**Technical Memorandum**

FDOT Master University Agreement BDV29-977-24

# Incorporating Transit Service Decisions into Express Lane Programs

## Final Report

*Prepared For*

Public Transit Office
Florida Department of Transportation

*Prepared By*

Xia Jin, Hamidreza Asgari, and Chenxiao Liu
Florida International University
10555 E Flagler St., EC 3603
Miami, FL 33174

*Date*

April 2018

# DISCLAIMER

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation or the U. S. Department of Transportation.

Prepared in cooperation with the State of Florida Department of Transportation and the U. S. Department of Transportation.

# METRIC CONVERSION CHART

## APPROXIMATE CONVERSIONS TO SI UNITS

| SYMBOL | WHEN YOU KNOW | MULTIPLY BY | TO FIND | SYMBOL |
|---|---|---|---|---|
| | | **LENGTH** | | |
| **in** | inches | 25.4 | millimeters | mm |
| **ft** | feet | 0.305 | meters | m |
| **yd** | yards | 0.914 | meters | m |
| **mi** | miles | 1.61 | kilometers | km |
| | | **AREA** | | |
| **$in^2$** | square inches | 645.2 | square millimeters | $mm^2$ |
| **$ft^2$** | square feet | 0.093 | square meters | $m^2$ |
| **$yd^2$** | square yard | 0.836 | square meters | $m^2$ |
| **ac** | acres | 0.405 | hectares | ha |
| **$mi^2$** | square miles | 2.59 | square kilometers | $km^2$ |
| | | **VOLUME** | | |
| **fl oz** | fluid ounces | 29.57 | milliliters | mL |
| **gal** | gallons | 3.785 | liters | L |
| **$ft^3$** | cubic feet | 0.028 | cubic meters | $m^3$ |
| **$yd^3$** | cubic yards | 0.765 | cubic meters | $m^3$ |
| NOTE: volumes greater than 1000 L shall be shown in $m^3$ | | | | |
| | | **MASS** | | |
| **oz** | ounces | 28.35 | grams | g |
| **lb** | pounds | 0.454 | kilograms | kg |
| **T** | short tons (2000 lb) | 0.907 | mega grams (or "metric ton") | Mg (or "t") |
| | | **TEMPERATURE (exact degrees)** | | |
| **°F** | Fahrenheit | 5 (F-32)/9 or (F-32)/1.8 | Celsius | °C |
| | | **ILLUMINATION** | | |
| **fc** | foot-candles | 10.76 | lux | lx |
| **fl** | foot-Lamberts | 3.426 | candela/$m^2$ | cd/$m^2$ |
| | | **FORCE and PRESSURE or STRESS** | | |
| **lbf** | pound force | 4.45 | newton | N |
| **lbf/$in^2$** | pound force per square inch | 6.89 | kilopascals | kPa |

## APPROXIMATE CONVERSIONS TO SI UNITS

| SYMBOL | WHEN YOU KNOW | MULTIPLY BY | TO FIND | SYMBOL |
|---|---|---|---|---|
| **LENGTH** | | | | |
| **mm** | millimeters | 0.039 | inches | in |
| **m** | meters | 3.28 | feet | ft |
| **m** | meters | 1.09 | yards | yd |
| **km** | kilometers | 0.621 | miles | mi |
| **AREA** | | | | |
| **$mm^2$** | square millimeters | 0.0016 | square inches | $in^2$ |
| **$m^2$** | square meters | 10.764 | square feet | $ft^2$ |
| **$m^2$** | square meters | 1.195 | square yards | $yd^2$ |
| **ha** | hectares | 2.47 | acres | ac |
| **$km^2$** | square kilometers | 0.386 | square miles | $mi^2$ |
| **VOLUME** | | | | |
| **mL** | milliliters | 0.034 | fluid ounces | fl oz |
| **L** | liters | 0.264 | gallons | gal |
| **$m^3$** | cubic meters | 35.314 | cubic feet | $ft^3$ |
| **$m^3$** | cubic meters | 1.307 | cubic yards | $yd^3$ |
| **MASS** | | | | |
| **g** | grams | 0.035 | ounces | oz |
| **kg** | kilograms | 2.202 | pounds | lb |
| **Mg (or "t")** | mega grams (or "metric ton") | 1.103 | short tons (2000 lb) | T |
| **TEMPERATURE (exact degrees)** | | | | |
| **°C** | Celsius | 1.8C+32 | Fahrenheit | °F |
| **ILLUMINATION** | | | | |
| **lx** | lux | 0.0929 | foot-candles | fc |
| **$cd/m^2$** | candela/$m^2$ | 0.2919 | foot-Lamberts | fl |
| **FORCE and PRESSURE or STRESS** | | | | |
| **N** | newton | 0.225 | pound force | lbf |
| **kPa** | kilopascals | 0.145 | pound force per square inch | $lbf/in^2$ |

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

# TECHNICAL REPORT DOCUMENTATION PAGE

<table>
<tr><td>1. Report No.</td><td>2. Government Accession No.</td><td>3. Recipient's Catalog No.</td></tr>
<tr><td colspan="2">4. Title and Subtitle<br>Incorporating Transit Service Decisions into Express Lane Programs</td><td>5. Report Date<br>April, 2018<br>6. Performing Organization Code</td></tr>
<tr><td colspan="2">7. Author(s)<br>Xia Jin, Hamidreza Asgari, and Chenxiao Liu</td><td>8. Performing Organization Report No.</td></tr>
<tr><td colspan="2">9. Performing Organization Name and Address<br>Florida International University<br>10555 W. Flagler Street<br>Miami, Florida 33174</td><td>10. Work Unit No. (TRAIS)<br>11. Contract or Grant No.<br>BDV29-977-24</td></tr>
<tr><td colspan="2">12. Sponsoring Agency Name and Address<br>Florida Department of Transportation<br>605 Suwannee St., Tallahassee, FL 32301</td><td>13. Type of Report and Period Covered<br>Final Report<br>January 2016 - June 2018<br>14. Sponsoring Agency Code</td></tr>
<tr><td colspan="3">15. Supplementary Notes</td></tr>
<tr><td colspan="3">16. Abstract<br>Considering the significant benefits that transit service could bring in contributing to the overall project goals in reducing congestion, enhancing system performance, and improving environmental, economic and social concerns, this project aims to provide a standard approach that enables the incorporation of transit service goals and benefit considerations into express lane (EL) programs. A planning framework is developed with five major components, including project initiation, market assessment, ridership forecast, alternative evaluation, service design and implementation. A ridership forecasting methodology is also proposed and demonstrated through a case study of the 95 Express service. The approach utilizes both STOPS and TBEST, combining their strengths in different aspects. STOPS is able to consider the competitiveness between highway and transit modes, while TBEST provides detailed considerations at stop and route level that enables detailed scenario analysis. The case study demonstrates that the proposed approach serves the purpose well on estimating ridership for express buses from two main perspectives: (1) it is able to estimate the mode shift due to the introduction of express bus services in terms of how many new transit users are being attracted; and (2) it provides a sufficient level of detail to support scenario analysis that can facilitate the decision-making in transit service planning, based on the capital and operating costs involved with alternative service plans.</td></tr>
<tr><td colspan="2">17. Key Word<br>express lane program, express bus service, ridership forecasting, transit service planning framework, benefit-cost analysis</td><td>18. Distribution Statement<br>No restrictions</td></tr>
<tr><td>19. Security Classif. (of this report)<br>Unclassified</td><td>20. Security Classif. (of this page)<br>Unclassified</td><td>21. No. of Pages<br>104<br>22. Price</td></tr>
</table>

**Form DOT F 1700.7** (8-72) Reproduction of completed page authorized

# ACKNOWLEDGEMENTS

We would like to thank the project manager Gabrielle Matthews for her guidance, time, and efforts in guiding this study. We want to acknowledge the information and technical support received from the TBEST team and the Connetics Transportation Group (CTG), and special gratitude to Rodney Bunner, Dr. Steven Polzin, Fengjiang Hu, and Ashutosh Kumar for their expertise and support.

# EXECUTIVE SUMMARY

Transit is a critical component to the success of an express lane (EL) program. Transit service could bring additional contribution in reducing congestion, enhancing system efficiency, and maximizing project benefits. Bus-only or high occupancy vehicle (HOV)/high occupancy toll (HOT) lanes on expressways offer many advantages for transit services, including reduced travel time, improved schedule adherence, and on-time performance, which makes the service competitive with automobiles, and therefore, attracts new riders.

Considering the significant benefits that transit service could contribute to the overall project goals in reducing congestion, enhancing system performance, and improving environmental, economic and social concerns, this project aims to provide a standard approach that enables the incorporation of transit service goals and benefit considerations into EL programs.

Express bus services are distinguished from local bus services by many operational features, including exclusive lanes, limited stops, specific operation hours, targeted service market, high travel speeds, and high capacity vehicles. Given these considerations, a planning framework was developed with five major components. The planning framework starts with project initiation that involves stakeholders and establishes project objectives. It continues with market assessment to identify specific markets through an evaluation of high-demand corridors or areas with an understanding of customer preference and behavior. Ridership estimations are then developed for one or more alternatives with varying service details. Following a benefit-cost analysis of the alternatives, recommendations are given for appropriate service strategies and service levels. Detailed operation elements are then addressed for implementation. Continuous service monitoring and evaluation are also critical to ensure that the service meets the objectives.

Realistic and reliable ridership forecasts are essential in sizing system design features, developing service plans, estimating capital and operating costs, and making investment decisions. Comparing with conventional bus services, especially local buses, express bus intends to provide services that are time-competitive with auto modes rather than other transit services. This has implications to express bus ridership estimation in several perspectives. First, the method should account for choice users beyond the conventional low-income transit-dependent users, which means the traditional 0.25-mile buffer for walk access may not be able to capture the full market. Secondly, the line-haul ridership is less likely to be affected by the level of service and connectivity of other transit services along the route. In other words, competition and complementarity relationship with nearby transit services are not a concern here. Thirdly, as the primary competing mode of express buses, driving modes also play an essential role in the relative attractiveness of express bus service and therefore its ridership. The performance of the highway network should be considered when estimating the demand for express bus services.

Considering the capabilities of existing tools, the recommended ridership forecasting approach combines the strengths of STOPS and TBEST, both are well accepted and user friendly to the transit community. Essentially, this approach incorporates the benefits of STOPS to account for the influence of highway network performance and TBEST to provide detailed considerations at stop and route level that enables detailed scenario analysis.

The 95 Express service is used as a case study to demonstrate the approach. At corridor level, the potential demand of identified high-demand OD pairs is estimated first using STOPS. The demand at the route level serves as a reference total for TBEST to identify the appropriate market size. Then service attributes are explored through multiple scenarios, which provides the inputs for further service planning considerations and cost analysis.

The proposed approach that combines STOPS and TBEST serves the purpose well on estimating ridership for express buses from two main perspectives: (1) it is able to estimate the mode shift due to the introduction of express bus services, in terms of how many new transit users are being attracted; and (2) it provides a sufficient level of detail to support scenario analysis that can facilitate the decision-making in transit service planning, based on the capital and operating costs involved with alternative service plans. Beyond supporting transit service planning decisions, it also provides the opportunity to incorporate transit considerations into EL programs by enabling the estimation of mode shift and associated congestion and emission benefits.

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# 1. INTRODUCTION

Public transportation in the 21st century is on the move, as more and more Americans are discovering the benefits of traveling on buses, trains, subways, trolleys, and ferries. According to published statistics, public transportation ridership has been increasing significantly. Americans took 10.8 billion trips on public transportation in 2014, which is the highest annual public transit ridership in 58 years, according to a report released by the American Public Transportation Association (APTA) (2014 Public Transportation Fact Book). From 1995-2014, public transit ridership increased by 39 percent, almost double the population growth, which was up to 21 percent.

Managed lanes also bring new opportunities for transit service, making them a viable choice by providing the express lane benefits without additional costs to the passengers. The Florida Department of Transportation (FDOT) is developing a statewide system of express lanes (ELs) to assist in managing congestion and improving mobility on major freeways and interstates. Many of these projects include express buses operating in the ELs. A recent study reported that the 95 Express bus ridership increased by an average of 22% between the first three months of 2009 and the first three months of 2010, despite a decrease of 12% in overall Miami-Dade Transit ridership (FHWA). The report indicated that 38% of the new riders on the 95 Express bus Service switched from driving, and 53% of new riders were influenced by the express lanes in their decision to use transit.

Although transit has not been the primary focus for EL programs, given the significant benefits that transit service could contribute to the overall project goals of reducing congestion, enhancing system performance, improving environmental, economic and social concerns, FDOT needs a standard approach that enables the incorporation of transit service goals and benefit considerations into EL programs. This research aims to equip FDOT with better tools and methods to facilitate the assessment of investment decisions for transit services to be provided in conjunction with EL projects and to maximize project benefits and system efficiency through both highway and transit alternatives.

In the aim of achieving the above goal in incorporating transit considerations into EL programs, the specific objectives of this project are:

- To recommend a framework for transit ridership forecasting within the EL context, including analysis needs, forecasting methodology, data requirements, tool development efforts, performance measures, etc.

- To develop a methodology for transit ridership forecasting (number of buses, bus sizes, frequency and headways) using I-95 Express case study, taking advantage of existing tools such as FSUTMS, STOPS, T-BEST, or other software/models as appropriate.

Given the increasing popularity of EL programs in the state and the nation, this study will facilitate state and local agencies in transit operation and investment decisions by promoting a standard framework to account for transit service considerations under EL context, and providing a platform to incorporate transit service objectives and performance measures into the planning process for EL programs. Without appropriate methods, the EL programs may not be able to reflect the full extent of multimodal solutions and provide accurate estimates on the demand for services, which are critical to investment and planning decisions.

This report is organized as follows. The second chapter summarizes existing literature in transit ridership forecast methodologies including national guidelines, research efforts and current practices. The next chapter describes a planning framework for express bus service planning considerations in conjunction with EL programs, including major components and activities involved. The following chapter discusses the features and capabilities of existing tools and presents the recommended methodology to estimate ridership for express services, followed by a case study that explores various potential scenarios that could be implemented through the tools to support service planning analysis. The last chapter concludes the report with major findings and potential enhancements for further consideration.

# 2. LITERATURE REVIEW

This section provides a review of existing studies and current practices in transit ridership forecasting, including national guidelines, forecasting methodologies, and existing tools, followed by a summary of key findings along with some discussions that lead to the next tasks of this project.

## 2.1. National Guidelines

This section mainly summarizes national guidelines in view of transit demand and ridership estimation provided by the Transit Cooperative Research Program (TCRP). TCRP is a research-oriented program which provides access to the latest findings, publications and reports on different aspects of public transit including planning, operations, maintenance, facilities, and human resources. TCRP is a cooperative effort of three organizations: the Federal Transit Administration (FTA); the National Academies, acting through the Transportation Research Board (TRB); and the Transit Development Corporation, Inc. (TDC), a nonprofit educational and research organization established by the American Public Transportation Association (APTA).

### 2.1.1. Factors Contributing to Transit Ridership

The very first efforts on transit ridership mainly targeted the impacts of different attributes on transit ridership rather than quantitative models. A 1996 TCRP study, "Transit Ridership Initiative," described ridership as "a fragile, somewhat ambiguous goal, and a moving target." The study found that many aspects of transit operations and investment decisions affected ridership. Most agencies that had increased transit ridership had undertaken a variety of programs concurrently. The report identified five main sources of increased ridership:

- Service adjustments;
- Fare and pricing adaptations;
- Market and information initiatives;
- Planning orientation (community- and customer-based approaches); and
- Service coordination, consolidation, and market segmentation

The TCRP Report 27, published in 1997, focused on the impacts of different policies on transit ridership. Accordingly, five major types of factors were pointed out which influence transit ridership:

- *Levels of travel-inducing activities*. Since travel is predominantly a derived demand, as the levels of those activities change, the demand for transit service is expected to change.
- *Price and other characteristics of the service*. The price and various aspects of the level of service provided by the transit system have been shown to affect the level of ridership by substantial previous research. At a national level, variations in fares and vehicle miles operated could “explain” about 80 percent of the year-to-year variation in transit trips made.
- *Other transportation options*. The price and service characteristics of substitute and complementary modes of travel may also be expected to influence transit passenger volumes.
- *Characteristics of the population served*. The market for transit services comprises individuals with heterogeneous tastes, and the level of demand can be expected to vary between different demographic and socioeconomic subgroups of the population.
- *Other factors.* Other determinants of transit patronage levels that are not easily classified into the above four categories include, for example, variations in the weather and changes in public tastes over time.

Furthermore, transit ridership was found to be elastic with respect to several policy implications including investment, pricing, environmental, energy, and tax policies.

In a successive effort, TCRP report 46 discussed the impacts of vehicle characteristics and amenities on transit ridership. Accordingly, Amenities impacted a broad range of passenger experience and the ridership decisions of passengers. Infrequent or "transit choice" riders, a major target audience for increasing ridership, showed significant interest in amenities in the case study cities surveyed. Amenities did not just help make transit more comfortable, but safer (with lighting and security cameras, for example) and more efficient (with features such as low-floor buses that are shown to reduce dwell time). Amenities may also impact new riders' perception of transit as a mobility option for themselves.

In a comprehensive study in 2000, TCRP report 95 investigated how travelers response to any types of changes in the public transit system. This provided a baseline for elasticity analysis in terms of public transit ridership. The system changes included a variety of aspects such as bus routing and coverage, scheduling and frequency, information and promotion, pricing and fares, parking prices and fees, road pricing, as well as land use attributes. Different service types such as local bus, express bus, light rail and commuter rail were considered. For each of the described attributes, elasticity values were provided and case studies were presented and analyzed.

The values provided by the TCRP report 95 seemed to have an immense role in transit demand ridership studies in the early years of the new century. The TCRP report 90, which provided basic guidelines for BRT implementation in 2003, required that ridership estimation be checked against the TCRP 95 standards.

### 2.1.2. Transit Ridership Forecast Methods

There were no national studies which focused on technical modeling guidelines until 2006, when the TCRP Synthesis 66 provided a comprehensive overview of fixed route transit ridership forecast practices throughout the United States through literature review, surveys and telephone interviews. Seven major techniques were recognized for transit ridership estimation, and most agencies used multiple methods.

- Professional judgement
- Rules of thumb/similar routes
- Service elasticities
- Four-step demand model
- Econometric model
- Regression analysis
- Other methods – include trend line analysis, ITE trip generation rates, etc.

While the report did not delve into the analytical details, it provided a clear picture in terms of the purpose of ridership forecast, the methodologies, data sources, the planning horizon. Some of the major findings from the report included:

- Qualitative forecasting techniques were still widely used by transit agencies, especially for small-scale and near-term changes. They highly relied on professional judgment and experience. However, these methods could not be considered simplistic by any means as they tended to involve consideration of a wide variety of factors, often geared toward identifying similar circumstances elsewhere in the transit system that could provide guidance for likely ridership responses.
- The use of service and headway elasticities was widespread among transit agencies. In view of this, *TCRP Report 95* were very useful in providing information on "typical" elasticities; however, several agencies desired to adapt these to their service areas using their own experiences.

- Formal travel modeling expertise was found at the MPOs, not usually at the transit agencies. The literature review noted that several MPOs were actively engaged in the development of forecasting methodologies at a more appropriate scale for transit needs than the traditional four-step travel model, including Georgia, Arizona, Texas, and Tennessee, where sketch planning tools were developed.
- Widespread use of new technologies such as Geographical Information System (GIS) and Automatic Passenger Counts (APCs) were expected to allow transit agencies to develop more sophisticated ridership forecasting tools.
- Transit agencies reported the value in ridership forecasting. Several noted that ridership forecasts provided a basis for prioritizing among competing proposals and, more generally, for decision making at the senior management and board levels. Internally, ridership forecasting could encourage discipline in the service planning process, particularly where there was ongoing interaction between modelers and service planners. This interaction could also result in improved methodologies. Sound ridership forecasting methodologies could also enhance a transit agency's credibility among stakeholders and peer local and regional agencies.
- New technologies that provided more accurate ridership data and enhanced the ability to summarize demographic and socioeconomic data at an appropriate level of detail were fostering continued development of ridership forecasting techniques and were increasing the confidence level in forecasting results. However, there would always be a role for professional judgment and experience, particularly in understanding the underlying factors affecting ridership behavior. The continued integration of ridership, service, demographic, and other data would provide new tools to assist in this understanding.

In addition, this report pointed out the necessities and needs for future analysis including transferability of ridership forecast methodologies, GIS applications, easy-to-use methodologies, implementation of new technologies along with cost-effective and reliable data collection efforts.

The TCRP report 118 provided detailed guidelines on BRT ridership estimation, including methodology and key planning issues to be considered. Accordingly:

- BRT ridership forecasts were needed for the base year, the opening year, the year when ridership reaches maturity, and a design year usually 20 years into the future. For larger projects, both 20-year and opening-year forecasts would be required.

- Ridership estimates should be provided for peak and off-peak conditions by line segment and by station boardings and alightings.
- On-board travel surveys should capture key traveler information (e.g., trip origins, destinations, purposes, and frequencies and socioeconomic characteristics). This information would provide an important input to various demand estimation procedures. A CBD employee survey would be desirable to provide origins and travel modes for downtown workers.
- Ridership could be estimated by the traditional four-step process (i.e., trip generation, trip distribution, mode choice, and trip assignment) where BRT operates on a new right-of-way (such as a busway). Household travel surveys could provide the basic information needed for modeling and analysis, but data from on-board surveys also should be gathered in order to have sufficient data representing transit users during model development.
  - ✓ The incremental logit mode choice model (also known as pivot point procedure), which is a modified form of logit models, was well-suited for estimating BRT ridership, especially when analyzing a new alignment.
  - ✓ Travel paths should use acceptable weights for in-vehicle and out-of-vehicle travel times. Network coding should treat BRT as a separate facility in terms of travel times and stop locations.
- Travel time, service frequency, and cost elasticities could be used for small scale projects where BRT would operate along existing bus routes. An onboard survey could provide information about desired travel patterns as well as demographic and socioeconomic information. Allowance should be made for "new" trips (i.e., trips diverted from automobiles, trips not made before, and trips made with greater frequency). Population and employment growth should be taken into account.
- BRT's unique physical and operating features must be recognized in the travel demand estimation process. Salient studies of aggregate and disaggregate customer response to new BRT systems (or upgraded express bus service) have found the following:
  - ✓ The attractiveness of BRT systems, not unlike that of new rail systems, had been greater than might be expected on the basis of reductions in travel times and costs.
  - ✓ All things being equal (i.e., newness, component quality, system configuration and completeness in terms of all the elements of rapid transit, origin-to-destination travel times, reliability, and costs), BRT systems were likely to attract levels of ridership similar to those of rail based systems.

