ☐3 My transit fare is subsidized or covered by government or health company etc.
- ☐4 The van/bus can pick me up from my trip origin location
- ☐5 The van/bus can drop me off at my destination location
- ☐6 The bus stop is close to my trip origin location
- ☐7 The bus stop is close to my destination location
- ☐8 I don't have access to a car
- ☐9 I don't have driver's license
- ☐10 Taking the van/bus is safer than I drive
- ☐11 Other, please specify_____

_____

17. Circle the number on a scale of 1 to 5 that best explains the likelihood that you would use the intercity transit if the following changes were made. 1 means "not likely at all" and 5 means "very likely".

The van/bus fare were lower
1 2 3 4 5

The travel time of the van/bus trip was shorter
1 2 3 4 5

The van/bus always arrives and leaves on time
1 2 3 4 5

Auto parking were available near the van/bus station
1 2 3 4 5

There were more leg room, wider aisles and more comfortable seats
1 2 3 4 5

The cost of gasoline were to increase
1 2 3 4 5

The environment of the van/bus stop is better or safer
1 2 3 4 5

Local city bus transportation were available or more convenient at destination city
1 2 3 4 5

The frequency of this transit increased
1 2 3 4 5

The operator of call reservation center or driver was friendlier
1 2 3 4 5

18. Do you have any complaint or improvement suggestions about this transit service?

_____

Tell us a little about yourself.

19. Your gender is

- ☐1 Male
- ☐2 Female

20. Your age is_____

21. Your race is:

- ☐1 White
- ☐2 African American, Black
- ☐3 Asian
- ☐4 American Indian, Alaskan Native
- ☐5 Native Hawaiian or other Pacific Islander
- ☐6 Multiracial
- ☐7 Hispanic/Mexican
- ☐8 Other, please specify_____

22. Your employment status is:

- ☐1 Employed
- ☐2 Unemployed
- ☐3 Self-employed
- ☐4 Student
- ☐5 Home maker
- ☐6 Retired

23. Highest education completed

- ☐1 Elementary school
- ☐2 Middle school
- ☐3 High school
- ☐4 College or university
- ☐5 Graduate school
- ☐6 Other, please specify _____

24. Do you rent or own your home?

- ☐1 Own
- ☐2 Rent
- ☐3 Other

25. Your PERSONAL total income for 2011 is

- ☐1 Under $5,000
- ☐2 $5,000-$10,000
- ☐3 $10,000-$15,000
- ☐4 $15,000-$20,000
- ☐5 $20,000-$25,000
- ☐6 $25,000-$30,000
- ☐7 $30,000-$35,000
- ☐8 $35,000-$40,000
- ☐9 $40,000-$45,000
- ☐10 $45,000-$50,000
- ☐11 $50,000 and over

26. Total income of your HOUSEHOLD for 2011 is

- ☐1 Under $10,000
- ☐2 $10,000-$20,000
- ☐3 $20,000-$30,000
- ☐4 $30,000-$40,000
- ☐5 $40,000-$50,000
- ☐6 $50,000-$60,000
- ☐7 $60,000-$70,000
- ☐8 $70,000-$80,000
- ☐9 $80,000-$90,000
- ☐10 $90,000-$100,000
- ☐11 $100,000 and over

27. How many automobiles are available at home for use by members of this household?

- ☐1 0
- ☐2 1
- ☐3 2
- ☐4 More than 2, please specify_____

28. Number of people in your household:

Number of children (under 18):_____

Number of adults (18 and above): _____

Number of **working** adults (18 and above): _____

Number of elderly (65 and above): _____

Appendix C. DRT Rider Survey Questionnaire (Front Page**)**

Delta Human Resource Agency | TENNESSEE DEPARTMENT OF TRANSPORTATION | University of Tennessee

Demand Responsive (Dial-a-ride) Transit Rider Survey

Dear Riders,

I am Hongtai Yang, a third-year doctoral student of the Civil and Environmental Engineering Department at the University of Tennessee at Knoxville. Thank you for your support of transit services in Tennessee. I am doing research on ways to improve the demand responsive transit service in Tennessee for my dissertation. I need your help to get input for my research project as well as my dissertation. Please help me out by completing this survey. I appreciate your help.

This survey is designed to give you the opportunity to provide input on the demand responsive transit service. **Demand Responsive Transit Service** is comprised of vehicles operating in response to calls from passengers or their agents to the transit operator, who then dispatches a vehicle to pick up the passengers and transport them to their destinations. It's also called **Dial-a-ride transit**. The van/bus you are riding is an example of demand responsive transit. Your feedback will help us make better planning decisions for future rural and urban intercity transit service.