The TCRP report 167 presented the results of the TCRP H-42 project, which focused on developing measures of success for effective fixed-guideway transit investments. Two sets of linear regression models were developed: project-level ridership models, and system-level passenger miles travelled (PMT) model. The ridership models expressed average weekday ridership as a function of jobs and population around the stations, parking rates in the CBD, the percent of the alignment at grade, the number of park-and-ride spaces, and the age of the project. The model was then enhanced by removing endogenous variables such as parking space. The total number of observations included 55 projects. The final model expressed system-wide annual PMT in terms of the metropolitan area's population, congestion level, and information about the ½-mile radius catchment areas around all rail stations in the region, including population; jobs; the number of jobs associated with food, shopping or entertainment; and the number of high-wage jobs. The total number of observations included 141 Metropolitan study areas.

### 2.1.3. FTA Project Review Process

Several FTA project-evaluation measures rely on travel forecasts prepared by the sponsors of the proposed New Starts and Small Starts projects. In its reviews to ensure their usefulness in project evaluation, FTA considers five aspects of the forecasts:

- The properties of the forecasting methods;
- The adequacy of current ridership data to support useful tests of the methods;
- The successful testing of the methods to demonstrate their grasp of current ridership;
- The reasonableness of inputs (demographics, service changes) used in the forecasts; and
- The plausibility of the forecasts for the proposed project.

Project sponsors may choose among three different approaches to prepare ridership forecasts:

- Region-wide travel models;
- Incremental data-driven methods; and
- FTA's Simplified Trips-on-Project Software (STOPS).

The first two options depend entirely on local efforts both to develop the forecasting methods and to prepare the forecasts. Consequently, for these options, FTA's review will consider all five aspects of the forecasts. The third option relies on the product of

FTA efforts to develop a forecasting method. Consequently, for this option, FTA's review needs to consider only the last two aspects of forecasts.

## 2.2. Technical Overview of the Literature

Having conducted a comprehensive review of the state of practice and research studies, this section summaries the major findings in transit ridership forecast in regards to the methodologies employed, the variables used, and the data sources.

### 2.2.1. Methodologies

This subsection focuses on major methodologies which have been adopted in the literature in the past 20-30 years. It is based on a comprehensive investigation of technical reports, memorandums, and research papers in the field. Accordingly, some of the most popular transit ridership forecast methods are described, including the traditional four-step model, time series analysis, segment/stop level forecast, integrated demand and supply model, and other methods.

#### 2.2.1.1. Traditional Four-Step Model

The conventional four-step model was still a popular methodology to estimate transit trips. The four-step demand models estimate travel flows between traffic analysis zones (TAZs) by first estimating the number of trips originating in each TAZ, distributing the trips between TAZs, splitting travelers among different modes, and then assigning traffic to the travel networks [Naesun et al. 2003, Zhang and Xiao 2007, Sanko et al., 2013; Peters, 2014, Cheon et al. 2015].

For transit ridership estimation, the most relevant step is the modal split, which differentiates the market shares of transit versus other modes. In order to improve the model's accuracy, several studies have been conducted which attempted to enhance or modify the four-step model, particularly the modal split step. Some of the suggested enhancements included:

- Improving mode choice models' goodness-of-fit and reliability
- Removing the transit/non-transit mode choice step by focusing directly on transit trips from the generation step.
- Using incremental logit models instead of regular synthetic models, which focus on the changes in the system rather than existing conditions.

The following subsections described the various approaches employed in the literature to improving the conventional four-step model for better transit ridership forecasting.

### *Mode Choice Model Enhancement*

The first approach mainly involved improving the logit model performance either by collecting data of higher resolution or through incorporating new variables or by experimenting with more accurate impedance measures at the micro level such as travel time, travel cost, level of service, etc. [Horowitz 1985, Nickesen et al. 1983, Preston, J. 1991, Eash et al. 1993, Chen & Naylor, 2011; Yun & Liu, 2014].

Horowitz (1985) developed a ridership forecast model based on the four-step concept. The modal split portion was particularly determined through measures of trip dissatisfaction in a logit structure, based on a combination of trip time and trip cost. Nickesen et al. (1983) developed a sequence of simple trip generation, trip distribution, and modal split models in order to generate trip-purpose-specific tables for transit. Using data from British Railways (BR), Preston (1991) developed both multinomial and nested disaggregate mode choice models based on commonly used measures such as in-vehicle time, out-of-vehicle time, and mode availability.

Based on the detailed OD information, Zhang and Xiao (2007) designed a comparatively low-cost method to forecast the passenger demand for the inter-urban public transport. Chen & Naylor (2011) considered household survey information to develop a mode choice model for Bus Rapid Transit system in Santa Clara, California. Yun & Liu (2014), based on Stated Preference (SP) and Revealed Preference (RP) survey data, conducted descriptive analysis for BRT model in Yichang, China. A nested logit model was developed based on gender, age, education, and monthly income to predict market shares of public transit.

### *Transit Trips Only*

The second approach focused only on transit trips from the beginning (i.e., trip generation). There were several practical methods for this approach including:

1. Estimate number of transit trips for each TAZ pair in the study area, then split the trips between different public transit alternatives based on variables such as fare, level of service, travel time, etc.
2. Directly estimate the number of transit trips for any origin-destination (OD) pair or along a specific corridor.

The models falling in this category were usually simple linear regression models which estimated the number of transit trips for an OD pair or for a specific study area based on variables such as socioeconomics and demographics, transit level of service, land use, and so on. Nelson and O'Neil (1982) developed a multiple regression model to predict home-based transit trips per thousand zonal population based on a 1981 on-board survey in Albuquerque, New Mexico. Predictor variables included Level of service, socioeconomic, and land use variables. Preston (1991) developed OD regression models for work and non-work trip purposes using socioeconomic-demographic variables, population, land use, level of service, value of time, and competition index. Trip generation models were developed for three different LRT projects in Korea by Cheon et al. (2015), based on trip purpose, education level, and land use.

### *Incremental Logit model*

The third approach, known as incremental models, were different from synthetic models in the way they predict future demand [Koppelman 1983; Dehghani and Harvey, 1994; WSDOT, 2015]. Synthetic models provide a relationship between absolute values of independent variables and the dependent variable.

$$S_i = \frac{\exp(V_i)}{SUM_j^m[\exp(V_j)]} \quad (1)$$

where, $V_i$=Utility of mode i in choice set m (j=1, 2, 3,…, I, …m), which contains measurable components of transportation systems such as travel time and cost as well as socioeconomic attributes of trip makers; and $S_i$= Share of demand using mode i.

Incremental models, on the other hand, consider the existing demand, take into account the changes in existing conditions, and predict the future demand. Ben Akiva and Lerman showed that in view of logit mode choice models, the logit formula could be simply modified into incremental logit formula, which relates the future forecast of the dependent variable to the initial value and the imposed changes in the independent variables.

$$S_i^f = \frac{S_i \times \exp(DIFF\ V_i)}{SUM_j^m[S_j \times \exp(DIFF\ V_j)]} \quad (2)$$

$$DIFF\ V_i = V_i^f - V_i = (DIFF\ CONST_i) + B_k \times DIFF\ VAR_{i,k} \quad (3)$$

where, $S_i$= base-year observed probability of using mode i from choice set

$S_i^f$ = new share (i.e., forecast year) of using mode i

DIFF $V_i$= change (future vs. base) in utility of mode i (interzonal average)

DIFF CONSTi = difference in mode-specific constant for mode i,

Bk = coefficient for attribute k

DIFF VARi,k = difference in numeric variable VAR k of alternative i

The incremental model was considered more realistic than the comprehensive regional synthetic models for transit ridership forecasting analysis due to a number of reasons:

- It is based directly on observed instead of estimated baseline travel patterns of transit users;
- It allows concentration of effort on transit network analysis for studies whose primary goals are concerned about alternative transit networks;
- It is more conducive to separate evaluation of changes in population and employment, highway congestion and cost, and transit services through the three stages of the forecasting process;
- It lends itself readily to intermediate evaluation by focusing on direct comparison instead of complete simulation of travel behavior; and
- It eliminates often laborious and time-consuming calibration of sub-choice models because it does not require replication of base year travel patterns.

An incremental modeling approach could be summarized in three major steps: 1) Start with observed zone to zone transit trips, 2) Estimate changes in trips for each zone pair due to changes in service, and 3) Assign the updated trips to the new service.

Koppelman (1983) developed a simplified form of the incremental logit model and applied it to the prediction of travel mode shares for a range of transit service changes. Accordingly, ridership variations due to new service changes were determined by an incremental logistic regression based on the change in in-vehicle travel time, out-of-vehicle travel time, and out-of-pocket cost. Dehghani and Harvey (1994) developed a fully incremental transit ridership model for the Regional Transit Authority (RTA) in Seattle. The RTA model used incremental methods to estimate new shares both for primary modes (i.e., automobile and transit) and transit sub-modes (i.e., automobile and walk access). Incremental logit models was explicitly explained and applied in a recent study in Sound region in Seattle, Washington [WSDOT, 2015].

#### 2.2.1.2. Time-Series Analysis

Time series analyses consider the fact that data points taken over time may have an internal structure (e.g. autocorrelation, trend, or seasonal variation) that should be accounted for. Theoretically, two most common types of dynamic time series models include: “trends” and “breaks”. A trend usually refers to a persistent long-term movement of a variable over time and it can be either deterministic or stochastic. The second type of dynamic models, “breaks”, may occur for a variety of reasons, such as policy changes.

Dynamic econometric models estimate relationships between explanatory and dependent variables over periods of time, where the concept of time plays a more central role. For example, a dynamic model might have the following form:

$$Y_i = \propto + \beta_0 X_t + \beta_1 X_{t-1} + \beta_2 X_{t-2} + \cdots + \beta_p X_{t-p} + U_t \quad (4)$$

where, $Y_t$= dependent variable

$X_t$= current value of the independent variable

$X_{t-k}, K \in [1, p]$: the past value of $X_t$ from k periods before

$u_t$= The error term, which represents measurement error and/or omitted factors

As reflected in equation 4, in this model, the dependent variable $Y_t$ does not only depend on the current value of $X_t$, but also on past (lagged) values of $X_t$.

Two specific time series models have been commonly used in the literature, mainly in Europe: known as 1) The Partial Adjustment Model (PAM), and 2) The Vector Error Correlation Model (VECM). The main reason to employ dynamic methodologies was to distinguish between the short and long-term elasticity analysis, i.e. impact of changes such as fare changes on patronage. It also provided an indication of the time required for the total response to be complete [Dargay and Hanly, 2002a, 2002b; Bresson et al., 2003; Garcia-Ferrer et al., 2006; Wang, 2011; Frei and Mahmassani, 2013].

PAM assumes a geometrically declining adjustment process. The idea behind PAM is that an individual's travel behavior to a certain extent is based on habit. One's choices today have an effect on one's future decisions. This is modelled by introducing the lagged independent variable on the right-hand side of the equation and the adjustment coefficient. For example, a PAM might be in the following form5:

$$Y_t = \beta_1 \lambda + (1 - \lambda) Y_{t-1} + \beta_2 \lambda X_t + U_t$$

(5)

where, a = the short-run reaction of $Y$ to a unit change in $X$ is $\beta_2\lambda$

b = the long-run reaction is given by $\beta_1$

c = an estimate of $\beta_1$ can be obtained by dividing the estimate of $\beta_2\lambda$ by one minus the estimate of $(1 - \lambda)$.

Sometimes two or more series have the same stochastic trend in common. In this special case, referred to as co-integration, regression analysis can reveal long-run relationships among time series variables. VECM is a model that can be applied in this case.

For example, if $X_t$ and $Y_t$ are cointegrated, a VECM might be in the following form:

$$\Delta Y_t = \beta_{10} + \beta_{11}\Delta Y_{t-1} + \cdots + \beta_{1p}\Delta Y_{t-p} + \gamma_{11}\Delta X_{t-1} + \cdots + \gamma_{1p}\Delta X_{t-p} + \alpha_1(Y_{t-1} - \theta X_{t-1}) + u_{1t} \quad (6)$$

$$\Delta X_t = \beta_{20} + \beta_{21}\Delta Y_{t-1} + \cdots + \beta_{2p}\Delta Y_{t-p} + \gamma_{21}\Delta X_{2-1} + \cdots + \gamma_{2p}\Delta X_{t-p} + \alpha_2(Y_{t-1} - \theta X_{t-1}) + u_{2t} \quad (7)$$

The term $Y_t - \theta X_t$ is called the error correction term. The combined model in equations 6 and 7 is called a VECM. In a VECM, past values of $Y_t - \theta X_t$ help to predict future values of $\Delta Y_t$ and/or $\Delta X_t$.

As illustrated in equations 6 and 7, a VECM estimates the interactions between variables over time with a set of simultaneous equations. In this example, only two variables are considered, $Yt$ and $Xt$. The number of parameters is dependent on the number of lags and the number of variables being considered. Both PAM and VECM have the capability to utilize time series information to measure long-term and short-term elasticities. Nevertheless, VECM is much more data intensive compared with PAM.

Dargay and Hanly (2002a, 2002b) developed time-series models to predict local bus service patronage in UK. The dependent variable was the natural logarithm of bus journeys per capita. Explanatory variables included fare and service variables, household disposable income per capita, motoring costs as well as population density and percentage of pensioners. Using data from France and England, Bresson et al. developed dynamic (time-dependent) regression models in order to evaluate and compare the impacts of changes in fare, service supply, income and other factors on public transit demand. Two different types of regression models were developed: fixed-coefficient and random-coefficient.

Garcia-Ferrer et al. (2006) studied the choice of different types of public transportation modes in the Madrid Metropolitan Area. Using monthly data, elasticities and demand were estimated for that were subject to the types of multiple, complex calendar effects, and superimposition of outliers, changing supply service, and changing seasonality. Two different methods were used to deal with these issues. The first one was a causal model based on a transfer function dynamic model that allowed the incorporation of intervention and exogenous variables in a flexible way. The other was the dynamic harmonic regression model, a new variant of unobserved component model with time varying parameters that allows the adaptability of the trend and the seasonal components as soon as the new information becomes available.

Wang (2011) examined the demand for local bus and rail services during the period 1996–2008 in the three major cities in New Zealand: Auckland, Wellington and

Christchurch. In order to determine the drivers behind the changes in public transport ridership over time, econometric analysis techniques were applied to analyze the time series data of patronage of major public transportation mode(s) in the three cities, collected for the last decade. A dynamic model was identified for each city by mode relating per capita patronage to fares, service level, car ownership, income, and fuel price.

Stop level transit elasticities with respect to service frequency were estimated and discussed via time series modeling by Frei & Mahmassani (2013). They estimated transit demand as a linear relationship between the log of boardings at a stop and the log of headway and other socio demographic variables which directly yields arc elasticities. The best explanatory predictors for disaggregate transit ridership appeared to be headway, peak vs. off-peak travel time, Walk Score, crime rate, and population and employment characteristics.

#### 2.2.1.3. Route/Segment/Stop Level Ridership Forecasts

In order to increase estimation accuracy as well as to provide a clear reflection of changes in the system, ridership forecasts could be developed in a more detailed level, such as stop, segment, or route level. These models were used to predict number of total boardings/alightings per stop for a specific route and a specific transit mode (Batchelder et al., 1983; Stopher, 1992; Lane et al., 2006; Li et al., 2007; Ryan and Frank, 2009; Usvyat et al., 2009; Cervero et al., 2010; Hazelton, 2010; Gutierrez et al., 2011; Wang et al., 2012; Horváth, 2012; Horváth et al., 2014; Pulugurtha & Agurla, 2012; Cardozo et al., 2012; Dill et al., 2013; Duduta, 2013; Kerkman et al., 2015; Chakrabarti, 2015; Umlauf et al., 2015; Durning and Townsend, 2015; Hsu et al., 2015; Li et al., 2015). Such models were usually referred to as Direct Ridership Models (DRM). DRMs were methodological tools that had grown in popularity due to the ease of implementation and interpretation of results. Fundamentally, DRMs estimated ridership, typically measured at the station, line, or system level, and were frequently used in the assessment of transit ridership. Methods of measuring station catchment areas included fixed boundaries, either network based or circular, or without fixed boundaries through the use of geographically, or distance-decay, weighted regression that discount the effects of variables as distance from the station increases.

The literature reveals a remarkable tendency toward using variety types of regression models regarding transit ridership forecast. In general, liner regression models intended to find a linear mathematical function between independent variables (i.e. socioeconomic and demographic, built-environment, land use) and a dependent variable (including peak hour/ daily/ monthly/ annual/ boarding per station, per rout or per land use zone). Popular regression models included: OLS (Ordinary Least Square) Regression, Distance Decay Regression, Geographically Weighted Regression (GWR) model Two-Stage Least Square Regression Model, and count (Poisson or Negative Binomial) models, which have been widely used for different service types, such as bus, BRT, LRT, high-speed rail, etc., in different studies and reports.

A global regression model has the following form:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_p x_p \quad (8)$$

where, $y$ = dependent variable

$x_j$ = $j$th independent variables or predictors ( $j = 1, \ldots, p$)

$\beta_j$ = $j$th model parameters to be estimated ($j = 0, 1, \ldots, p$)

Route level demand forecasting models were developed by Stopher (1992) to predict changes to ridership resulting from small changes in the service provided by a given bus line. He established that service level is a major determinant of ridership performance.

Lane et al., (2006) used two multivariable regression equations to predict ridership by using available demographic and transportation-system data. They showed close relationships between actual and predicted values, with adjusted $R$-squared values of 0.97 for commuter rail and 0.92 for light rail. The models also validated well to existing rail systems in six regions and successfully predicted actual line ridership with adjusted $R$ squared values of 0.84 for commuter rail and 0.47 for light rail. Their research successfully developed a nationally relevant, reliable, sketch-level ridership forecasting tool for light rail and commuter rail.

Usvyat et al. (2009) developed a sketch-level ridership forecasting tool for heavy-rail for medium and smaller size cities. They used multiple transit catchment bands to estimate transit ridership. A linear multivariate regression equation was applied to show how close the actual and predicted values were. The presented sketch model for heavy rail could be used in place of a full-blown four-step modeling approach and required only ArcGIS and Microsoft Excel.

An OD estimation algorithm was presented by Li et al. (2007) for transit passengers. The algorithm generated estimates based upon passenger boarding and alighting counts at each stop along the route. It was also suited to routes that serve stops near these activity centers (referred to here as ‘‘major’’ stops) along with stops in other zones, such as residential areas (‘‘minor’’ stops). It did not only estimate an OD matrix for the vehicle trip from which the boarding and alighting counts were taken. Rather, it further estimated the passenger alighting probabilities at every stop on the route and these were more apt to remain fixed across transit trips.

Hazelton (2010) developed a model which directly sampled candidates from the set of feasible O-D trip vectors without the need for enumeration of this set. Time-dependent origin-destination matrix was known as a reliable passenger data used in Horváth (2012). He developed a model that combined origin-destination matrices of the runs through transfers. The newly developed iterative method presented in Horváth et al. (2014), used full scope cross-section data and a sample origin-destination matrix to produce multipliers to correct the sample origin-destination matrix and to help the calibration of the matrix for accurate prediction of the transit load.

Since transit ridership is an integer number, there has been technical attempts to develop count models which intrinsically treat the dependent variable as a discrete integer value. Two major forms of count regression models include Poisson regression and Negative Binomial regression.

A random variable Y is said to have a Poisson distribution with parameter μ if it takes integer values y = 0, 1, 2, … with probability

$$Pr\{Y = y\} = \frac{e^{-u}\mu^{y}}{y!} \tag{9}$$

for μ > 0. The mean and variance of this distribution can be shown as

$$E(Y) = var(Y) = \mu$$

Since the mean is equal to the variance, any factor that affects one will also affect the other. Thus, the usual assumption of homoscedasticity would not be appropriate for Poisson data.

Negative binomial regression is a type of generalized linear model in which the dependent variable Y is a count of the number of times an event occurs.

$$(y) = p(Y = y) = \frac{\Gamma\left(y+\frac{1}{\alpha}\right)}{\Gamma(y+1)\Gamma\left(\frac{1}{\alpha}\right)}\left(\frac{1}{1+\propto\mu}\right)^{1/\alpha}\left(\frac{\alpha\mu}{1+\alpha\mu}\right)^{y} \tag{10}$$

Where $\mu > 0$ is the mean of Y and $\propto > 0$ is the heterogeneity parameter.

The FDOT report NCTR-473-04, which was prepared in 2004, investigated different aspects of a stop-level transit ridership models based on Jacksonville regional data and developed a count model using Poisson distribution at stop level. A Negative Binomial count model was developed using LIMDEP software. The final model related average weekday boarding at each stop with six categories of factors: 1) socio-demographics in a catchment area; 2) TLOS value; 3) the street environment for pedestrians; 4) accessibility to population and employment; 5) interaction with other modes; and 6) competition with other TLOS stops. Despite some data limitations, the model fitted the data well and behaved as expected. Researchers mentioned that ideally it should be a simultaneous equations system which included the supply equation, however, developing simultaneous equations with a count model, was out of their software capability at the time.