This survey is administered by Tennessee Department of Transportation and University of Tennessee. Please complete the survey only if you are over 18 years old. This survey is anonymous.

There is a pencil in the attached envelope. Please return the completed survey to the van/bus driver when you leave the van/bus, or put the survey in the postage-paid envelop and mail it back. I am grateful for your participation in the survey.

Hongtai Yang

Hongtai Yang

1. Please indicate the time you got on the van/bus and the time you get off the van/bus:

Getting on:_____am/pm

Getting off:_____am/pm

2. Where did your current trip start? (This is called "trip origin")

Description:_____
(example: Home, work place, medical center)

Zip Code:_____

Address or nearest intersection:

_____

3. Where will your current trip end? (this is called your "destination")

Description:_____
(example: Home, work, medical center)

Zip Code:_____

Address or nearest intersection:

_____

4. What is the main purpose of this trip?

- ☐1 Work
- ☐2 School
- ☐3 Health care
- ☐4 Shopping
- ☐5 Recreation
- ☐6 Visiting families or friends
- ☐7 Access to airport, Greyhound station or other transit stations.
- ☐8 Other, please specify _____

5. How often do you use this demand responsive transit?

- ☐1 Less frequently than once a year
- ☐2 1-6 times a year
- ☐3 7-12 times a year
- ☐4 1-4 times per month
- ☐5 1-4 times per week
- ☐6 More than 4 times per week
- ☐7 I don't know

6. Do you have a regularly scheduled time or day to use this intercity transit? (example: every Thursday at 8am)

- ☐1 Yes, it's _____
- ☐2 No, it's not regularly scheduled.

7. Before this intercity transit service was available to you, how did you make this trip?

- ☐1 Did not make this trip
- ☐2 Drove myself
- ☐3 Someone else drove me
- ☐4 Used other transit services provided by local Human Resource Agencies
- ☐5 Taxi
- ☐6 Airplane
- ☐7 Other, please specify_____

8. If this intercity transit service were not available anymore, how would you make this trip?

- ☐1 Will not make this trip
- ☐2 Drive myself
- ☐3 Someone else drives me
- ☐4 Use other transit services provided by local Human Resource Agencies
- ☐5 Taxi
- ☐6 Airplane
- ☐7 Other, please specify_____

9. How difficult would it be to find alternative transportation if this service was not provided?

- ☐1 Very difficult
- ☐2 Difficult
- ☐3 Neutral
- ☐4 Relatively easy
- ☐5 Very easy

Appendix D. DRT Rider Survey Questionnaire (Back Page)

Delta Human Resource Agency | TENNESSEE DEPARTMENT OF TRANSPORTATION | University of Tennessee

10. What are the TWO main reasons that you use this transit service?

- ☐1 The transit fare is cheap
- ☐2 Driving a car is more expensive than taking this van/bus
- ☐3 My transit fare is subsidized or covered by government or health company etc.
- ☐4 The van/bus can pick me up from my trip origin location and drop me off at my destination location
- ☐5 I don't have access to a car
- ☐6 I don't have driver's license
- ☐7 Taking the bus is safer than I drive
- ☐8 Other, please specify_____

11. Circle the number on a scale of 1 to 5 that best explains the likelihood that you would use the intercity transit if the following changes were made. 1 means "not likely at all" and 5 means "very likely".

The van/bus fare were lower
1 2 3 4 5

The travel time of the van/bus trip was shorter
1 2 3 4 5

The van/bus always arrives on time
1 2 3 4 5

There were more leg room, wider aisles and more comfortable seats
1 2 3 4 5

The cost of gasoline were to increase
1 2 3 4 5

Local city bus transportation were available or more convenient at destination city
1 2 3 4 5

The operator of call reservation center or driver was friendlier
1 2 3 4 5

12. Do you have any complaint or improvement suggestions about this demand responsive transit service?

_____

_____

_____

Tell us a little about yourself.

13. Your gender is

- ☐1 Male
- ☐2 Female

14. Your age is_____

15. Your race is:

- ☐1 White
- ☐2 African American, Black
- ☐3 Asian
- ☐4 American Indian, Alaskan Native
- ☐5 Native Hawaiian or other Pacific Islander
- ☐6 Multiracial
- ☐7 Hispanic/Mexican
- ☐8 Other, please specify_____

16. Your employment status is:

- ☐1 Employed
- ☐2 Unemployed
- ☐3 Self-employed
- ☐4 Student
- ☐5 Home maker
- ☐6 Retired

17. Highest education completed

- ☐1 Elementary school
- ☐2 Middle school
- ☐3 High school
- ☐4 College or university
- ☐5 Graduate school
- ☐6 Other, please specify _____