As transit ridership varies across geographic areas, it is likely that the strengths of the relationships between transit use and independent variables also change across space. Some variables may have strong explanatory power at certain locations and are weak at other locations. Such spatial variations, if they exist, need to be understood, modeled, and quantified to determine the most effective measures for increasing transit use and the best ways to invest limited resources. Geographically Weighted Regression (GWR) models were developed in a number of research works (Chow et al., 2006; Chow et al. 2010; Cardozo et al., 2012).

In a GWR model, the dependent variable $y$ is predicted by a set of independent variables of which the coefficients $\beta_j$ ( $j = 0, 1, . . . , p$) may vary by location. In other words, at each location defined by a pair of coordinates ($u_i$, $v_i$), $y_i$ is predicted as:

$$y_i = \beta_0(u_i, v_i) + \beta_1(u_i, v_i)x_1 + \beta_2(u_i, v_i)x_2 + \cdots + \beta_p(u_i, v_i)x_p \qquad (9)$$

Note that $\beta_j$ ($j = 0, 1, . . . , p$) is now a function of location ($u_i$, $v_i$). This means that, for the same $x_j$ ( $j = 1, 2, . . . , p$) values, the equation may give different predictions of the $y$ value depending on the location where $x_j$ are measured.

The literature also shows that within GIS environments, different traffic growth strategies can be easily developed and their impact on land use can be analyzed. Azar and Ferreira (1995) successfully combined a transit ridership forecast model with GIS. A GIS-based methodology was adopted to extract spatial data and develop ridership models using Spatial Proximity Method (SPM) and Spatial Weight Method (SWM) (Pulugurtha & Agurla, 2012). In addition, GIS tools were also used in several studies in order to feed regression models (Gutiérrez et al., 2011; Cardozo et al., 2012; Jones, 2013; Chakrabarti, 2015; Umlauf et al., 2015).

Belz et al. (2010) used spatial analysis in GIS to develop an objective process for determining the level and spatial arrangement of transit demand potential in the rural State of Vermont. The 2000 base-year Vermont Statewide Travel Demand Model (VSTDM) was used to extract the number of daily person-trips by trip purpose between each TAZ, which included trips that are currently being made by transit. The result of the model was an OD matrix depicting the number of daily person-trips by five trip purposes (home-based work, home-based shopping, home-based school, home-based other and non-home-based) between each TAZ state-wide.

#### 2.2.1.4. Integrated Demand Supply Models

Integrated demand supply models refer to a set of regression equations where three fundamental measurements (or at least the first two) are modeled simultaneously. They include: 1) Demand (transit ridership), 2) Service supply, and 3) The inter-route relationships. The methodology was founded on the assumption that transit riders were responding to service changes while transit planning was responding to ridership changes (endogeneity effect between demand and supply). In other words, transit patronage and service supply were highly interrelated. It was also noticed that transit riders transfer from route to route, the introduction of new service might draw some riders from the existing routes, which implied that transit patronage on a route was also affected by other parallel and intersecting routes. In this regard, analytic tools were developed to examine these complex relationships in the transit system (Peng 1994, Peng and Dueker 1995, Peng et al. 1997, Pendyala et al. 2002, Chu 2004, Estupinan and Rodriguez 2008).

Peng 1994 used Tri-Met data from Portland/Oregon to develop the simultaneous demand/supply model based on buffered socio-demographic variables, park-and-ride capacity, competing route attributes, and employment density, etc. A three stage least square method (3SLS) was applied where both ridership values and total seat supply were used as endogenous variables which account for the cause/effect interrelationships between the two parameters. Five different models were developed for different time-of-day sections: AM Peak, Mid-day, PM Peak, Evening, and Night. Pendyala et al. (2002) described the basics of a Regional Transit Feasibility Analysis and Simulation Tool (known as RTFAST) by developing an integrated demand supply equation system. In a Bus Rapid Transit (BRT) study in Bogotá, Colombia, Estupiñán and Rodríguez (2008) applied a 2SLS regression model to predict station boardings. In addition to considering the demand/supply endogeneity, researchers incorporated four latent environmental factors into account, namely walking supports, barriers to car use, low safety and insecurity, and connectivity.

#### 2.2.1.5. Other Methods

While the previous methods covered the majority of commonly used methodologies in the literature, there were other approaches applied in a number of researcher studies. Some of these approaches included autoregressive error terms, neural networks, hybrid models, and fuzzy logic, etc.

Kikuchi and Miljkovic (2001) used fuzzy logic to predict bus ridership at individual stops based on the factors such as transit service quality and condition of bus stop. An optimization algorithm to determine the transit service frequencies was presented by Furth and Wilson (1981). The algorithm was further improved to capture service patterns, bus loads, and heterogeneity of elasticities as described in detail by Verbas and Mahmassani (2013). Back Propagation Neural Network model (BPNN) was presented in Li et al. (2015) which can reflect non-linear relationship between ridership and its predictors.

Monthly ridership was analyzed in Chiang et al. (2011) to identify the relevant factors that influence transit use. Alternative forecasting models were developed and evaluated based on these factors using regression analysis with autoregressive error correction, neural networks, and Autoregressive Integrated Moving Average (ARIMA) models to predict transit ridership. ARIMA model together with a dynamic Partial Adjustment Model (PAM) were used in Tsai et al. (2013). In order to overcome the disadvantages related to the use of single models, the combination or hybridization of several models have become a powerful solution in order to reduce forecast error rates. Ma et al. (2014) adopted the Interactive Multiple Model-based Pattern Hybrid (IMMPH) algorithm in the context of short-term passenger demand prediction in public transport, with three time series models generated.

### 2.2.2. Variables Used in Ridership Forecasts

This section focuses on the common input variables used in transit ridership forecast. Accordingly, variables can be classified as 1) socioeconomics and demographics, 2) land use and accessibility measures, and 3) transit level of service characteristics, etc. Based on the methodology used, more variables could be taken into account. For instance route/stop level models also consider station attributes as an explanatory variable. Some of the most popular variables used in a variety of ridership forecast methods are summarized.

The stop-level transit ridership models developed by Kikuchi and Miljkovic (2001) for the BRT system in Delaware, USA, included the following variables: household automobile ownership, number of households, average household income, bus stop condition, bus stop accessibility, commercial activities, and quality of transit service.

Another stop–level ridership model in San Diego, California, was developed by Ryan & Frank (2009) considering income, no vehicle households, percentage of female population, percentage of Hispanic population , percentage of White population, and percentage of youth.

Chiang et al. (2011) explored how explanatory variables affected the ridership in different locations in their study. They examined data regarding population, income, gas prices, Tulsa Transit budget levels, and seasonality and considered them as potential variables to build their model for the bus transit system in Tulsa, Oklahoma.

Two explanatory (service reliability) variables were used in Chakrabarti (2015) study in Los Angeles, California. He considered average on-time performance and standard deviation of schedule deviation. The other independent variables (or controls) chosen for estimating regression models included stop neighborhood built environment, socioeconomic and demographic factors, and planned service quality of a line serving a stop (i.e., line population density, employment accessibility, stops per mile, line type, and headway).

Aging Effects on Transit (AET) model was conducted in report NCHRP-86 (2006) to predict the usage of public transportation on the travel day as a binary variable, applicable for different counties within the U.S. Independent variables considered in this report all came from household surveys, including 65 and over age group, zero-vehicle household, workforce participant, public transit available within two miles, and different categories based on population.

According to Azar and Ferreira (1995), there was an increasing need to have systematic and robust capabilities for integrating and managing large sets of geo-referenced data and computing spatial overlays (i.e., combining several layers of information together based on geographic location). They successfully combined a transit ridership forecast model with a GIS, using length of the segment, population, number of employment, and average speed of transit vehicles as model inputs for a bus system in Boston, Massachusetts.

Transit ridership models were developed using a geographically weighted regression (GWR) method exploring the spatial variability in the strength of the relationship between transit use and explanatory variables that included demographics, socioeconomic, land use, transit supply and quality, and pedestrian environment characteristics (Chow et al. 2006; Chow et al. 2010), both were done in Broward, Florida. Chow et al. (2006), divided predictors in two categories; two global variables (regional accessibility of employment and percentage of households with no car) and three local variables (employment density, average number of cars in households with children, and percentage of the population who are black).

Cervero et al. (2010) developed a DRM for BRT system in Los Angeles, California, as a function of three key sets of variables related to bus stops (or stations) and their surroundings. The other stop-level ridership forecasting study which was done in Charlotte, North Carolina, by (Pulugurtha & Agurla, 2012), used demographic and socioeconomic together with land use data, and they considered speed limit, presence of median, one-way or two-way street, number of lanes, as on-network data.

Cardozo et al. (2012), which investigated bus system in Madrid, Spain, incorporated four independent variables, of which three were related to the station's catchment area (number of workers, number of jobs, number of suburban bus services) and one was related to the station characteristics (number of lines passing through it). Duduta (2013) considered neighborhood attributes, station and service characteristics as independent variables for BRT system in Mexico City, Mexico. Independent variable categorized in potential demand and transit supply for bus service in Nijmegen, Netherlands, in Kerkman et al. (2015) study.

Umlauf et al. (2015) used demographic data along the corridor, origin-destination survey data and new and existing transit service features as model inputs for the BRT system in El Paso, Texas.

### 2.2.3. Data Sources

Mainly two data sources were identified in transit ridership studies: 1) study-specific surveys, such as stated preference survey, revealed preference survey, or OD surveys, and 2) demographic and travel statistics from various agencies at national or regional level, such as the American Community Survey (ACS), Public Use Microdata Samples (PUMS), Census Transportation Planning Products (CTPP), Bureau of Transportation Statistics (BTS), and the National Transit Database (NTD).

Appendix A shows the summary of various transit ridership studies from 1995 to 2015, in regard to the transit service type, the methodology, variables used, data sources, and location of the study.

## 2.3. Tools in Practice

This section intends to provide an overview of a few transit ridership forecasting tools that have been used in practice in Florida or at the national level.

### 2.3.1. FDOT Transit Ridership Forecasting Tools

The Public Transit Office of the Florida Department of Transportation (FDOT) has been leading the efforts in developing transit ridership forecasting models and planning tools to meet the needs of various planning and transit agencies throughout the state.

#### 2.3.1.1. ITSUP

The Integrated Transit Demand and Supply Model (ITSUP), developed in 1999, represents the earlier efforts in developing stop-level ridership forecasting tools. ITSUP explicitly incorporates the two-way interactions between transit demand and service supply. It is an econometric simultaneous equations system that is estimated on commonly available socioeconomic and transit system data. This model consists of a two-equation system as follows:

1) Ridership equation in which the number of boardings at each stop is modeled as a function of socioeconomic variables and service frequency, and
2) A service supply equation in which the frequency of service is modeled as a function of socioeconomic variables and ridership (number of boardings).

The model has been implemented within a user-friendly menu-driven software architecture that provides the user flexibility with respect to input variables and model parameters. In addition, the model has been interfaced with the ArcView GIS to provide visual and database management capabilities.

ITSUP can serve as a short-term transit demand forecasting model as well as a short-term operations planning tool. Given a set of input variables, the model will predict ridership at individual route level. Also, through a series of iterative feedback computations, the model will suggest alternative service parameters (e.g., headway values) based on the socioeconomic market potential of the buffer areas surrounding the routes. The model predicts transit supply as a function of demand in order to generate improved service configurations that enhance overall route- and system-wide performance measures. The model requires three sets of data including: demographic and socioeconomic data at TAZ or census tract level, transit service characteristics, and secondary data (which allows you to re-route existing segments or add new transit route segments).

#### 2.3.1.2. RTFAST

The 2nd generation of transit ridership model in Florida, is the Regional Transit Feasibility Analysis and Simulation Tool (RTFAST), completed in 2002. The RTFAST is the enhancement of demand/supply equations with geocoded data in a GIS environment. In particular, RTFAST provides the following features:

- Extraction of socioeconomic and other data from buffers drawn around transit routes and stops;
- Estimation of transit route ridership given socioeconomic and transit service conditions; and
- Determination of equilibrium ridership and service supply given market characteristics.

#### 2.3.1.3. T-BEST

Incorporating many features and methodologies of its predecessors (i.e., ITSUP and RTFAST), the Transit Boardings Estimation and Simulation Tool (T-BEST) represents the latest effort in developing a robust stop-level ridership forecasting tool. T-BEST is an operational and powerful transit analysis and ridership forecasting software package. Offering full GIS functionalities and network coding capabilities, the tool is capable of estimating stop level transit demand while accounting for network connectivity, spatial and temporal accessibility, time-of-day variations, and route competition and complementarity.

TBEST is a micro-level model which simulates transit ridership at the individual stop level, by route, direction and time period. Technically, the model estimates total boarding at each stop (the dependent variable) using a negative binomial count model. Two types of independent variables are applied as input data: the first set includes the characteristics of the buffer area surrounding a subject stop which impacts the overall and transit trip generation; the second set reflects the stop characteristics in view of spatial accessibility. Different models are estimated for different TODs on a weekday along with separate models for weekends. The tool has been implemented in several regions outside Florida.

#### 2.3.1.4. TLOS

The transit level-of-service (TLOS) software measures transit availability that incorporates service coverage, frequency, and duration; the availability and quality of pedestrian routes to transit stops; and population and job density. The TLOS's basic concept is that at any given minute, a transit vehicle serves a small group of people; that is, those people who could board a vehicle when leaving their job site or residence that minute, walk no more than a specified distance to a transit stop, and wait no more than a specified time for a vehicle to arrive.

GIS–based software developed for the TLOS can be applied to every transit vehicle for each minute in a day. The data can be compiled for time frames ranging from 15 minutes to 1 week to assess the amount of service for each part of a transit system's service area. The TLOS was tested in Tallahassee, Florida, and produced results compatible with, but more detailed than, the availability measures contained in the TCRP's Transit Capacity and Quality of Service Manual. Potential applications include service evaluation, transportation modeling, and improvement of modal-split calculations (Ryus et al., 2000).

### 2.3.2. FTA Tools

#### 2.3.2.1. STOPS

In response to the 2013 Final Rule on major capital investments projects, FTA developed the Simplified Trips-on-Project Software (STOPS) to predict the trips-on-project measures and the automobile-VMT change needed for the environmental measure. STOPS is a stand-alone software package that applies a set of travel models to predict detailed transit travel patterns for the no-build and build scenarios, quantifies the trips-on-project measure for all travelers and for transit dependents, and computes the change in automobile VMT based on the change in overall transit ridership between the two scenarios.

Fundamentally, STOPS follows a modified four step model which estimates zone to zone travel markets stratified by household auto ownership. It employs simple mode choice model to predict transit shares and then assigns those trips to fixed guideways on various rail and BRT facilities. The model however deviates from the conventional four step modeling in a number of ways. First, trip generation and distribution steps are replaced by CTTP worker-flow tabulations. Second, instead of using the coded transit network, STOP uses the data from General Transit Feed Specification (GTFS) developed by local transit services. Third, the model does not include any representation of actual highway network, instead it only considers the zone-to-zone impedance factors (travel time and distance). The model considers three different trip purposes: home-based work, home-based other, and non-home-based.

One advantage of STOPS is that it has been calibrated and validated for a broad range of areas and travel behavior contexts across the United States, including Kansas City, Houston, Minneapolis, Nashville, Norfolk, Portland, San Jose, Seattle, and St. Louis.

When applied for different metropolitan areas, STOPS basic calibrations are adjusted by changing the following parameters: the current total number of system-wide transit boarding, the share of CTPP worker flows to jobs in each subarea that is captured by transit, and the daily number of boarding at individual stations on any existing fixed-guideway facilities.

#### 2.3.2.2. Aggregate Rail Ridership Forecast (ARRF)

The Aggregate Rail Ridership Forecast (ARRF I), is a sketch planning tool developed by AECOM and sponsored by FTA. It uses CTPP 2000 data and GIS information to develop an estimate of ridership potential for a new rail system. The model is based on data for twenty recently built light rails and commuter rails.

Two different sets of models were developed, respectively for LRT (light rail) and CR (commuter rail). The models were simple regression formulas based on journey-to-work (JTW) flow data occurring within specific distance buffers of rail stations cross tabulated by socioeconomic and workers' density. In particular, the LRT model used CTTP flows by employment density. The CR model used CTTP flows stratified by employment density and income as well as level of service variables such as speed, train miles per direction route, and connection to rail distributor. The final dependent variable is the weekday unlinked trips. Models were calibrated based on available data from the National Transit Database for the period of 2000-2002. Eleven cities were used for the LRT model, including Baltimore, Buffalo, Cleveland, Dallas, Denver, Portland, Sacramento, Salt Lake City, San Diego, San Jose, and St. Louis. Nine different commuter rail systems were used to calibrate the CR model, including Baltimore-DC MARC, Dallas-Ft. Worth TRE, LA Metrolink, Miami Tri-Rail, San Diego Coaster, San Francisco Caltrain, San Jose ACE, Seattle Sounder, Washington DC VRE.

An enhanced version of the model, **ARRF II**, was further developed. Some of the modifications included one unified CR/LRT model, more accurate characterization of trips, and improved CTPP data processing, etc. Separate models were estimated for four different purposes, including home-based work with walk access, home-based work with drive access, others with walk access, and others with drive access.

## 2.4. Summary and Discussions

Both qualitative (professional judgment and similar routes, etc.) and quantitative (elasticity analysis and econometric modeling, etc.) methods were proven useful in transit ridership forecasting, and many agencies employed multiple methods in their analysis.

Among the quantitative methods, regional travel demand models remain a powerful tool to estimate transit share based on system characteristics, built environment, and the demographics and other contributing factors. These tools are usually readily available and provide a systematic and holistic view of travel choices. With recent advancements in activity-based modeling and better representation of land use factors at higher resolutions, these models may equip the agencies with better capabilities for transit analysis. However, since these regional models generally are not geared toward transit planning and service analysis, they may not be able to reflect the impacts of changes in the transit network or services on travel behavior to the full extent. Complexity of the regional model, cumbersome procedures, long run times, and lack of flexibility are the other common obstacles a transit agency may face.

Consequently, local transit agencies were more likely to develop models at finer scales, such as route-level, stop-level, or segment-level ridership models. These tools would provide more user-friendly features that allow the transit agencies to explore and analyze various strategies and scenarios in transit service planning and operations. In this regard, regression models were the most widespread methodology for ridership estimation. This approach would also allow the analyst to take into account additional factors within the corridor or at the route or stop level that may have significant impacts on the usage of transit. On the other hand, it may also require the collection of additional data.

Enhanced modeling techniques have also been proposed which tended to enhance the existing models either through the consideration of additional dimensions (geographically weighted regression models and time-series analysis, etc.) or better handling of the demand and supply (dynamic demand formulations and neural network, etc.). However, applying these methods in practice has not been well established at least in the United States, perhaps due to the complexity of the methods, or the data required for model calibration.

There are several existing tools (such as, T-BEST and STOPS) that present great potential for estimating transit ridership within the context of express lanes. It is also worth mentioning that, through this literature review, no study was found that detailed the methodology or technical analysis regarding transit ridership in this context, perhaps because the managed lane concept is still relatively new. In this regard, the next task of this project will evaluate available tools and models in the region, identify available data sources, and develop a framework for transit ridership forecasting within the express lane context. The framework will consider several aspects including the analysis needs of the agency, the advantages and disadvantages of various forecasting methodologies, the data requirements, the user features needed for transit operation and planning analysis, and performance measures, etc.

# 3. PLANNING FRAMEWORK

Transit is a critical component of the success of an express lane (EL) program. Transit service could bring additional contributions to reducing congestion, enhancing system efficiency, and maximizing project benefits. Bus-only or high occupancy vehicle (HOV)/high occupancy toll (HOT) lanes on expressways offer many advantages for transit services, including reduced travel time, improved schedule adherence and on-time performance, which makes the service competitive with automobiles, therefore, attracts new riders.

This chapter focuses on the planning framework of express bus service planning in conjunction with EL projects. Major components in the framework, including stakeholder involvement, transit market assessment, ridership forecasts, benefit-cost analysis, and service monitoring and evaluation are discussed.

## 3.1. Express bus Service Features

Express bus service is a type of fixed route service designed to connect commuters from suburban areas to urban centers with high travel speed and level of service. It typically makes a few stops to pick up passengers at designated areas, such as park-and-ride lots and regional transit centers, then proceeds non-stop to urban employment and activity centers, utilizing any available HOV/express lanes. Express buses usually serve longer distance trips (10-20 miles) that have common origins and destinations, especially during peak commuting hours. Fares for the service may be slightly higher than regular local fixed route service.

Express bus service provides riders a direct, quick connection to high demand destinations, such as major employment centers, institutions of higher education, or other activity centers. It provides workers in a metropolitan area with an alternative for their daily commute. Express bus service boasts quicker travel times which makes it time-competitive with automobile trips. In addition to alleviating congestion, express bus service can provide a community with an alternative means of maximizing employment and educational opportunities for its citizens, particularly those who are transit dependent.

Express bus services are distinguished from other types of bus services by a number of operational features, including exclusive/shared lane, limited stops, operation hours, service applications, travel speeds, high capacity vehicles, and high economic development potential (Texas A&M Transportation Institute, 2012; Valley Transportation Authority, 2007).

- **Stop/speed:** Express buses operate with high travel speeds for the line-haul portion of the trip and make limited stops on the outlying portions of the route to accumulate passengers.
- **Exclusive lane:** Express bus routes usually maximize the utilization of HOV or dedicated express lanes.
- **Operation hours:** They primarily operate during rush hours in the peak direction and usually only on weekdays, although some may offer all-day, mid-day, evening and weekend services if markets for these services exist.
- **Fare:** Express bus service typically commands higher fares than normal parallel services, for faster travel times. Express buses are exempt from tolls on HOT or express lanes. Many express buses require passengers to purchase tickets before boarding the bus, speeding up the service.
- **Target population:** An express bus service usually intends to connect major local employers, institutions of higher education, or other concentrated centers, enabling greater access to these destinations. It is generally an appealing option for long-distance commuters, those who would otherwise utilize freeways to travel to and from work.
- **Transit vehicle:** Many express services use larger vehicles (such as coaches and articulated buses), with more comfort and amenities, such as plush seats, overhead storage, arm rest, foot rest, and restroom facilities, etc.
- **Park & Ride facilities:** The service usually originates from park-and-ride lots, or transit centers (usually with park-and-ride lots) that are located close to freeways or major roadways. Many express services allow direct access to the HOV or express lanes from the park-and-ride lots through exclusive transit access ramps.

These unique features of express bus services and facilities need to be recognized in the transit service planning process. The next section presents a general planning framework for Express bus service in conjunction with EL programs.

### 3.2. Planning Framework

This framework intends to provide a standard approach to express bus service planning in conjunction with EL projects. In general, the process covers a planning horizon of 15 to 20 years which could be extended to up to 30 to 35 years with special considerations for longer range transportation needs. The planning process includes a technical approach to identifying specific markets through an evaluation of high-demand corridors or areas with an understanding of customer preference and behavior. Ridership estimations are then developed for one or more alternatives with varying service details. Following a benefit/cost analysis of the alternatives, recommendations are given for appropriate service strategies and service levels. Detailed operation elements are then addressed for implementation. Continuous service monitoring and evaluation are critical to ensure that the service meets the objectives. Figure 1 below demonstrates the process for service planning and enhancement on an ongoing basis.

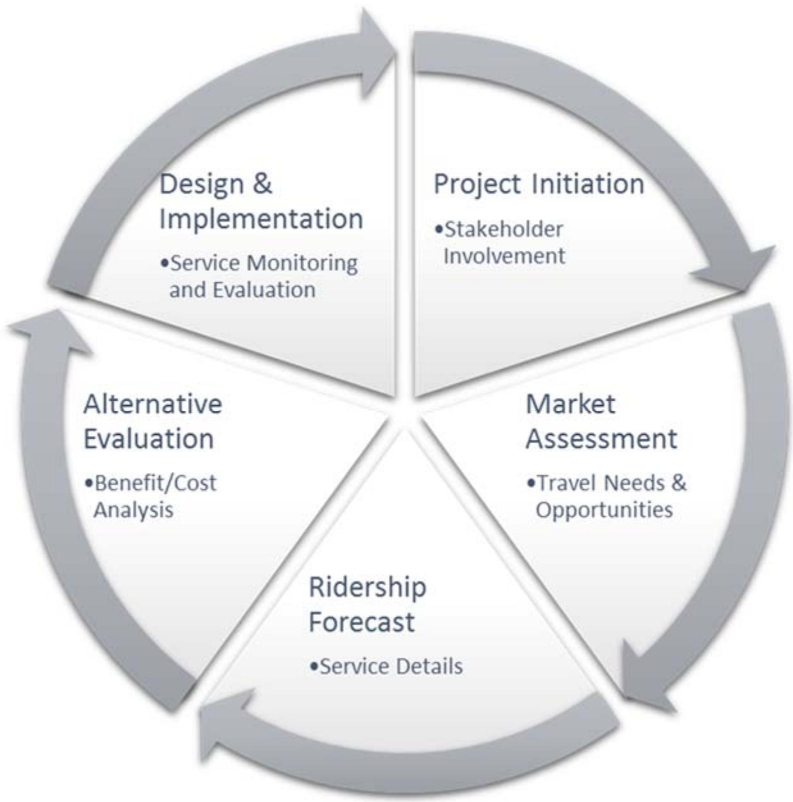



**Figure 1 Transit service planning process on an ongoing basis.**

Figure 1 shows the five major components in the planning process. For each component in the process, the key issue involved is also identified.

- Project initiation provides the opportunity to establish a platform for coordination among all stakeholders. It is essential to involve transit agencies and service providers at the early stage as they have the leading role in planning and operating bus services and facilities associated with the EL program.
- Market assessment focuses on identifying high demand corridors/areas and potential opportunities for transit, which serves as a prerequisite for further

ridership analysis at greater details. It is based on a thorough examination of current travel patterns and future growth.

- Ridership forecast requires the development of alternatives with considerations given to various service details, such as routing, service frequency, stop locations, and vehicle type, etc., as these elements often have significant influences on the demand and ridership.
- Alternative evaluation compares the benefits and costs of each alternatives, and makes recommendations on express bus service strategies and levels. Beside ridership levels and benefits to the customers, capital and maintenance cost is an important factor in the evaluation process.
- Design and implementation refines the recommended service strategy into operational plans for program implementation. Continuous service monitoring and evaluation provides the means to assess service performance and ensures that the service meets the project goals. Service enhancements may be evaluated on an ongoing basis.

Figure 2 below illustrates the planning framework with detailed elements, which are further discussed in the following sections.

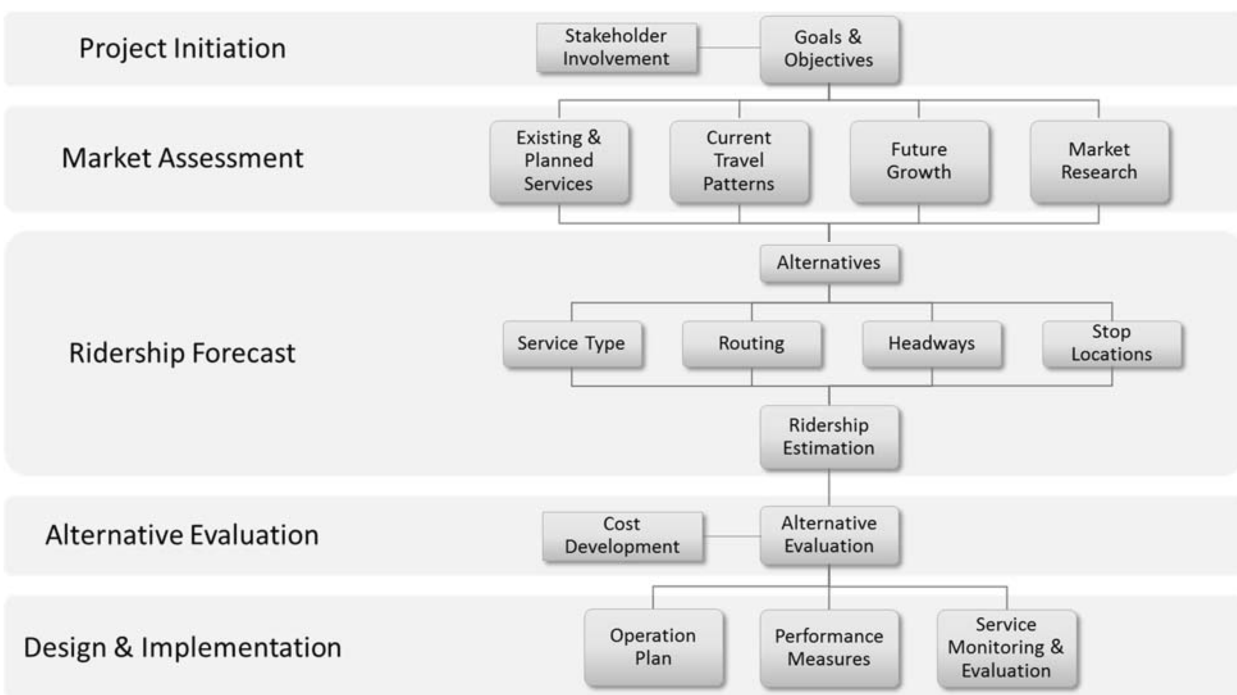



**Figure 2 Planning framework for express bus service in conjunction with express lane projects.**

### 3.2.1. Project Initiation

Project initiation is the first step in the process, and serves many important purposes that are critical to the success of an EL project. It sets the stage and provides a platform for multi-agency coordination. It ensures that all stakeholders participate in the development of the strategic goals of the project and all involved agencies work towards the same goals. An understanding of each other's needs and priorities also help define the project priorities and maximize the contribution from each member agency. The National Cooperative Highway Research Program (NCHRP) Report 414 (1998) provided a comprehensive discussion on the involved agencies and their roles and responsibilities in planning and operating transit services with HOV facilities.

- **Transit agencies and service providers** should be actively involved throughout the course of planning, designing, implementing, marketing, operating and evaluation of the EL project. Transit agencies have the overall responsibility for planning, operating and monitoring transit services. They may also help with public information, marketing and public relations.
- **State departments of transportation**, as the lead on EL programs, provides assistance and coordination with the planning and operation of transit services.
- Metropolitan planning organizations (MPO) may assist with coordination and provide technical support with transit planning activities. MPOs may also be responsible for the impact study or other regional corridor studies that include the EL project. The EL project also needs to be included in relevant plans and programs, such as the Long Range Transportation Plan (LRTP), Transportation Improvement Plan (TIP), and work programs.
- **FTA and FHWA** approve funding requests and may provide guidance and assistance during the process.
- **Commuters and public groups** represent the potential users of the facilities. Surveys, focus groups, meetings and workshops could be useful to obtain inputs and feedbacks.
- **Local municipalities** should be involved for the design and operation of bus facilities along local roads.
- **Other service providers and special-user groups**, such as taxi, airport limousine services and school buses may need to be considered if they are likely to operate on the EL facility.

If there is a demand for travel within the EL, transit could contribute to an EL program from many aspects, including providing options for commuters, improving level of service, reducing congestion and vehicle emissions, as well as negating the Lexus lane argument that most EL opponents raise. There must be clearly defined project goals and objectives in order to provide the necessary context for decision making regarding considerations and commitment for transit services in the EL corridor.

### 3.2.2. Market Assessment

Examining current transit routes and planning future bus services should be an integral part of the overall EL program planning process. The level of detail associated with the transit planning activities depends on the potential transit market in the EL corridor or area. In some areas, there may not be an existing need for a route in the EL, however, future considerations should not be eliminated. The primary goal of this step is to obtain relevant information and provide a preliminary assessment of the potential demand for express bus service on the EL facilities, before a detailed ridership analysis. Figure 2 illustrates four major components in market assessment.

- **Review Existing and Planned Services**. This task establishes an understanding of the supply of transit services and supporting facilities in the corridor or area. This may include existing commuter bus route or other transit services that serve the corridor, available feeder system, and existing or potential parking spaces. The goals and policies of the transit agencies should be identified and reviewed. Future roadway plans and transit projects should also be reviewed.
- **Examine Current Travel Patterns**. This step analyzes current travel patterns (such as trip length, productions and attractions, trip mode and purpose), in association with population and employment distributions, characteristics of transit services, and traffic conditions on the highway network. This analysis will help identify deficiencies and needs for improvement.
- **Incorporate Future Growth**. This task looks at projections for future growth, including socioeconomic-demographic forecast, existing and future land use and economic development, and environmental factors. Incorporating current travel patterns with future growth, major attraction locations and high demand origin-destination pairs can be identified and analyzed. This information will help determine whether there is or going to be a market for express bus service, and if so, the potential size of the market.
- **Conduct Market Research**. Additional market research could be conducted to obtain further knowledge on the interest and preferences of potential customers to the types and levels of transit services provided or proposed. These research activities may include origin-destination (OD) surveys, transit on-board surveys, establishment surveys at major attraction sites, focus groups, interviews and public meetings, etc. It may also be beneficial to identify transit programs in

conjunction with EL project from other regions, similar to the study area, regarding their service strategies, characteristics and policies. Experience from other programs may provide meaningful references regarding the potential market for transit services.

### 3.2.3. Ridership Forecast

A full ridership analysis needs to be conducted if a market assessment signifies a potential market for express bus services. The first step is to develop a set of alternatives with sufficient details that describes the proposed service characteristics. These may include the service type (i.e. full-day or part-day operation, etc.), route design, headways and service frequency, stop locations, and vehicle type/capacity, etc. This information serves as important inputs for ridership estimation.

- **Service Type**. A variety of bus services and operating strategies can be employed with EL facilities. The most appropriate service type can be determined based on the level and characteristics of demand. Generally, there may be three types of express bus service (Valley Transportation Authority, 2007), including:
  - Limited stop service over existing local routes, with faster service during peak periods only
  - Express service tailored for daily commuters, typically during weekday peak period in peak direction
  - Regional express that provide all-day service in both directions for longer multi-purpose trips.

  Reich and Davis (2013) also discussed a range of transit treatment that can be considered with EL projects, from low to high levels of intensity, including:
  - Toll exemption for transit vehicles
  - Express bus service
  - Park-and-rides
  - Direct access ramps
  - In-line stations
  - Exclusive lane(s) for BRT
  - Fixed guideway right of way
- **Routing and Stop Locations**. Route structure and stop locations should be designed to serve key trip generators and maximize ridership and revenues based on existing land use and development. The key considerations may include (Valley Transportation Authority, 2007):
  - Utilize ELs to the extent possible to attract a sustainable ridership level and maintain a competitive operating speed.

- Coordinate with current bus routes offered by the fixed-route services.
  - Locate suburban stops to maximize ridership potential and provide direct and safe access to/from surrounding land uses.
  - Locate urban stops within employment and activity centers with high demand.
  - Consider regional transit centers, bus and rail transit stations, and existing park-and-ride facilities.
  - Locate close to major highway on- and off-ramps to provide direct and quick access.
  - Safety, physical constraints, right-of-way, and bus pull-out/turn around space, etc.
  - Potential route locations based on identified tolling ingress and egress points of the EL should be identified as well to help narrow the ridership forecasts.
- **Service Frequency and Headways**. Service frequency refers to how often buses arrive at a particular stop. Headways refer to the interval in minutes between two successive bus departures. The terms are often used interchangeably. Key considerations in determining headways may include:
  - Current service policies in place
  - Expected level of demand at stops
  - Minimal service frequency levels
  - Service capacity standards
  - Vehicle type and fleet size
  - Coordination with parallel local routes, intersecting main routes and timed transfers

  Express services are expected to offer shorter headways and more frequent minimal service levels than local routes. In the U.S., in order to qualify as a Small Start under Federal Transit Administration (FTA) guidelines, a corridor-based bus project is required to offer a minimum 10-minute service frequency during peak periods and 15-minute service frequency during off peak times, for at least 14 hours per day in total (American Public Transportation Association, 2010).
- **Park-and–Ride Facilities**. Parking will impact ridership as insufficient parking may limit non-transit dependent individuals from accessing the express service. If current park-and-ride lots cannot cover the market area or do not have enough space to serve the parking needs, additional parking needs to be considered in the alternatives. The NCHRP Report 414 provided general guidelines in determining the location and size of park-and-ride facilities. Generally, the

facilities should be located proximal to areas experiencing major congestion, with high levels of demand, have good accessibility and visibility. Other considerations include cost, security, proximity to transit services and other user amenities, potential for expansion, and environmental impacts.

When the service alternatives are determined, detailed ridership analysis can be performed. Realistic and reliable ridership forecasts are essential in sizing system design features, developing service plans, estimating capital and operating costs, performing alternative analysis and cost benefit comparisons, and making investment decisions. In general, the analysis should be able to provide ridership forecasts for the base year, the opening year, the year when ridership reaches maturity, and a design year usually 20 years into the future. Ridership estimates are needed for peak and off-peak conditions by line segment and by station boardings and alightings.

Various methods can be used for transit ridership estimation, including service elasticity, econometric models, regression analysis, and regional planning models, etc. The next task of this project will discuss detailed methodologies for express bus ridership forecast. It should be noted that, studies have shown that the attractiveness of express bus systems would be greater than expected on the basis of reductions in travel times and costs, and they are likely to attract levels of ridership similar to those of rail based systems.

### 3.2.4. Alternative Evaluation

Based on the results of ridership estimation; transit ridership, bus operating speed and travel times will be estimated and the capital and operating costs for each alternative will be developed and analyzed. A cost-benefit analysis is needed to develop recommendations on the alternative that best meets the project objectives and is financially viable. This analysis identifies and quantifies all potential benefits and costs that will accrue to the public during the analysis period (usually 10 to 30 years) for each alternative, which are converted to present year dollar values. The net present value (when total costs are subtracted from total benefits) then provides a consistent and comparable measure across the alternatives.

The benefits and costs of the express bus program depend on the project features and characteristics of the local area or region. The benefits usually include travel time savings, travel cost savings, reduced incident costs, reductions in emissions, noise, and other environmental impacts. There are also indirect/secondary benefits, such as increased economic activity and land development, which are often difficult to estimate and usually not considered in project-level analysis because these indirect benefits are also influence by a number of external factors and it would be impossible to isolate the impacts of a single transit program along a freeway. The costs against which these benefits are weighed usually include capital costs, operation and maintenance costs. A key assumption in the analysis is the monetary value associated with the various benefits and costs. The study area, the baseline features and the analysis period also needs to be defined.

Since the net benefit value usually depends on several contributing parameters, such as the ridership of the express bus, total VMT, operation and maintenance costs, etc., a sensitivity analysis can be conducted to examine how the net impact may change with respect to a change in any of these parameters. This helps develop worst/best case scenarios and account for the uncertainties in the project outcomes.

### 3.2.5. Design and Implementation

Once the overall approach and strategies are determined, a more detailed operating plan needs to be developed. Operational level route and schedule planning, fare establishment, supporting facility design, training, service monitoring and assessment, and other operating elements need to be addressed. There may be off-route considerations that could facilitate the express bus service, such as feeder systems, or transit signal priority, which would require coordination with local agencies.

With regard to express bus service, a significant marketing effort and public information campaign would be needed to raise awareness and promote the service. Specialized branding and coloring on the express buses are commonly employed to distinguish the service from local buses.

A key component in this step is the development of a monitoring and evaluation program to ensure that the service meets the goals and objectives established for the service. Ongoing assessment and enhancement of the service is also a critical contributing factor to the success of the express bus program. Data collection and processing methods, performance measures, desired threshold values, and evaluation procedures should be established to standardize and facilitate the monitoring and evaluation effort. The transit agencies and service providers should already have procedures and guidelines in place, which should serve as the basis for the development of the monitoring and evaluation program. Considering the physical and operation features of express services in conjunction with EL facilities, commonly employed performance measures may include but are not limited to the following:

- Number and percent increase in bus riders

- Number of auto trips reduced
- Travel time savings and reliability enhancement
- On-time performance, headway adherence
- System accessibility
- Daily and monthly boarding, boarding/vehicle mile, boarding/vehicle hour
- Annual revenue, average fare
- Vehicle revenue miles, vehicle revenue hours
- Operating cost/revenue mile, operating cost/boarding
- Number of riders at park-and-ride lot
- Safety, etc.

### 3.3. Summary

This chapter presents a framework for express bus service planning in conjunction with EL programs. The framework covers the major components in express bus service planning, including: project initiation, market assessment, ridership forecast, alternative evaluation, and design and implementation. The key elements in each component are discussed. This framework does not intend to be comprehensive in transit service planning and design, but rather serves a general guideline when considering transit services with EL programs.

The next chapter discusses the features and capabilities of available tools and recommends ridership forecast methodologies to help evaluate ridership potentials of express bus services provided with EL programs.

# 4. RIDERSHIP FORECASTING METHODOLOGY

Realistic and reliable ridership forecasts are essential for sizing system design features, developing service plans, estimating capital and operating costs, and making investment decisions. Various methods have been used for ridership forecasting as summarized in the literature review report, including elasticity analysis, regional travel models, econometric models, and regression analysis (direct ridership models), etc. The right methods/tools depend on the study purpose and the desired functional features.

For this study, the main purpose was to provide ridership forecasts that support the service planning for express buses in conjunction with EL programs. As such, the methodology should take into account the unique characteristics of Express bus services. Comparing with conventional bus services, especially local buses, Express bus intends to provide services that are time-competitive with auto modes rather than other transit services. They usually serve longer distance markets and operate nonstop for the line-haul portion of the trip and make limited stops on the outlying portions of the route to accumulate or unload passengers.

The implications on express bus ridership forecasting are threefold. First, the market potential should consider additional segments beyond the traditional low-income transit-dependent population to account for "choice users" (those who divert from auto modes). Secondly, direct estimation of route/stop level ridership that relies on buffer analysis of the population and employment intensities along the route or around the stations may not be suitable to capture the demand for Express buses which operate nonstop for the majority of the route. For the same reason, the line-haul ridership is less likely to be affected by the level of service and connectivity (competition and complementarity) of other transit services along the route. Thirdly, as the primary competing mode of Express buses, driving modes also play an essential role in the relative attractiveness of Express bus service and therefore its ridership. The performance of the highway network should be taken into account when estimating the demand for express buses. In addition, park-n-ride facilities (location, capacity, safety, and amenities, etc.) also have a significant influence on the attractiveness of Express bus services.

Given the above considerations, the ridership forecasts for Express bus services should meet the following objectives.

- Capture key demographic segments to be served (underserved neighborhoods, high demand corridors and areas, transit-dependent users, low income segments, etc.);
- Correspond to the spatial distribution as well as level of major activities (employment clusters, shopping and entertainment centers, etc.);
- Provide stop and route level ridership estimates for peak and off-peak conditions to support transit service planning;
- Consider various service details (routing and coverage, scheduling and frequency, stop locations, park-n-ride facilities, and pricing and fares, etc., as these elements all have significant influences on the demand and ridership;
- Recognize the unique physical and operating features of Express bus services (speed, reliability, vehicle characteristics and amenities, etc.);
- Reflect the influence of price and service characteristics of competing and complementary modes of travel and facilities, and congestion levels in the corridor;
- Capture choice users and "new" trips (i.e., trips diverted from automobiles, trips not made before, and trips made with greater frequency); and ideally
- Represent the interrelationship/equilibrium between supply (service details) and demand (ridership).

The following sections discuss the methods and capabilities of candidate tools that are considered for the purpose of this study. More detailed summary of each tool/method can be found in Appendix B of this report.