18. Do you rent or own your home?

- ☐1 Own
- ☐2 Rent
- ☐3 Other

19. Your PERSONAL total income for 2011 is

- ☐1 Under $5,000
- ☐2 $5,000-$10,000
- ☐3 $10,000-$15,000
- ☐4 $15,000-$20,000
- ☐5 $20,000-$25,000
- ☐6 $25,000-$30,000
- ☐7 $30,000-$35,000
- ☐8 $35,000-$40,000
- ☐9 $40,000-$45,000
- ☐10 $45,000-$50,000
- ☐11 $50,000 and over

20. Total income of your HOUSEHOLD for 2011 is

- ☐1 Under $10,000
- ☐2 $10,000-$20,000
- ☐3 $20,000-$30,000
- ☐4 $30,000-$40,000
- ☐5 $40,000-$50,000
- ☐6 $50,000-$60,000
- ☐7 $60,000-$70,000
- ☐8 $70,000-$80,000
- ☐9 $80,000-$90,000
- ☐10 $90,000-$100,000
- ☐11 $100,000 and over

21. How many automobiles are available at home for use by members of this household?

- ☐1 0
- ☐2 1
- ☐3 2
- ☐4 More than 2, please specify_____

22. Number of people in your household:

Number of children (under 18):_____

Number of adults (18 and above): _____

Number of **working** adults (18 and above):

_____

Number of elderly (65 and above): _____

Appendix E. Rural-Urban Household Travel Survey Questionnaire (Front Page)

THE UNIVERSITY of TENNESSEE
KNOXVILLE

Rural-Urban Travel Survey

Dear Tennessee Resident:

I am Hongtai Yang, a third-year doctoral student of the Civil and Environmental Engineering Department at the University of Tennessee at Knoxville. My doctoral dissertation topic is Planning, Design and Optimization of Rural-Urban Intercity Transit Service and I need your help to get input for my dissertation. Please help me out by completing this survey and help me graduate on time.

This survey is conducted to obtain information about rural household's travel behavior between their residence and nearby cities to help plan and design better transportation service. Since it is not possible to send questionnaires to all households in Tennessee, a small number of households are selected at random. The requested information is needed to insure the success of my dissertation. This survey should take about five minutes and all responses are anonymous.

Two identical survey forms are included. If possible, please have two adults from your household complete the survey forms and return both in the business reply envelope provided. If that is not possible, please complete one survey form and return it in the business reply envelope.

I am grateful for your participation in the survey. Please complete the requested information as best you can and return the survey forms in the enclosed, postage-paid envelope at your earliest convenience. Feel free to call or email me if you have any questions.

Sincerely,

Hongtai Yang

Hongtai Yang
Department of Civil and Environmental Engineering
University of Tennessee
(865)974-5144
hyang17@utk.edu

Appendix F. Rural-Urban Household Travel Survey Questionnaire (Back Page)

THE UNIVERSITY of TENNESSEE UT KNOXVILLE

GO VOLS!

Think back to the LAST TIME you went to one of Tennessee's big cities.

1. What is the most recent city you have visited?
- ☐1 Chattanooga
- ☐2 Clarksville
- ☐3 Franklin
- ☐4 Jackson
- ☐5 Johnson City
- ☐6 Knoxville
- ☐7 Memphis
- ☐8 Murfreesboro
- ☐9 Nashville

2. When did that trip happen?
Month/Year:_____/_____

3. What was the main purpose of that trip?
- ☐1 Work
- ☐2 School
- ☐3 Health care
- ☐4 Shopping
- ☐5 Recreation
- ☐6 Visiting families or friends
- ☐7 Access to airport, Greyhound station or other transit stations.
- ☐8 Other, please specify _____

4. How did you travel to that city?
- ☐1 I drove a personal vehicle
- ☐2 I rented a car
- ☐3 My relative or friend drove me there
- ☐4 Regularly scheduled intercity transit (bus, van, or shuttle that travels **between cities)**
- ☐5 Dial-a-ride transit (bus, van, or shuttle) provided by local Human Resource Agencies
- ☐6 Airplane
- ☐7 Other, please specify_____

5. What are your feelings about the following statements?

I will always dislike the idea of riding intercity bus no matter how good the service is.
☐1 Agree ☐2 Neutral ☐3 Disagree

Federal or state money should be used to subsidize intercity transit operating cost.
☐1 Agree ☐2 Neutral ☐3 Disagree

6. Circle the number on a scale of 1 to 5 that best explains the likelihood that you would use intercity transit if the following changes were made. 1 means "not likely at all" and 5 means "very likely".