## 4.1. TBEST

The Transit Boarding Estimation and Simulation Tool (TBET) is a micro-level tool that estimates transit ridership at individual stop level, by route, direction and time period (*1*). Using a negative binomial count model, TBEST estimates both direct and transferred boarding at each stop based on three major inputs:

- Socioeconomic and demographics, which are calculated based on a 0.25-mile buffer analysis for each stop. They are derived from sources such as Census, InfoUSA, and American Community Survey (ACS), etc.
- Stop/route characteristics, including scheduling attributes, level of service, and other physical supply attributes. The values are defined by the users.
- Adjacent/neighboring stops' attributes. These attributes are used to measure the potential of trip transfer or being redirected to competing routes/stops.

The model specifications for direct and transfer boarding estimation are shown below:

**Direct Boarding**

$D_n^s = g(C^s, A_{1n}^s, A_{2n}^s, A_{3n}^s, A_{4n}^s, X_n^s), n = 1, \dots, N$
where
s = index for any origin stop
n = index for any time period
N = number of time periods
$D_n^s$ = direct boardings at stop $s$ during period $n$ for the direction and along the route that define stop $s$.
$C^s$ = vector of buffer characteristics for stop $s$. These characteristics include the amount of population and employment as well as their characteristics. s C
$A_{1n}^s$ = vector of accessibility to employment and population in the buffer areas of $S1$ stops during period $n$.
$A_{2n}^s$ = vector of accessibility to employment and population in the buffer areas of $S2$ stops during period $n$.
$A_{3n}^s$ = vector of accessibility to employment and population in the buffer areas of $S3$ stops during period $n$.
$A_{4n}^s$ = vector of accessibility to employment and population in the overlapped buffer areas $S3$ stops and $S1$ stops during period $n$.
$X_n^s$ = vector of other stop and route characteristics during period $n$.

**Transfer Boarding**

$T_n^s = t(P_{0n}^s, A_{1n}^s, A_{2n}^s, A_{3n}^s, A_{4n}^s, Y_n^s), n = 1, \dots, N$
where
$T_n^s$ = transfer boardings at stop $s$ during period $n$ for the direction and along the route that define stop $s$.
$P_{0n}^s$ = transfer potential from upstream boarding at $S0$ stops toward stop $s$ during period $n$.
$Y_n^s$ = vector of other stop and route characteristics for period n.

TBEST is capable of providing several types of outputs and performance measures at each stop, including Direct/Transfer boarding, revenue service trips, route miles, revenue service miles, passenger boarding per service/hour/mile, etc. In addition, it provides analysis on population and employment access to the transit service based on total/percentage of population being served. The tool is also capable of an efficiency analysis that evaluates operating costs per passenger trips/per service miles.

The latest enhancement of the TBEST also allows the user to incorporate BRT adjustments. These adjustments can account for the ridership effect of various service features, including vehicle characteristics, station amenities, traffic priorities such as signal preemption and presence of exclusive lanes, as well as branding/marketing.

In summary, TBEST provides robust analysis for scenario-based transit ridership estimation and service planning, with full GIS functionalities and network coding capabilities. It accounts for critical transit network attributes, including connectivity, temporal availability, and competitive and complementary interrelationship among different transit routes. Also, TBEST supports individually calibrated models for individual transit systems, which are already in place for most agencies in Florida.

However, TBEST does not consider the performance of the highway network, therefore not able to account for the relative attractiveness between highway and transit modes. As a result, the analysis may not be able to capture the full potential market of Express bus service and under-estimate the benefits of the service (choice users diverted from auto modes). Also, TBEST considers service supply attributes (e.g. number of arrivals, headway, etc.) as exogenous variables. Service optimization is realized through manual adjustment and professional judgement based on the level of demand.

## 4.2. STOPS

The Simplified Trips-on-Project Software (STOPS) is a simplified version of the conventional four-step travel model that produces zonal transit trip tables in the study area (*2, 3*). It simplifies the four-step method in the sense that the total origin-to-destination travel demand are derived from Census Transportation Planning Package (CTPP) data rather than elaborate trip generation and destination choice procedures. This avoids the need to calibrate these tools to the degree of accuracy required to estimate transit ridership. Based on the zonal travel demand, a conventional FTA mode choice model is applied to estimate O-D trips by transit mode.

The mode choice model utilizes a nested structure, which covers non-transit modes (auto and walk), and transit modes separated by access mode (walk, kiss-n-ride, and park-n-ride) and service type (fixed guideway only, fixed guideway and bus, and bus only). The model employs a guideway visibility factor (with a value between 0.1 and 1) in the nest coefficients to differentiate fixed guideway transit services from other transit, such as streetcars, and local buses. The mode choice model considers factors including trip purpose, auto ownership, travel times (in vehicle time, access time, initial wait time), and transfer attributes (transfer time and number of transfers).

Major features of STOPS are summarized below:

- STOPS uses a simplified trip generation/distribution calculation method. It directly uses Year 2000 CTPP JTW (Journey to work) zone-to-zone travel flows as an input to the mode choice model. One direct inference is that there are no visible socioeconomic variables in the model structure as they are latently reflected in the trip tables.
- There is only one calibrated model (one set of coefficients) implemented in the software, based on data collected from 15 metro areas and 24 fixed-guideway transit systems in the nation. Some effort of calibration is needed to apply the model to local data.
- The mode choice model follows a conventional nested structure and takes into account level-of-service variables for different modes and service types. This requires both highway skims and transit level of service information.
- The Highway data includes OD distances and travel times. STOPS does not directly process information on highway attributes and instead relies on estimates of zone-to-zone highway travel times and distances obtained from regional travel forecasting model sets maintained by Metropolitan Planning Organizations (MPOs). Since MPO models might not still use the same geographic zone system used in the CTPP, STOPS includes a procedure to convert MPO geography to CTPP geography.
- Transit supply: STOPS does not use coded networks. Instead, it takes advantage of a recent advance in on-line schedule data—the General Transit Feed Specification (GTFS). This data format is a commonly-used format for organizing transit data so that on-line mapping programs can help customers find the optimal paths (times, routes, and stop locations) for their trips. STOPS includes a program known as GTFPath that generates the shortest path between every combination of regional origin and destination. This path is used for estimating travel times (as an input to mode choice) and for assigning transit trips (an output of mode choice) to routes and stations.

In comparison to TBEST, STOPS provides aggregate zonal results rather than detailed boarding measures for individual routes/stops. The final outcomes are zonal transit productions and attractions, as well as origin-destination matrices for transit trips. Considering that STOPS is based on a mode choice model, it is capable of capturing the impacts of highway network performance (reliability, toll, congestion level, etc.) on the demand for Express bus service.

## 4.3. Integrated (simultaneous) Demand-Supply Model

The underlying assumption for integrated models is that transit ridership and level of service have mutual feedback effects on one another. In other words, while transit ridership is affected by level of service attributes (e.g. headway, frequency, work hours, amenities, etc.), it is also reasonable to assume that transit ridership on the route will impose changes on the level of service decisions (e.g. total hourly route capacity). Theoretically, this is referred to as the endogeneity (simultaneity) effect, where specific variables are used on both sides (dependent and independent) of the equations.

In general, integrated demand supply models mainly consist of two core equations:

- Demand equation: This is a route/stop level demand model (similar to TBEST). The dependent variable is usually number of boarding in a particular stop on the route of interest and the explanatory variables include socioeconomics, demographics, and certain instances of supply attributes on the route of interest (such as capacity, headway, etc.).
- Supply equation: The supply variable used on the right-hand side of the demand model is now shifted to the left-hand side (as the dependent variable) and is explained by a number of socio-demographic variables, transit ridership, and other stop/route attributes.

The major advantage of integrated demand-supply models is that they provide estimates of key supply attributes (i.e. frequency, headway, or total number of seats) needed to serve the demand.

## 4.4. Incremental Logit Model

An incremental logit model is a modified version of conventional logit models which can be used to predict changes in behavior on the basis of existing choice probabilities of the alternatives plus changes in the independent variables (*4*, *5*). The incremental form of logit models is:

$$S_i^f = S_i \times \frac{\exp(\Delta u_i)}{\sum_j [S_j \times \exp(\Delta u_j)]}$$

Where,

$S_i$ = Base-year observed probability of using mode i from choice set m

$S_i^f$ = Forecast year share of using mode I

$\Delta u_i$ = Change in utility of mode i = $\Delta Constant + \beta_k \times \Delta VAR_{ik}$

$\beta_k$ = Coefficient for attribute k

$\Delta VAR_{ik}$ = Difference in numeric variable $VAR_k$ of alternative i

It is assumed that the difference between unmeasured attributes (represented through the constant value) is negligible in the base and future year, i.e. $\Delta Constant = 0$. Hence, the changes in utilities only pertain to measured attributes such as travel time and cost. In a nested logit structure, the differences in the logsum value could be calculated as follows:

$$\Delta logsum^m = \ln\left\{\ln\sum_i \exp(u_i + \Delta u_i)\right\} - \ln\left\{\ln\sum_i \exp(u_i)\right\} = \left[\frac{\sum_i \exp(u_i + \Delta u_i)}{\sum_i \exp(u_i)}\right]$$
$$= \ln[\sum_i (S_i \times \exp(u_i))]$$

Where,

$\Delta logsum^m$ = Difference in logsum term for mode m in the upper level of the nested structure.

The major advantage of incremental logit models is that they directly account for the changes in the transportation system and their corresponding impacts on the ridership. There is no need to address all variables in the model, instead, only those variables that have changed are taken into account. Based on existing regional mode choice models, and estimated changes in the core variables (travel time, cost, etc.), mode shifts can be estimated.

## 4.5. Recommended Approach

Considering the service features of Express buses, and the capabilities of existing tools, the recommended approach will utilize multiple methods as illustrated in Figure 3.

Essentially this approach incorporates the benefits of mode choice model (to account for the influence of highway network performance) and TBEST (to provide stop level estimates for detailed service planning). At corridor level, the potential demand between identified high-demand OD pairs will be estimated first. Both STOPS and other forms of mode choice models (regional travel demand models or incremental logit models) will be evaluated for the suitability for this task. The demand for the express route will serve as a reference total for TBEST stop level estimation. Service attributes could be developed through multiple alternatives/scenarios as TBEST usually works. Alternatively, integrated modeling approach may be another potential approach that can be explored for future enhancement.

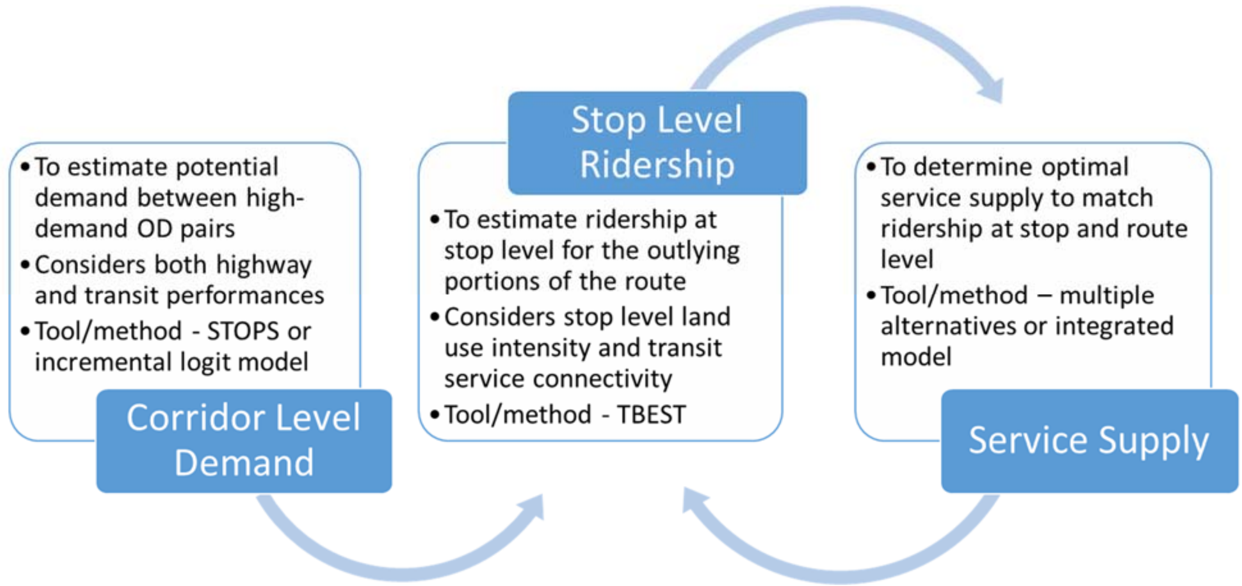



**Figure 3 Recommended approach for express bus ridership forecasting.**

The next chapter will describe the case study using 95 Express to evaluate the feasibility of the procedures in the recommended approach. Scenario analysis are conducted and performance measures are calculated to compare productivity and efficiency between the scenarios to support service planning purposes.

# 5. CASE STUDY

95 Express service was chosen for this case study. 95 Express service is a 27-mile (27.3 Northbound, 26.1 Southbound) route traverse Miami-Dade and Broward Counties. The route provides direct express service from downtown Fort Lauderdale to downtown Miami. This route serves seven stops, including: Broward Blvd Park and Ride, Fort Lauderdale Tri-Rail Station within the Broward county boundaries and, NW 8 St & 1 Ave, NW 1 Ave @ NW 5 St, NW 1 Ave @ NW 1 St, SW 1 St @ SW 1 Ave, SE 1 St & 1 Ave. in the Miami-Dade County. The service operates on weekdays during the peak hours and night. Figure 4 illustrates the detailed route map.

The detailed service characteristics are summarized in Table 1.

**Table 1 95 Express Current Service Characteristics.**

| | | Stop Name | Location | Arrivals | Headway | Stop Type |
|---|---|---|---|---|---|---|
| Route 195 Southbound 154486 | AM Peak | FORTLAUT | Broward Blvd Park & Ride | 12 | 15 | PARK-n-RIDE |
| | | FTL21TRS | Ft Lauderdale Tri-Rail Station | | | Regular Stop |
| | | D#8S#1V5 | NW 8 St. & 1 Ave | | | Regular Stop |
| | | D1AV##54 | NW 1 AV@NW5 St (S/F) | | | Regular Stop |
| | | NW1S1AVS | NW 1 AV @ NW 1 ST | | | Regular Stop |
| | | SW1S1AVX | SW 1 ST @ SW 1 AV | | | Regular Stop |
| | | SE1S1AVS | SE 1 ST & 1 AVE | | | Regular Stop |
| Route 195 Southbound 154485 | PM Peak | FORTLAUT | Broward Blvd Park & Ride | 6 | 20 | PARK-n-RIDE |
| | | FTL21TRS | Ft Lauderdale Tri-Rail Station | | | Regular Stop |
| | | D#8S#2V5 | NW 8 St. & 2 Ave | | | Regular Stop |
| | | D#8S#1V5 | NW 8 St. & 1 Ave | | | Regular Stop |
| Route 195 Northbound 154487 | AM Peak | SE1S1AVS | SE 1 ST & 1 AVE | 7 | 25 | Regular Stop |
| | | FTL21TRN | Ft Lauderdale Tri-Rail Station | | | Regular Stop |
| | | FORTLAUT | Broward Blvd Park & Ride | | | PARK-n-RIDE |
| Route 195 Northbound 154488 | PM Peak | D#8S#1V5 | NW 8 St. & 1 Ave | 9 | 20 | Regular Stop |
| | | D1AV##54 | NW 1 AV@NW5 St (S/F) | | | Regular Stop |
| | | NW1S1AVS | NW 1 AV @ NW 1 ST | | | Regular Stop |
| | | SW1S1AVX | SW 1 ST @ SW 1 AV | | | Regular Stop |
| | | SE1S1AVS | SW 1 ST @ SW 1 AV | | | Regular Stop |
| | | FTL21TRN | Ft Lauderdale Tri-Rail Station | | | Regular Stop |
| | | FORTLAUT | Broward Blvd Park & Ride | | | PARK-n-RIDE |
| | Night | D#8S#1V5 | NW 8 St. & 1 Ave | 4 | 30 | Regular Stop |
| | | D1AV##54 | NW 1 AV@NW5 St (S/F) | | | Regular Stop |
| | | NW1S1AVS | NW 1 AV @ NW 1 ST | | | Regular Stop |
| | | SW1S1AVX | SW 1 ST @ SW 1 AV | | | Regular Stop |
| | | SE1S1AVS | SW 1 ST @ SW 1 AV | | | Regular Stop |
| | | FTL21TRN | Ft Lauderdale Tri-Rail Station | | | Regular Stop |
| | | FORTLAUT | Broward Blvd Park & Ride | | | PARK-n-RIDE |

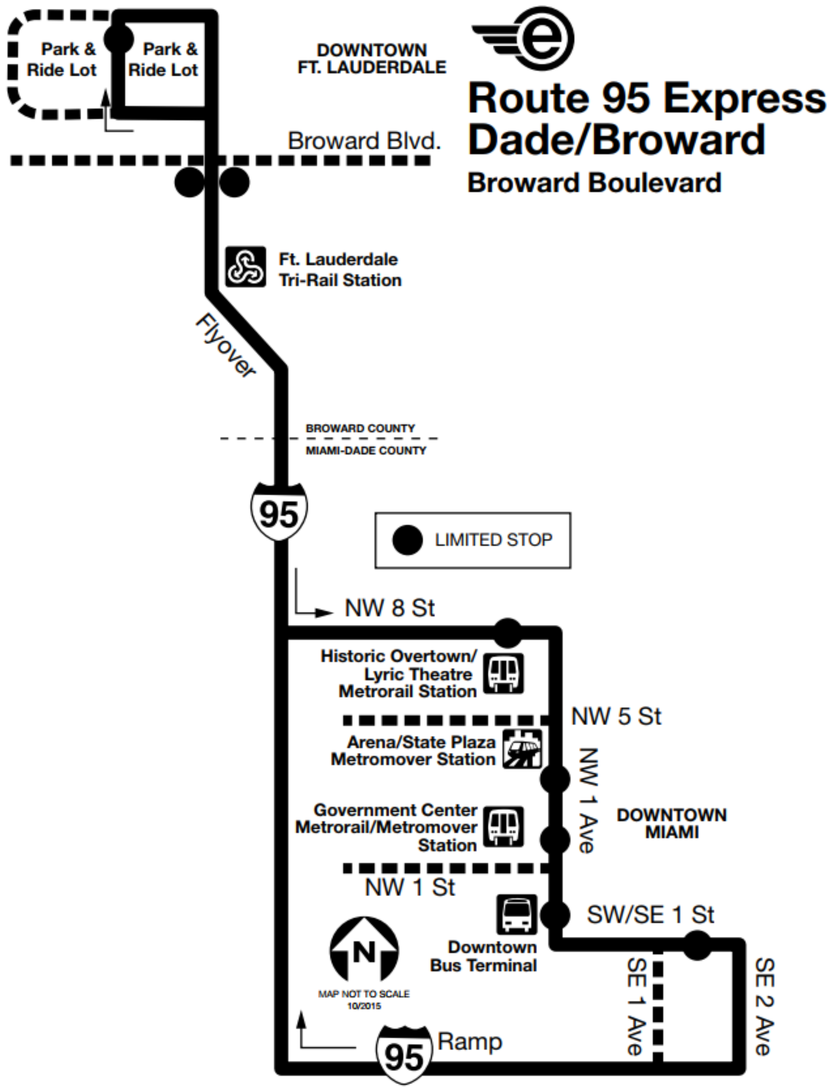



**Figure 4** **95 Express detailed route (Miami-Dade Transit, 2017).**

Based on the latest GTFS file released on 15 November 2017, provided by the Miami-Dade Transit, 95 express (route 195) provides 38 arrival services a day on weekdays for AM peak, PM peak and night hours. The available fleet size which is consisted of 6 buses for AM peak, and 7 buses for PM peak and night hours can provide an average capacity of 1520 passengers per day for the route. The Park-n-Ride facility located near the Broward Blvd station provides 794 parking spaces.

## 5.1. Route Level Estimate

### 5.1.1. STOPS

STOPS is designed to estimate ridership of transit projects. Its core function is a nested logit mode choice model that predicts the share of transit trips between any two zones, given the total travel demand between any zone pairs based on CTPP Journey to Work (JTW) data, highway skims obtained from regional travel demand models, and transit network characteristics derived from the General Transit Feed Specification (GTFS).

The nested logit model considers three hierarchies of modes: transit and non-transit at the first level; access mode (i.e., walk, kiss-n-ride, and park-n-ride) at the second level; and facility type (i.e., fixed guideway only, fixed guideway and bus, and bus only) at the third level. The core utility function for mode share estimation considers in-vehicle time, walk access time, initial wait time, transfer wait time, and transfer penalty. Generic coefficients were adopted for all service types, except that a 0.8 factor was applied for fixed guideway services. Two groups of constants were applied to account for the influence of vehicle ownership, trip purpose, access mode, and facility type.

As reflected in the utility function, the primary determinants of mode share were travel times or skims for both highway and transit modes. The highway skims were directly obtained from the regional travel demand model, while the transit skims were derived using GTFPath based on GTFS data. Service attributes that were considered in GTFS include stop locations, routing, time schedule for each stop and route, and park-n-ride information. These are all potential attributes that can be explored for service planning of new routes.

### 5.1.2. Model Setup

For this study, the Southeast Florida (SEFL) Regional STOPS model developed in 2016 by AECOM and Connetics Transportation Group (CTG) was adopted. The model covers Palm Beach, Broward, and Miami-Dade Counties. As part of this effort, the team developed a user interface to automate the preparation of certain STOPS input files for any fixed-guideway transit project in the tri-county region. The model was calibrated to base year 2015, which had a total of 504,119 unlinked trips in the study area. The package provides all the required input files readily available, including the CTPP and census files, regional SED forecast files and highway skims, and GTFS files. Figure 5 provides a list of input files.

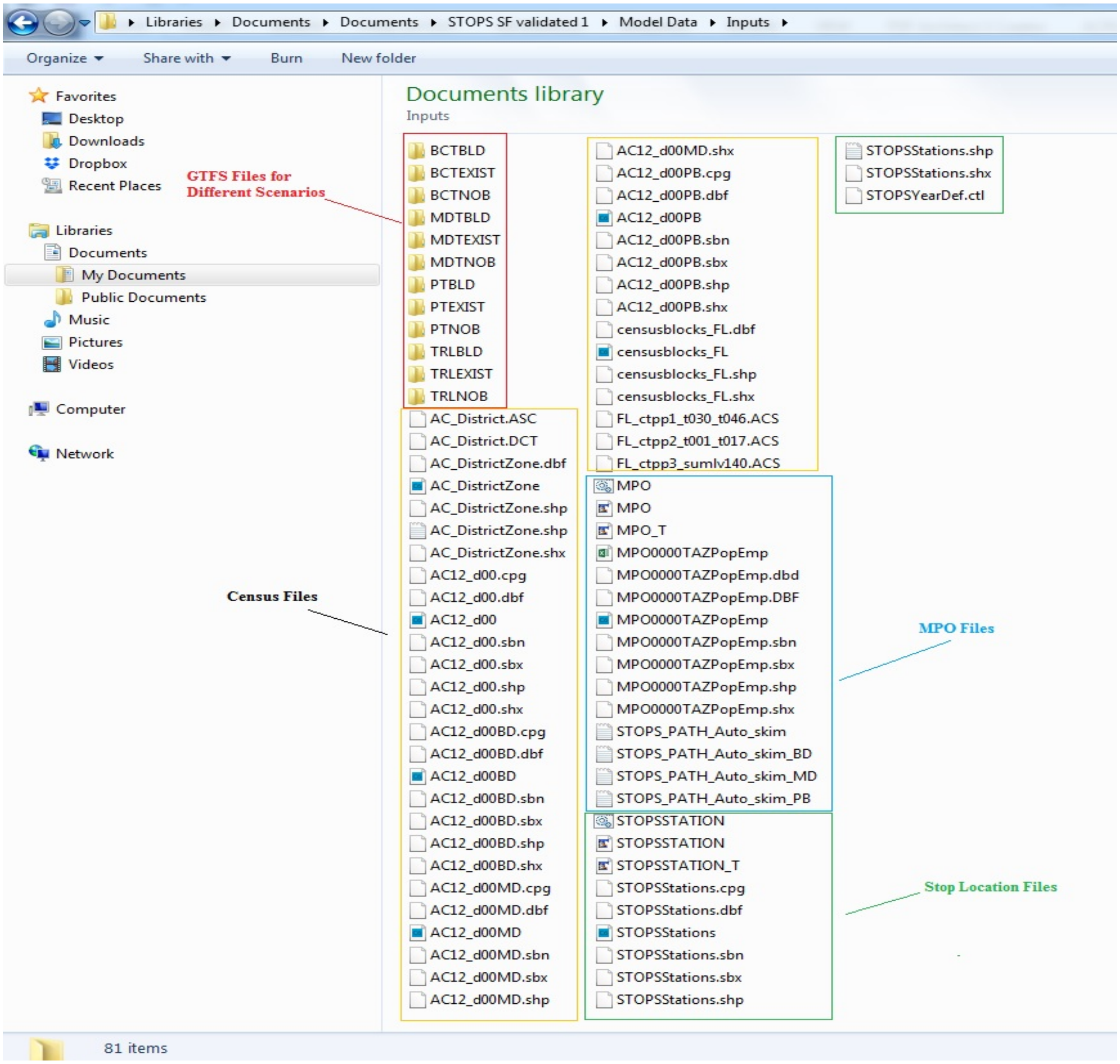



**Figure 5 Input files for STOPS.**

### 5.1.3. Ridership Estimation

Since the 95 Express is already in service for base year 2015, it is considered as the Build scenario. A No-Build scenario is created by removing the 95 Express through the GTFS Editor. The model output is presented in Table 2 below.

The Build scenario estimated a total ridership of 1,287, which is fairly close to the actual ridership of 1,168. Comparison between the Build and No-Build scenarios showed that of the 1,287 ridership, 799 are new transit users, about 62%, shifted from non-transit mode, and 488 are attracted from other existing transit services.

## Table 2 STOPS Model Outputs

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Program STOPS - FTA Simplified Trips-on-Project<br>Software Version: STOPS-v2.00 - 02/06/2016<br>Run: Regional STOPS Model<br>System: RSTOPS Study<br>Table 10.01<br>***** AVG WEEKDAY ROUTE UTILIZATION ************<br>Comparison of Route Boardings by Scenario<br>Total Transit Trips | | | | | | | | | | |
| | | Y2015 Build (existing) | | | | Y2015 No Build (95 Express removed) | | | | Diff. |
| | | ======= | ====== | ====== | ====== | ===== | ====== | ====== | ====== | |
| Route_ID | #NAME? | WLK | KNR | PNR | ALL | WLK | KNR | PNR | ALL | |
| ======= | =================== | ====== | ====== | ====== | ====== | ====== | ====== | ====== | ====== | |
| 10 | P--31-Wpb X-Town Via 45th | 857 | 58 | 111 | 1,026 | 857 | 59 | 111 | 1,026 | 0 |
| 11 | P--33-Lkp -Wpb Via Australn/pbl | 1,051 | 76 | 130 | 1,257 | 1,051 | 76 | 130 | 1,257 | 0 |
| 12 | P--40-Wpb - Blg Via Sr-80 [ltd | 478 | 75 | 98 | 651 | 478 | 75 | 98 | 651 | 0 |
| . | . | . | . | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . | . | . | . |
| 15262 | M--150-MIAMI BEACH AIRPORT FLYE | 1,419 | 154 | 378 | 1,951 | 1,421 | 155 | 380 | 1,956 | -5 |
| 15263 | M--183-NW 87 AV/186 ST- AVENTUR | 3,295 | 171 | 131 | 3,597 | 3,295 | 171 | 131 | 3,597 | 0 |
| 15264 | M--195-I-95 DADE-BROWARD EXPRES | 555 | 164 | 567 | 1,287 | 0 | 0 | 0 | 0 | 1,287 |
| 15265 | M--200-CUTLER BAY LOCAL | 40 | 2 | 2 | 44 | 40 | 2 | 2 | 44 | 0 |
| 15266 | M--202-LITTLE HAITI CONNECTION | 484 | 5 | 7 | 495 | 484 | 5 | 7 | 495 | 0 |
| 15267 | M--204-KILLIAN KAT | 910 | 38 | 51 | 999 | 911 | 39 | 51 | 1,001 | -2 |
| . | . | . | . | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . | . | . | . |
| BCT88 | B--88 | 1,531 | 69 | 19 | 1,619 | 1,530 | 69 | 19 | 1,618 | 1 |
| tri-rail | T--Tri-Rail-Tri-Rail | 6,542 | 2,678 | 4,995 | 14,215 | 6,629 | 2,716 | 5,076 | 14,420 | -205 |
| Total | | 418,962 | 30,955 | 49,577 | 499,495 | 418,456 | 30,903 | 49,338 | 498,696 | 799 |

## 5.2. Stop Level Estimate

### 5.2.1. TBEST

Transit Boardings Estimation and Simulation Tool (TBEST) represents an effort to develop a multi-faceted GIS-based modeling, planning and analysis tool which integrates socioeconomic, land use, and transit network data into a unique platform for scenario-based transit ridership estimation and analysis. Originally developed to support the ridership estimation requirement for Florida transit agencies within their strategic Transit Development Plans (TDPs), TBEST has evolved to support a variety of complex transit planning tasks.

The distinguished feature of TBEST (compared to STOPS) is that it allows for detailed stop level ridership analysis by taking into account the socioeconomic and demographic attributes (population, employment, etc.) of the market within a certain buffer distance from each stop, service-related attributes (e.g. headways, number of arrivals, amenities, etc.), as well as the potential transfer of riders from adjacent stops. SED attributes are obtained from the readily available parcel data which can be downloaded for the state of Florida within the TBEST user interface. Similar to STOPS, TBEST also uses the General Transit Feeds System (GTFS) files to access routes and service attributes.

In view of model structure, TBEST is similar to a trip generation model which estimates transit ridership at stop level. Total boardings at each stop is estimated through a negative binomial count model based on two sets of independent variables: population and employment characteristics within the buffer area surrounding a stop, and service attributes. Table 3 shows the coefficent values of the independent variables. Unlike STOPS, TBEST does not consider a modal split model and therefore does not take into account competing modes' attributes such as highway skims.

In addition to these model coefficients, TBEST uses a set of control parameters including Capacity, Impedance Distance Decay, Market Area, Network Build and Technology Adjustments. These parameters could be modified for each scenario to evaluate their impact on the estimated ridership. In this study, we explore the influence of bus capacity and market capture distance which will be further elaborated in the next sections.

**Table 3 Direct Boardings Model for I-95 Express Route**

| Parameters | Time period 1 (AM Peak) | Time period 3 (PM Peak) | Time period 4 (Night) |
|---|---|---|---|
| Bus Constant | -6.492 | -6.805 | -6.772 |
| Route Type | - | 0.198 | - |
| Park-n-Ride | - | 2.516 | NA |
| Parking Spaces at Park-n-Ride (Express) | 0.204 | - | - |
| Log of Arrivals (Bus) | 0.35 | 0.35 | 0.2 |
| Decrease transferability towards the end of route (Bus) | -2.156 | -1.643 | -2.613 |
| Log of O2 Trips Total | 0.348 | 0.372 | 0.396 |
| Log of Origin Buffer Trips | - | 0.261 | NA |
| Dwelling Unit Density | 1572 | 1971 | NA |
| Black Population (%) (Bus) | 1.445 | 0.604 | 1.061 |
| Hispanic Population (%) (Bus) | 0.49 | - | NA |
| Zero Vehicle Households (Bus) | 1.134 | 1.098 | 1.519 |
| Share of Service Employment | 1.313 | 1.83 | 2.134 |
| Share of Commercial Employment | 1.994 | 1.913 | 3.032 |
| Log of Buffer Total Population and Employment | 0.479 | - | 0.462 |

### 5.2.2. Model Setup

For the purpose of this study we use the latest version of TBEST (4.4), which was developed and upgraded by the State of Florida Department of Transportation (FDOT) in 2016. The software is available for download at www.tbest.org.

We use the latest update on the socioeconomic data package that includes the 2014 American Community Survey 5-Year Estimates, the 2014 InfoUSA Employment data, and the 2015 Florida Department of Revenue Parcel-level Land Use. The software also employs the TBEST 2016 Land use model with default control parameter values (including bus capacity = 40 seats, a market capture buffer distance of 0.25 mile, etc.) and default service level attributes (i.e. no changes implied in headways, number of arrivals, park-n-ride parking capacities, etc.). Furthermore, in order to comply with STOPS results, the model is run for year 2015 (i.e. no growth rates are set).

TBEST provides a user friendly graphical interface which interoperates with ESRI ArcGIS software. The unit of analysis in TBEST is a transit system, which comprises its extent (i.e., what counties are included), parcel data, and imported routes from the GTFS files. Within the software environment, the user can easily manipulate any of the socio-demographics, route-level attributes, stop-level characteristics, or transit service patterns in order to evaluate different scenarios (Figure 6).

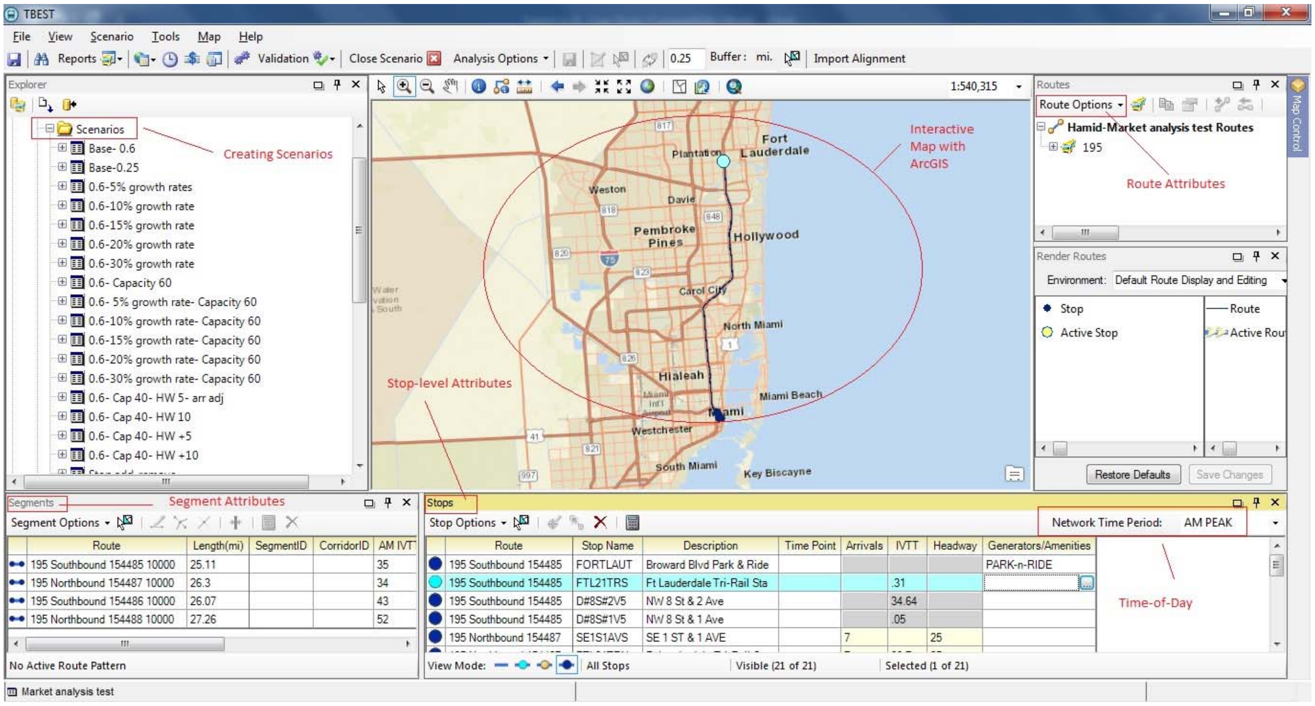



**Figure 6 TBEST software environment.**

### 5.2.3. Ridership Estimation

Similarly, the base year condition of 2015 is considered as the Build scenario. TBEST provides an estimation of 828 direct boardings for 95 Express (Figure 7). This estimate is much lower than the STOPS estimation as well as the actual ridership. This is probably because TBEST is best suited for capturing local transit market, considering the 0.25 mile buffer size for transit access. Given the larger market expected from commuter rails, trains and express services, the buffer size needs to be increased to reflect the attractiveness of express services and the access distance that passengers are willing to take. Accordingly, a buffer distance of 0.6 miles results in a boarding of 1290, which is fairly close to the control total measure from STOPS (Table 4).

TBEST Report

## Scenario Report

### Transit Stop Summary

**Transit System:** Hamid
**Scenario:** Base-0.25
**Time Period:** Weekday
**Report Date/Time:** 4/21/2018 12:09:59 PM

| Pattern | Stop | Inbound Transfer Opportunities | Outbound Transfer Opportunities | Direct Boardings | Transfer Boardings | Total Boardings |
|---|---|---|---|---|---|---|
| 195 Southbound 154485 | FORTLAUT | 0 | 0 | 39.06 | 0 | 39.06 |
| 195 Southbound 154485 | FTL21TRS | 0 | 0 | 1.92 | 0 | 1.92 |
| 195 Southbound 154485 | D#8S#2V5 | 0 | 0 | 3.4 | 0 | 3.4 |
| 195 Southbound 154485 | D#8S#1V5 | 0 | 0 | 0 | 0 | 0 |
| 195 Northbound 154487 | SE1S1AVS | 0 | 0 | 19.99 | 0 | 19.99 |
| 195 Northbound 154487 | FTL21TRN | 0 | 0 | 0.17 | 0 | 0.17 |
| 195 Northbound 154487 | FORTLAUT | 0 | 0 | 0 | 0 | 0 |
| 195 Southbound 154486 | FORTLAUT | 0 | 0 | 480 | 0 | 480 |
| 195 Southbound 154486 | FTL21TRS | 0 | 0 | 9.33 | 0 | 9.33 |
| 195 Southbound 154486 | D#8S#1V5 | 0 | 0 | 15.15 | 0 | 15.15 |
| 195 Southbound 154486 | D1AV##54 | 0 | 0 | 6.68 | 0 | 6.68 |
| 195 Southbound 154486 | NW1S1AVS | 0 | 0 | 8.22 | 0 | 8.22 |
| 195 Southbound 154486 | SW1S1AVX | 0 | 0 | 2.44 | 0 | 2.44 |
| 195 Southbound 154486 | SE1S1AVS | 0 | 0 | 0 | 0 | 0 |
| 195 Northbound 154488 | D#8S#1V5 | 0 | 0 | 95.09 | 0 | 95.09 |
| 195 Northbound 154488 | D1AV##54 | 0 | 0 | 51.91 | 0 | 51.91 |
| 195 Northbound 154488 | NW1S1AVS | 0 | 0 | 58.96 | 0 | 58.96 |
| 195 Northbound 154488 | SW1S1AVX | 0 | 0 | 25.84 | 0 | 25.84 |
| 195 Northbound 154488 | SE1S1AVS | 0 | 0 | 10.83 | 0 | 10.83 |
| 195 Northbound 154488 | FTL21TRN | 0 | 0 | 0.21 | 0 | 0.21 |
| 195 Northbound 154488 | FORTLAUT | 0 | 0 | 0 | 0 | 0 |
| **Total Stops** | | **0** | **0** | **829.2** | **0** | **829.2** |

**Figure 7** **TBEST model results with a buffer distance of 0.25 miles.**

**Table 4 Comparison of Ridership under Different Buffer Distances**

**Scenario Report**
**Transit Stop Summary**

| | |
|---|---|
| Transit System: | Hamid |
| Scenario: | Buffer distance impacts |
| Time Period: | Weekday |
| Report Date/Time: | 4/21/2018 12:21:59 PM |

| Pattern | Stop | Total Boardings (Buffer= 0.3 miles) | Total Boardings (Buffer=0.4 miles) | Total Boardings (Buffer = 0.5 miles) | Total Boardings (Buffer = 0.6 miles) |
|---|---|---|---|---|---|
| 195 Southbound 154485 | FORTLAUT | 46.93 | 68.09 | 93.26 | 121.55 |
| 195 Southbound 154485 | FTL21TRS | 2.84 | 4.52 | 6.26 | 8.38 |
| 195 Southbound 154485 | D#8S#2V5 | 4.31 | 5.68 | 7.04 | 8.14 |
| 195 Southbound 154485 | D#8S#1V5 | 0 | 0 | 0 | 0 |
| 195 Northbound 154487 | SE1S1AVS | 28.62 | 42.16 | 52.76 | 62.22 |
| 195 Northbound 154487 | FTL21TRN | 0.3 | 0.58 | 0.94 | 1.35 |
| 195 Northbound 154487 | FORTLAUT | 0 | 0 | 0 | 0 |
| 195 Southbound 154486 | FORTLAUT | 480 | 480 | 480 | 480 |
| 195 Southbound 154486 | FTL21TRS | 15.38 | 27.1 | 38.78 | 51.75 |
| 195 Southbound 154486 | D#8S#1V5 | 16.09 | 21.18 | 24.75 | 27.44 |
| 195 Southbound 154486 | D1AV##54 | 9.06 | 11.82 | 16.67 | 20.51 |
| 195 Southbound 154486 | NW1S1AVS | 7.31 | 9.32 | 13.27 | 16.79 |
| 195 Southbound 154486 | SW1S1AVX | 5.66 | 8.42 | 11.31 | 15.65 |
| 195 Southbound 154486 | SE1S1AVS | 0 | 0 | 0 | 0 |
| 195 Northbound 154488 | D#8S#1V5 | 98.34 | 123.95 | 143.06 | 160.17 |
| 195 Northbound 154488 | D1AV##54 | 66.26 | 82.79 | 109.12 | 128.33 |
| 195 Northbound 154488 | NW1S1AVS | 55.81 | 68.26 | 86.67 | 100.68 |
| 195 Northbound 154488 | SW1S1AVX | 44.71 | 57.76 | 69.52 | 72.09 |
| 195 Northbound 154488 | SE1S1AVS | 14.34 | 18.94 | 22.63 | 15.9 |
| 195 Northbound 154488 | FTL21TRN | 0.34 | 0.61 | 0.94 | 1.31 |
| 195 Northbound 154488 | FORTLAUT | 0 | 0 | 0 | 0 |
| Total Stops | | 896.3 | 1031.2 | 1177 | 1292.3 |

TBEST also provides a full market analysis for the study area. This procedure allows the user to analyze the share of different land use types in generating transit trips or to conduct a full analysis of socioeconomic and demographic attributes of the market.

Figure 8 shows the geographic view of the land use within the buffers, for the production end (Broward park-n-Ride) and the attraction end (Miami-Dade downtown) based on two different buffer distances of 0.25 and 0.6 miles.