a) If it's safer to ride on the transit
1 2 3 4 5

b) If the transit always arrives and departs on time
1 2 3 4 5

c) If the travel time of transit trip is shorter
1 2 3 4 5

d) If the service is more frequent
1 2 3 4 5

e) If the bus stop is closer to my home
1 2 3 4 5

f) If the fare is less expensive
1 2 3 4 5

g) If the vehicle condition is better with more leg room, wider aisles and more comfortable seats
1 2 3 4 5

h) If the local city public transportation at destination city is more convenient
1 2 3 4 5

i) Overall, if intercity transit could pick you up close to your home with a reasonable price and schedule, how likely are you to use it?
1 2 3 4 5

7. Assuming adequate speed, service frequency, and stop location: What is the maximum amount you would pay to go to that city you answered in Question 1 using intercity transit (one way)? $_____

8. Are you aware of any regularly scheduled intercity transit (bus, van, shuttle) that can take you from near your home to one of Tennessee's cities listed in the Question 1? Which company or agency is it provided by?
- ☐1 Yes, it's offered by_____
- ☐2 No.

9. Do you have a regularly scheduled time or day to travel to that city? (example: every Thursday at 8am)
- ☐1 Yes, it's _____
- ☐2 No, it's not fixed

10. About how many times did you visit that city in 2011?
_____

Tell us a little about yourself.

11. What is the zip code of your current residence?_____

12. Your gender is
- ☐1 Male
- ☐2 Female

13. Your age is_____

14. Your race is:
- ☐1 White
- ☐2 African American, Black
- ☐3 Asian
- ☐4 American Indian, Alaskan Native
- ☐5 Native Hawaiian or other Pacific Islander
- ☐6 Multiracial
- ☐7 Hispanic/Mexican
- ☐8 Other, please specify____

15. Your employment status is:
- ☐1 Employed
- ☐2 Unemployed
- ☐3 Self-employed
- ☐4 Student
- ☐5 Home maker
- ☐6 Retired

16. Highest education completed
- ☐1 Elementary school
- ☐2 Middle school
- ☐3 High school
- ☐4 College or university
- ☐5 Graduate school
- ☐6 Other, please specify _____

17. Your PERSONAL total income for 2011 is:
- ☐1 Under $5,000
- ☐2 $5,000-$10,000
- ☐3 $10,000-$15,000
- ☐4 $15,000-$20,000
- ☐5 $20,000-$25,000
- ☐6 $25,000-$30,000
- ☐7 $30,000-$35,000
- ☐8 $35,000-$40,000
- ☐9 $40,000-$45,000
- ☐10 $45,000-$50,000
- ☐11 $50,000 and over

18. Total income of your HOUSEHOLD for 2011 is:
- ☐1 Under $10,000
- ☐2 $10,000-$20,000
- ☐3 $20,000-$30,000
- ☐4 $30,000-$40,000
- ☐5 $40,000-$50,000
- ☐6 $50,000-$60,000
- ☐7 $60,000-$70,000
- ☐8 $70,000-$80,000
- ☐9 $80,000-$90,000
- ☐10 $90,000-$100,000
- ☐11 $100,000 and over

19. Do you rent or own your home?
- ☐1 Own
- ☐2 Rent
- ☐3 Other

20. How many automobiles are available at home for use by members of this household?
- ☐1 0
- ☐2 1
- ☐3 2
- ☐4 More than 2, please specify_____

21. Number of people in your household:
Number of children (under 18):_____
Number of adults (18 and above): ____
Number of **working** adults (18 and above): ____
Number of elderly (65 and above): ____

Vita

Mr. Hongtai Yang was born on July 26, 1987 in Weifang, China and grew up there. In 2005, he entered Shandong University. Four years later, he graduated with B.Eng. in Civil Engineering. Then he went to University of Tennessee-Knoxville and studied there as a PhD student. He obtained his PhD degree in Civil Engineering with emphasis on Transportation Engineering in 2013.

During his PhD study, Mr. Yang has conducted research on various topics, including rural intercity transit planning and evaluation, traveler mode choice behavior analysis, traffic safety and passenger forecasting. He gained a lot of experience of using statistical tools and spatial analysis tools to solve engineering problem. He also obtained a M.S. in Statistics from Department of Statistics, Operations, and Management Science.

Mr. Yang is a member of ITE, ASA and ASCE. He holds an Engineer-in-Training certification. He won the first place of TSITE paper competition, third place of 20th National Conference on Rural and Intercity Bus Student Paper Competition, first place winner of TSITE Traffic Bowl competition. He was awarded McClure Scholarship by UT Knoxville for international research.

Mr. Yang hopes to obtain a career in academia to inspire engineering students to perform interdisciplinary studies and to advocate the use statistical and spatial analysis tools to solve engineering problems.