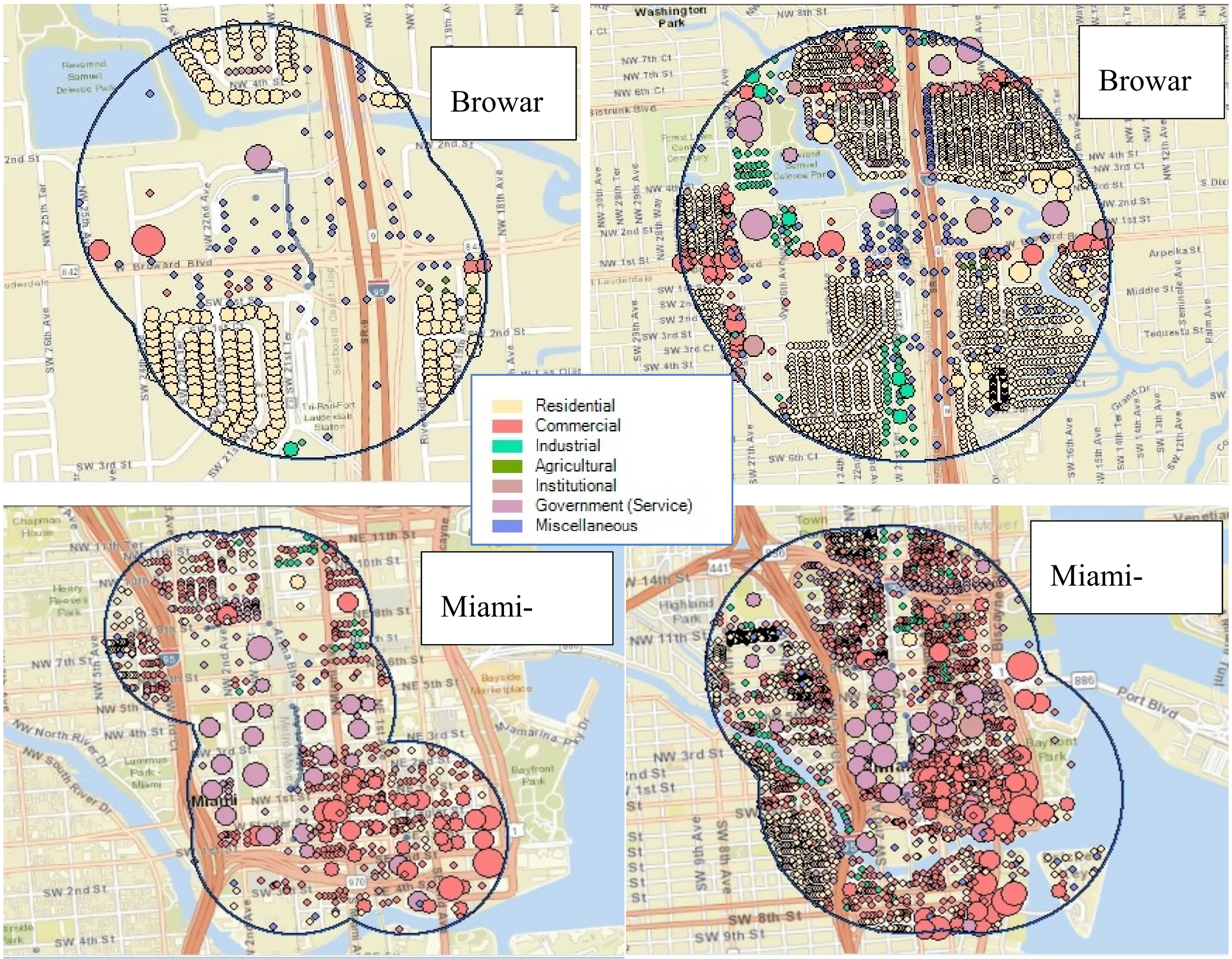



**Figure 8** Geographical view of land use distribution.

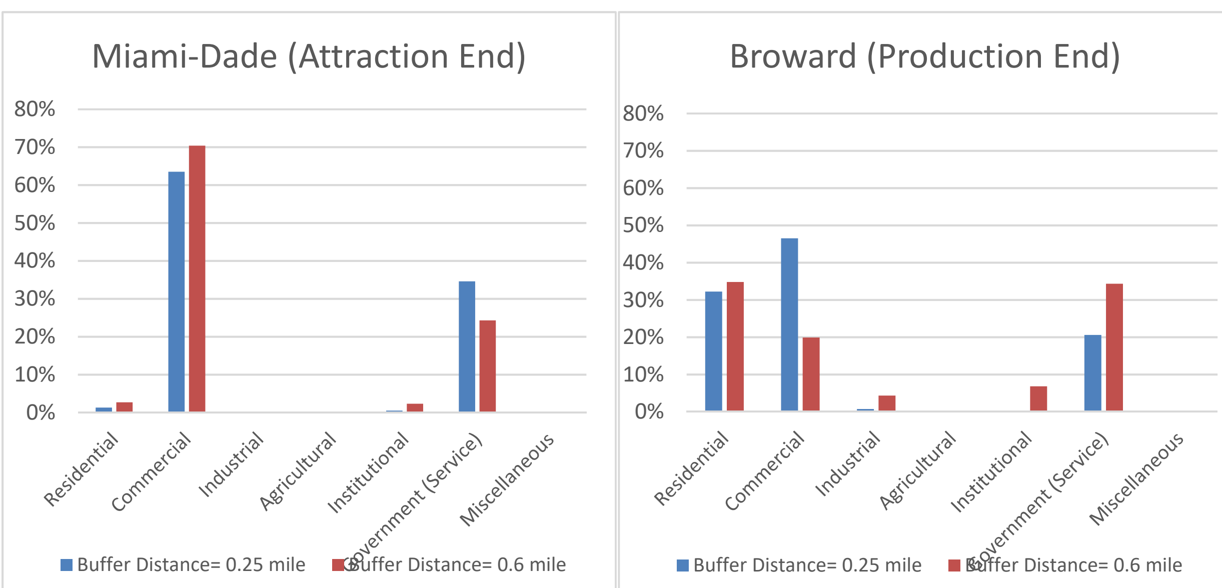



**Figure 9** Land use distribution for production and attraction ends.

On the trip production end, a significant share of land use is residential as shown in Figure 9, which is reasonable. As expected, the trip attraction end is dominated by commercial and government land use. When the buffer distance increases, there is a slight increase in residential land use share on the Broward end.

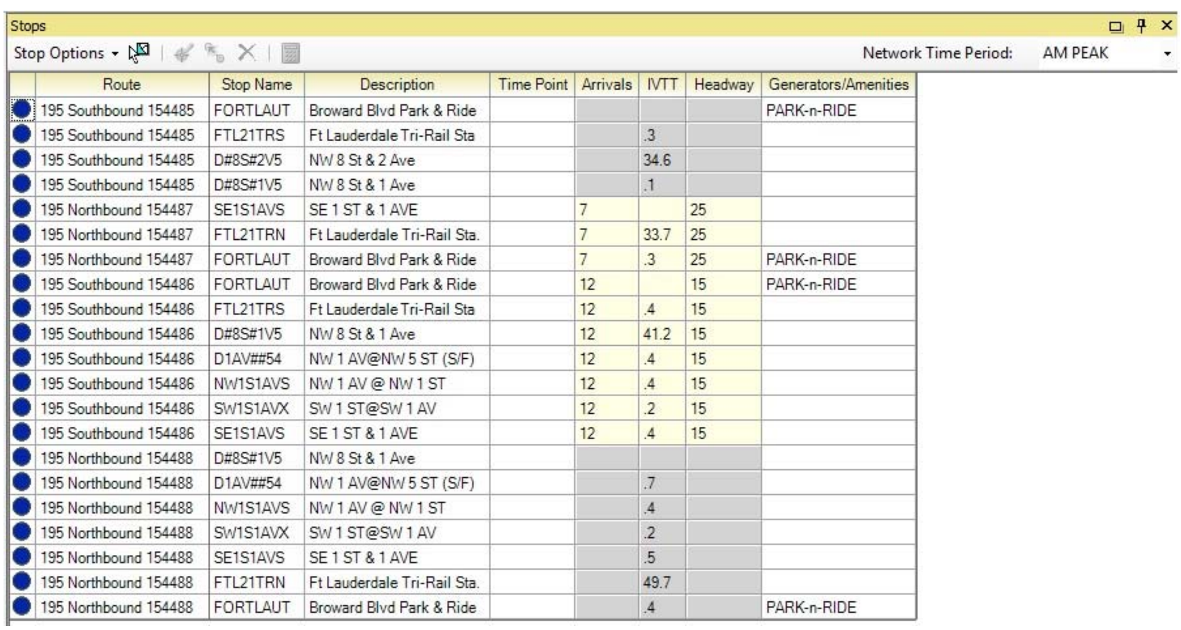
In view of the market for the express bus service, we mainly focus on the demographic characteristics of the trip production end. When buffer distance increases to 0.6 miles, the market captures relatively higher shares of minority population (especially African Americans), females, seniors, low-income households, and zero-vehicle households. These factors all have implications on the potential of using transit services.

### 5.2.4. Service Attribute Scenarios

To explore the capabilities of TBEST, a few scenarios were developed, mainly focusing on service attribute changes, including headways, capacity, and park-n-ride, etc. We also explored the effects of adding or removing a stop from the route, to conduct a full comparison analysis.

#### 5.2.4.1. Headways

Headways can be manipulated using the stops attributes window under different scenarios in the TBEST user interface (Figure 10). The stops attributes window allows modification of several attributes including description, number of arrivals, headways, in-vehicle travel time between two adjacent stops (IVTT), and types of amenities available at the stop location.




| Route | Stop Name | Description | Time Point | Arrivals | IVTT | Headway | Generators/Amenities |
|---|---|---|---|---|---|---|---|
| 195 Southbound 154485 | FORTLAUT | Broward Blvd Park & Ride | | | | | PARK-n-RIDE |
| 195 Southbound 154485 | FTL21TRS | Ft Lauderdale Tri-Rail Sta | | | .3 | | |
| 195 Southbound 154485 | D#8S#2V5 | NW 8 St & 2 Ave | | | 34.6 | | |
| 195 Southbound 154485 | D#8S#1V5 | NW 8 St & 1 Ave | | | .1 | | |
| 195 Northbound 154487 | SE1S1AVS | SE 1 ST & 1 AVE | | 7 | | 25 | |
| 195 Northbound 154487 | FTL21TRN | Ft Lauderdale Tri-Rail Sta. | | 7 | 33.7 | 25 | |
| 195 Northbound 154487 | FORTLAUT | Broward Blvd Park & Ride | | 7 | .3 | 25 | PARK-n-RIDE |
| 195 Southbound 154486 | FORTLAUT | Broward Blvd Park & Ride | | 12 | | 15 | PARK-n-RIDE |
| 195 Southbound 154486 | FTL21TRS | Ft Lauderdale Tri-Rail Sta | | 12 | .4 | 15 | |
| 195 Southbound 154486 | D#8S#1V5 | NW 8 St & 1 Ave | | 12 | 41.2 | 15 | |
| 195 Southbound 154486 | D1AV##54 | NW 1 AV@NW 5 ST (S/F) | | 12 | .4 | 15 | |
| 195 Southbound 154486 | NW1S1AVS | NW 1 AV @ NW 1 ST | | 12 | .4 | 15 | |
| 195 Southbound 154486 | SW1S1AVX | SW 1 ST@SW 1 AV | | 12 | .2 | 15 | |
| 195 Southbound 154486 | SE1S1AVS | SE 1 ST & 1 AVE | | 12 | .4 | 15 | |
| 195 Northbound 154488 | D#8S#1V5 | NW 8 St & 1 Ave | | | | | |
| 195 Northbound 154488 | D1AV##54 | NW 1 AV@NW 5 ST (S/F) | | | .7 | | |
| 195 Northbound 154488 | NW1S1AVS | NW 1 AV @ NW 1 ST | | | .4 | | |
| 195 Northbound 154488 | SW1S1AVX | SW 1 ST@SW 1 AV | | | .2 | | |
| 195 Northbound 154488 | SE1S1AVS | SE 1 ST & 1 AVE | | | .5 | | |
| 195 Northbound 154488 | FTL21TRN | Ft Lauderdale Tri-Rail Sta. | | | 49.7 | | |
| 195 Northbound 154488 | FORTLAUT | Broward Blvd Park & Ride | | | .4 | | PARK-n-RIDE |

**Figure 10 Modification of stop attributes in TBEST.**

Headways are systematically changed by 5-minute intervals to evaluate the impact of headway changes on ridership attraction. It should be noticed that TBEST preserves a fixed time span for service hours. In other words, by reducing/increasing the headways, the software automatically and proportionally adjusts the number of arrivals to fully cover the whole service hour period. Results for headway changes are illustrated in Figure 11. As expected, there is a negative association between headway intervals and ridership, however, the magnitudes of ridership elasticities are somewhat different in the two directions. Accordingly, increasing the headway by 5 and 10 minutes decreases ridership by 18% and 28%, respectively. On the other hand, decreasing the headway by 10 minutes will result in a drastic increase of approximately 96% in the ridership. This might indicate that there is a latent potential for using the express service route along I-95; however, the realization of this potential is highly dependent on improvements in the level of service offered by the express service.

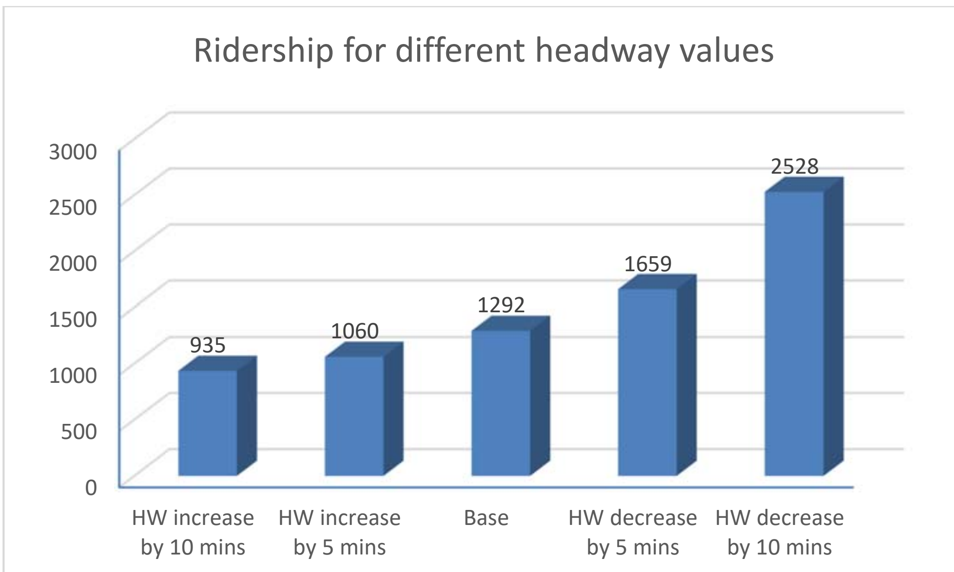



**Figure 11 Ridership estimate for different headway values.**

#### 5.2.4.2. **Capacity**

One important parameter in TBEST model structure is the ridership capacity. Capacity refers to the number of seats available in an individual bus. The capacity acts as an upper-limit constraint on the number of boardings. In other words, if the total number of boardings in a specific stop exceeds the total capacity (i.e., number of arrivals multiplied by maximum number of seats available), the software automatically restrains the boarding to the maximum available capacity (Figure 12).

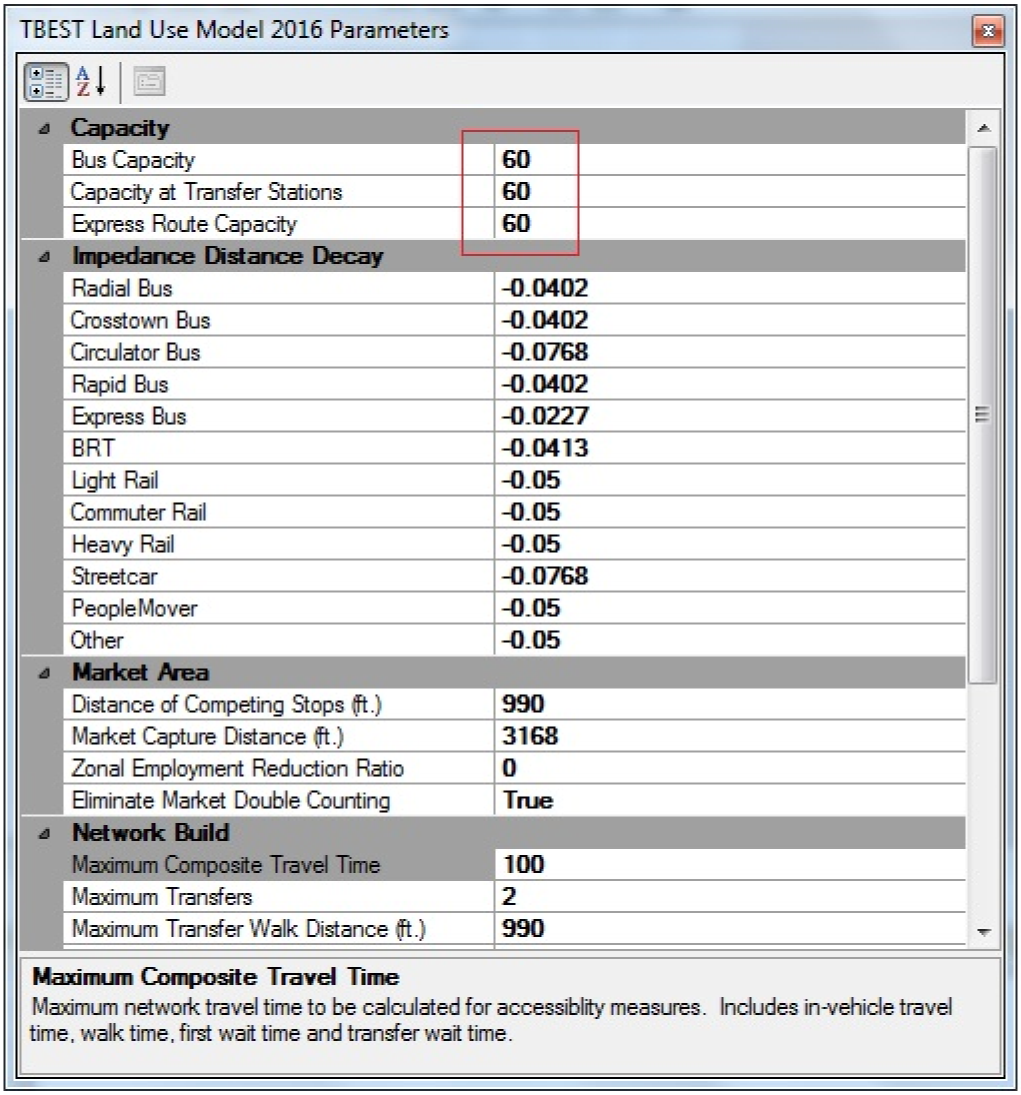



**Figure 12 TBEST model parameters.**

By default, TBEST considers a regular capacity of 40 seats per bus. To evaluate the impacts of capacity on express ridership, we manually changed the capacity to 60 seats per bus and re-ran the model (Figure 13). Results show that increasing the capacity from 40 to 60 will increase daily ridership by 266.

TBEST Report

## Scenario Report

### Transit Stop Summary

**Transit System:** Hamid

**Scenario:** 0.6- Capacity 60

**Time Period:** Weekday

**Report Date/Time:** 4/21/2018 1:21:01 PM

| Pattern | Stop | Inbound Transfer Opportunities | Outbound Transfer Opportunities | Direct Boardings | Transfer Boardings | Total Boardings |
|---|---|---|---|---|---|---|
| 195 Southbound 154485 | FORTLAUT | 0 | 0 | 121.55 | 0 | 121.55 |
| 195 Southbound 154485 | FTL21TRS | 0 | 0 | 8.38 | 0 | 8.38 |
| 195 Southbound 154485 | D#8S#2V5 | 0 | 0 | 8.14 | 0 | 8.14 |
| 195 Southbound 154485 | D#8S#1V5 | 0 | 0 | 0 | 0 | 0 |
| 195 Northbound 154487 | SE1S1AVS | 0 | 0 | 62.22 | 0 | 62.22 |
| 195 Northbound 154487 | FTL21TRN | 0 | 0 | 1.35 | 0 | 1.35 |
| 195 Northbound 154487 | FORTLAUT | 0 | 0 | 0 | 0 | 0 |
| 195 Southbound 154486 | FORTLAUT | 0 | 0 | 720 | 0 | 720 |
| 195 Southbound 154486 | FTL21TRS | 0 | 0 | 51.75 | 0 | 51.75 |
| 195 Southbound 154486 | D#8S#1V5 | 0 | 0 | 27.44 | 0 | 27.44 |
| 195 Southbound 154486 | D1AV##54 | 0 | 0 | 20.51 | 0 | 20.51 |
| 195 Southbound 154486 | NW1S1AVS | 0 | 0 | 16.79 | 0 | 16.79 |
| 195 Southbound 154486 | SW1S1AVX | 0 | 0 | 15.65 | 0 | 15.65 |
| 195 Southbound 154486 | SE1S1AVS | 0 | 0 | 0 | 0 | 0 |
| 195 Northbound 154488 | D#8S#1V5 | 0 | 0 | 160.17 | 0 | 160.17 |
| 195 Northbound 154488 | D1AV##54 | 0 | 0 | 128.33 | 0 | 128.33 |
| 195 Northbound 154488 | NW1S1AVS | 0 | 0 | 100.68 | 0 | 100.68 |
| 195 Northbound 154488 | SW1S1AVX | 0 | 0 | 87.66 | 0 | 87.66 |
| 195 Northbound 154488 | SE1S1AVS | 0 | 0 | 26.15 | 0 | 26.15 |
| 195 Northbound 154488 | FTL21TRN | 0 | 0 | 1.31 | 0 | 1.31 |
| 195 Northbound 154488 | FORTLAUT | 0 | 0 | 0 | 0 | 0 |
| **Total Stops** | | **0** | **0** | **1558.1** | **0** | **1558.1** |

**Figure 13 Ridership estimation output with capacity of 60.**

Similar to the previous section, we also considered the role of headways in transit ridership with a capacity of 60 seats per bus. The combined capacity and headway results are presented in Figure 11. Results show that when service levels are improved by increasing the capacity and decreasing the headways, ridership can be increased by almost 56% and 150% respectively. Increasing the capacity to 60 and increasing the headway by 5 minutes results in the same level of ridership as the base scenario.

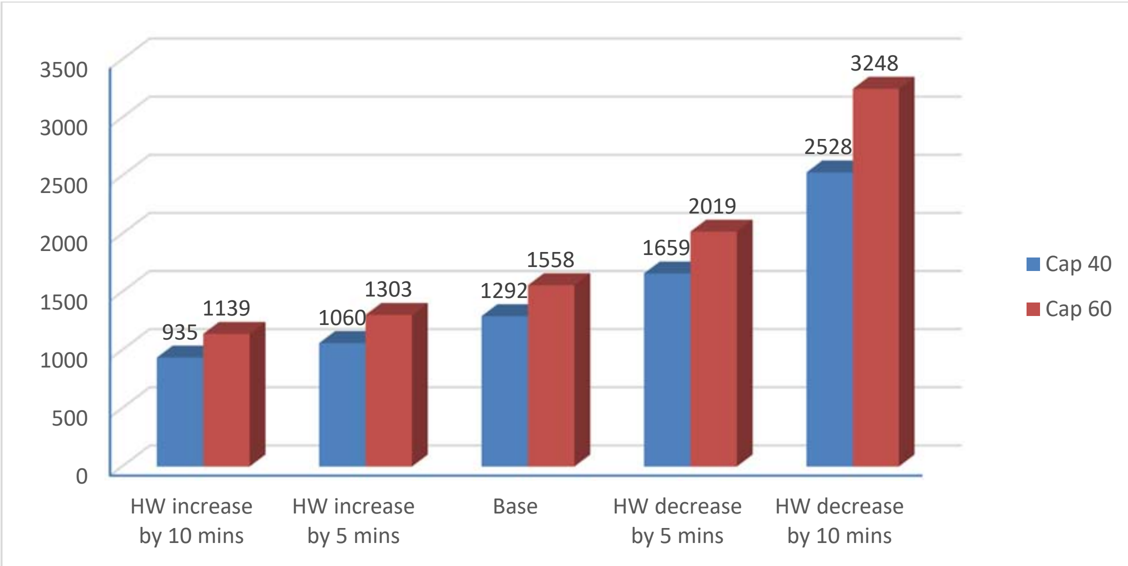



**Figure 14 Combined impacts of capacity and headway.**

#### 5.2.4.3. Park-n-Ride

Park-n-Ride has two different impacts on the model. 1) The presence of Park-n-Ride at a specific stop through a binary (0 and 1) variable, and 2) the parking capacity of the Park-n-Ride facility. Results show that parking capacity even at small values (> 15) will result in a huge increase in the number of direct boardings (e.g. by $10^{10}$ ) and therefore is limited by the total ridership capacity, i.e. number of arrivals multiplied by bus seating capacity, as shown in Figure 12. Therefore, changes in the Park-n-Ride parking capacity will not impact the ridership unless it is accompanied by increases in bus capacities.

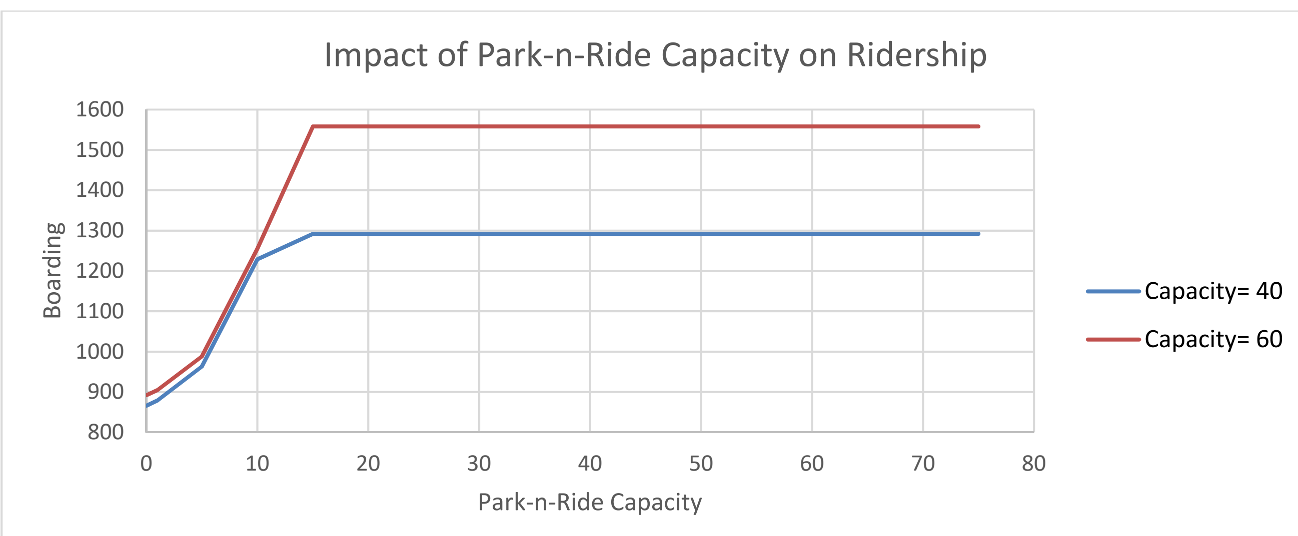



**Figure 15 Park-n-Ride capacity impacts on ridership.**

#### 5.2.4.4. Stop Allocation

In this section we explore the effects of adding/removing a stop on the total ridership and the redistribution of transit boarding within adjacent stops. For this purpose, we remove the stop coded as D1AV##54 located at NW 1 AV@NW5 St. The base scenario shows that this stop was operating during AM peak hours in southbound with a boarding of 20.51 and in northbound during the PM peak hours with a boarding of 128.33. Table 5 shows that when the stop is removed from the route, the total daily ridership decreases by approximately 70. Considering that this stop serves about 149 daily boarding in the base scenario, around 47% (79 passengers) of the original boarding are redistributed to adjacent stops along the route, while around 53% are lost to other alternative modes or routes.

**Table 5 Ridership Comparison for Removing a Stop**

**Scenario Report**

**Transit Stop Summary**

**Transit System:** Hamid
**Scenario:** Base- 0.6 vs. Stop Removed
**Time Period:** Weekday
**Report Date/Time:** 4/26/2018 2:22:08 PM

| Pattern | Stop | Total Boarding with the stop | Total Boarding w/o the stop |
|---|---|---|---|
| 195 Southbound 154485 | FORTLAUT | 121.55 | 121.55 |
| 195 Southbound 154485 | FTL21TRS | 8.38 | 8.38 |
| 195 Southbound 154485 | D#8S#2V5 | 8.14 | 8.14 |
| 195 Southbound 154485 | D#8S#1V5 | 0 | 0 |
| 195 Northbound 154487 | SE1S1AVS | 62.22 | 62.22 |
| 195 Northbound 154487 | FTL21TRN | 1.35 | 1.35 |
| 195 Northbound 154487 | FORTLAUT | 0 | 0 |
| 195 Southbound 154486 | FORTLAUT | 480 | 480 |
| 195 Southbound 154486 | FTL21TRS | 51.75 | 52.2 |
| 195 Southbound 154486 | D#8S#1V5 | 27.44 | 31.65 |
| 195 Southbound 154486 | D1AV##54 | 20.51 | Removed |
| 195 Southbound 154486 | NW1S1AVS | 16.79 | 19.72 |
| 195 Southbound 154486 | SW1S1AVX | 15.65 | 17.97 |
| 195 Southbound 154486 | SE1S1AVS | 0 | 0 |
| 195 Northbound 154488 | D#8S#1V5 | 160.17 | 175.98 |
| 195 Northbound 154488 | D1AV##54 | 128.33 | Removed |
| 195 Northbound 154488 | NW1S1AVS | 100.68 | 115.79 |
| 195 Northbound 154488 | SW1S1AVX | 72.09 | 98.4 |
| 195 Northbound 154488 | SE1S1AVS | 15.9 | 27.56 |
| 195 Northbound 154488 | FTL21TRN | 1.31 | 1.31 |
| 195 Northbound 154488 | FORTLAUT | 0 | 0 |
| **Total Stops** | | **1292.3** | **1222.2** |

### 5.2.5. Scenario Analysis

This section puts an effort to illustrate how the ridership analysis can provide inputs to transit service planning, through comparing the cost and revenue for different scenarios.

From a general point of view, transit project costs include capital (fixed) costs and operational/maintenance (variable) costs. Capital costs mainly covers the infrastructure, e.g. buses, stations, stops, buildings, and rolling stock, etc. Variable costs are comprised by driver wages, fuel costs, maintenance and operation, etc. The literature indicates several approaches to estimate variable costs. The methods either focus on cost per unit of service revenue hours, service revenue miles, or a combination of both (FAMPO 2007, Corradino 2008, TMSR 2009, AVTA 2012, APTA 2016, TCRP 78 2012).

Literature shows that the average total cost per unite of service revenue hours ranges from $85 to $130 in different projects. Most of the literature agrees to a total cost per service revenue miles of $10-11. Some other methods use combinations of service revenue hours and miles. It is assumed that a portion of the variable costs, including driver salaries and wages, and fringe benefits, etc. are better estimated on an hourly basis while some other costs such as services, materials and supplies, fuel, utilities and liabilities are more accurately estimated thorough a mileage basis. Table 6 below presents the detailed estimates of different types of costs that was applied in this analysis.

**Table 6 Transit System Unit Costs Derived from APTA 2016 Report**

| Capital Costs | |
|---|---|
| Park-n-ride | $ 10 M |
| Stops/amenities/facilities ($/unit) | $ 10k-12k |
| 40-foot Bus ($/vehicle) | $ 300k-500k |
| 60-foot bus ($/vehicle) | $ 700k-900k |
| Maintenance Facility | $ 1 M |
| **Operational Costs** | |
| Costs per hour | |
| Driver salary and wages ($/service hour) | $ 47.9 |
| Fringe benefits ($/service hours) | $ 35.9 |
| Purchased Transportation ($/service hours) | $ 13.09 |
| other ($/service hour) | $ 1.77 |
| Total ($/service hour) | $ 98.66 |
| Costs per mile | |
| Services ($/service mile) | $ 0.67 |
| Materials and supplies ($/service mile) | $ 1.4 |
| Utilities ($/service mile) | $ 0.127 |
| Casualty and liabilities ($/service mile) | $ 0.265 |
| Total ($/service mile) | $ 2.462 |

Table 7 shows the service and cost comparison between five different scenarios. Net present values (NPV) are calculated based on an interest rate of 5% and a project life span of 15 years. The first set of cost estimation is derived considering separate hourly cost and mileage cost components as shown in Table 6. The second set are obtained from TBEST estimated performance measures in productivity and efficiency.

It shows that scenario 3 is able to attract the highest ridership by decreasing the headway by 5 minutes, but also imposes the highest costs, which leads to the lowest fare recovery rate and highest operating cost per passenger trip among all five scenarios. On the other hand, scenario 4, by using a 60-seat bus with less service frequency, serves the same level of ridership as the base scenario, but requires much less operating cost, which yields the highest fare recovery rate and lowest operating cost per passenger trip.

**Table 7 Cost Analysis for Different Scenarios**

| | **Scenario** | **1- Base** | **2- 5 min HW Increase** | **3- 5 min HW Decrease** | **4- CAP 60- 5 min HW Increase** | **5- One Stop Removed** |
|---|---|---|---|---|---|---|
| TBEST Output | Fleet Size | 40-foot 5 buses | 40-foot 4 buses | 40-foot 5 buses | 60-foot 5 buses | 40-foot 5 buses |
| | Daily Revenue Service Miles | 999.50 | 788.96 | 1367.00 | 788.96 | 999.50 |
| | Daily Revenue Service Hours | 27.30 | 21.42 | 37.40 | 21.42 | 27.30 |
| | **Daily Ridership** | **1,292** | **1,060** | **1,659** | **1,303** | **1,222** |
| Cost Estimation | Capital Cost ($M) | $13.56 | $13.06 | $14.06 | $14.26 | $13.05 |
| | Annual Operating Hourly Cost ($M) | $0.81 | $0.63 | $1.10 | $0.63 | $0.81 |
| | Annual Operating Mileage Cost ($M) | $0.64 | $0.50 | $0.87 | $0.50 | $0.64 |
| | Total Annual Operation Cost ($M) | $1.44 | $1.14 | $1.98 | $1.14 | $1.44 |
| | Total Annual Revenue ($M) | $0.89 | $0.73 | $0.94 | $0.90 | $0.84 |
| | 15-Year Operating Cost NPV ($M) | $14.99 | $11.80 | $20.53 | $11.80 | $14.99 |
| | 15-Year Fare Revenue NPV ($M) | $9.24 | $7.58 | $9.78 | $9.32 | $8.74 |
| | **Fare Recovery Rate** | **0.616** | **0.643** | **0.476** | **0.790** | **0.583** |
| | *TBEST Performance Measure* | | | | | |
| Service Characteristics | Estimated Annual Service Miles | 259,858 | 205,033 | 355,411 | 205,033 | 259,858 |
| | Average System Speed | 32 | 32 | 32 | 32 | 32 |
| | Average System Headway | 50 | 49 | 50 | 49 | 50 |
| Productivity | Estimated Annual Ridership | 335,988 | 275,558 | 431,343 | 338,868 | 317,778 |
| | Boardings Per Service Mile | 1.3 | 1.3 | 1.2 | 1.7 | 1.2 |
| | Boardings Per Service Hour | 41.1 | 43.0 | 38.6 | 52.9 | 38.9 |
| Efficiency | Estimated Operating Cost ($M) | $1.44 | $1.14 | $1.98 | $1.14 | $1.44 |
| | **Operating Cost Per Service Mile** | **$5.6** | **$5.5** | **$5.6** | **$5.5** | **$5.6** |
| | **Operating Cost Per Passg. Trip** | **$4.3** | **$4.1** | **$4.6** | **$3.4** | **$4.5** |

In view of scenario 5, removing a stop from the route results in a lower level of ridership and less capital cost, with no changes in operating cost. This is one limitation of TBEST as it does not directly consider absolute layover times in each stop and therefore, removing a stop will not affect travel times and service hours. Ideally, less stops would be accompanied by less dwelling time and less operating cost.

This case study demonstrates the approach in estimating ridership for express bus services, utilizing existing tools and combining their strengths in different aspects. Both tools are well accepted and utilized by the transit community, and provide user friendly package. STOPS is able to consider the competitiveness between highway and transit modes, while TBEST provides detailed considerations at stop and route level that enables detailed scenario analysis. The proposed approach that combines STOPS and TBEST, serves the purpose well on estimating ridership for express buses from two main perspectives: 1) it is able to estimate the mode shift due to the introduction of express bus services, in terms of how many new transit users are being attracted; and 2) it provides sufficient level of details to support scenario analysis that can facilitate the decision-making in transit service planning, based on the capital and operating costs involved with alternative service plans.

Beyond supporting transit service planning decisions, it also provides the opportunity to incorporate transit considerations into EL programs, by enabling the estimation of mode shift and associated congestion and emission benefits.

# 6. CONCLUSIONS

Express bus service is a type of fixed-route service designed to connect commuters from suburban areas to urban centers with high travel speed and level-of-service. Utilizing available express lanes, it boasts quicker travel times which lenses itself time-competitive with automobile trips. In addition to alleviating congestion, express bus service can provide a community with an alternative means of maximizing employment and educational opportunities for its citizens.

Considering the significant benefits that transit service could bring in contributing to the overall project goals in reducing congestion, enhancing system performance, improving environmental, economic and social concerns, this project aims to provide a standard approach that enables the incorporation of transit service goals and benefit considerations into EL programs.

A scan of existing literature and practices in ridership forecasting reveals that although regional travel demand models provide a robust and holistic view of travel choices based on system attributes, generally they are not geared toward transit planning and service analysis. Consequently, local transit agencies are more likely to employ models at finer scales, such as route-level, stop-level, or segment-level ridership estimation. These tools would provide user-friendly features that allow the transit agencies to explore and analyze various strategies and scenarios in transit service planning and operations. Among the existing tools, TBEST and STOPS present great potentials.

A planning framework is developed for express bus service planning within the EL context. The framework considers several aspects including the analysis needs of the agency, the advantages and disadvantages of various forecasting methodologies, the data requirements, the user features needed for transit operation and planning analysis, and performance measures, etc. The framework has five major components, including stakeholder involvement, transit market assessment, ridership forecasts, benefit-cost analysis, and service monitoring and evaluation. The technical approach and key elements in each component are further discussed. This framework does not intend to be comprehensive in transit service planning and design, but rather serves a general guideline when considering transit services with EL programs.

Comparing with conventional bus services, especially local buses, Express bus intends to provide services that are time-competitive with auto modes rather than other transit services. For this reason, the proposed ridership forecasting method utilizes both STOPS and TBEST. Essentially it incorporates the benefits of STOPS, to account for the influence of highway network performance, and TBEST, to provide detailed considerations at stop and route level that enables detailed scenario analysis.

This method is demonstrated through the case study based on the 95 Express service. At corridor level, the potential demand between identified high-demand OD pairs is estimated using STOPS, which provides close value as the actual ridership. Then the route level serves a reference total for TBEST to identify the appropriate market size. Based on the updated market size, service attributes are explored in TBEST through multiple scenarios, which show expected results and effects on ridership. Given the service characteristics of multiple scenarios, revenue and cost analysis are further conducted for alternative evaluation and further service planning considerations.

The proposed approach that combines STOPS and TBEST, serves the purpose well on estimating ridership for express buses from two main perspectives: 1) it is able to estimate the mode shift due to the introduction of express bus services, in terms of how many new transit users are being attracted; and 2) it provides sufficient level of details to support scenario analysis that can facilitate the decision-making in transit service planning, based on the capital and operating costs involved with alternative service plans. Beyond supporting transit service planning decisions, it also provides the opportunity to incorporate transit considerations into EL programs, by enabling the estimation of mode shift and associated congestion and emission benefits.

This research provides FDOT with a feasible and reliable method to estimate express bus service ridership, which are essential to facilitate the assessment of investment decisions for transit services to be provided in conjunction with EL projects, and to maximize project benefits and system efficiency through both highway and transit alternatives.

# REFERENCES


Abdel-Aty, M.A., 2001. "Using ordered probit modeling to study the effect of ATIS on transit ridership". Transportation Research Part C: Emerging Technologies 9 (4), 265–277.

American Public Transportation Association (APTA), 2010. "Bus Rapid Transit Service Design". APTA Standards Development Program, APTA BTS-BRT-RP-004-10.

American Public Transportation Association (APTA), 2014. "2014 Public Transportation Fact Book", 65th Edition, Published by American Public Transportation Association, November 2014.

American Public Transportation Association (APTA), 2017. "2016 Public Transportation Fact Book", 67th Edition, Published by American Public Transportation Association, February 2017.

Antelope Valley Transit Authority, 2012. "AVTA Business Plan FY 2013". Antelope Valley Transit Authority Board of Directors, Approved April 27, 2012

Azar, K. and J. Ferreira, 1995. "Integrating Geographic Information Systems into Transit Ridership Forecast Models". Journal of Advanced Transportation, Vol. 29, No. 3, pp. 263-279.

Batchelder, J. et al., 1983. "Bus Route Planning Models: Final Report," prepared for the U.S. Department of Transportation, Urban Mass Transportation Administration and Transportation Systems Center by Multiplications, Inc., Contract/Grant No. DOT TSC-1756.

Belz, N.P., G. R. Patil, and L. Aultman-Hall, 2010. "Spatial Models for the Statewide Evaluation of Transit-Supportive Zones". The 89th Annual Meeting of the Transportation Research Board, Paper No. 10-2118, Washington., D.C., January 2010.

Ben-Akiva, M. and T. Morikawa, 2002. "Comparing ridership attraction of rail and bus". Transport Policy 9 (2), 107–116.

Blum, J. J., A. Sridhar and T. V. Mathew, 2010. "Origin–Destination Matrix Generation from Boarding–Alighting and Household Survey Data". Transportation Research Record, 2183: 1–8.

Bresson, G., J. Dargay, J.-L. Madre and A. Pirotte, 2003. “The main determinants of the demand for public transport: a comparative analysis of England and France using shrinkage estimators”. Transportation Research, Part A, 37 (2003), pp. 605-627

Button, K. J., M. Hardy, S. Doh, J. Yuan and X. Zhou, 2009. “Transit Forecasting Accuracy: Ridership Forecasts and Capital Cost Estimates”. Final Research Report, Research and Innovative Technology Administration, University Transportation Center Program, Transportation and Economic Development Center, George Mason University.

Cardozo, O.D., J. C. García-Palomares and J. Gutiérrez, 2012. “Application of geographically weighted regression to the direct forecasting of transit ridership at station-level”. Journal of Applied Geography 34 (2012), 548-558.

Cervero, R., J. Murakami and M. Miller, 2010. “Direct Ridership Model of Bus Rapid Transit in Los Angeles County, California”. Transportation Research Record: Journal of the Transportation Research Board, No. 2145, Washington D.C., pp. 1–7.

Chakrabarti, S., 2015. “The demand for reliable transit service: New evidence using stop level data from the Los Angeles Metro bus system”. Journal of Transport Geography, 48, pp.154-164.

Chakraborty, A. and S. Mishra, 2013. “Land Use and Transit Ridership Connections: Implications for State–Level Planning Agencies”. Land Use Policy 30, 458–469.

Chakraborty, A., S. Mishra and T. W. Count, 2012. “A Case for Increased State Role in Transit Planning: Analyzing Land Use and Transit Ridership Connections Using Scenarios”. The 91st Transportation Research Board Annual Meeting, Paper No. 12-3895, Washington, D.C.

Chen, Chun-Hung P and G. A. Naylor, 2011. “Development of a Mode Choice Model for Bus Rapid Transit in Santa Clara County, California”. Journal of Public Transportation, 14 (3): 41-62.

Chen, Z., 2010. “Analysis of factors affect high speed train ridership in the United States. The Acela express case study”. The 51st Annual Transportation Research Forum, Arlington, Virginia, March 11-13, 2010 207261, Transportation Research Forum.

Cheon, S. H., C. S. Kim and S. P. Hong, 2015. “An Empirical Analysis of Forecasting Light Rail Transit (LRT) Demand According to Realization of Land Development Projects for Residence in Korea”. Proceedings of 2015 International Conference on Innovations in Civil and Structural Engineering (ICICSE'15), Universal Researchers in Science and Technology, Istanbul (Turkey), June 3-4, 2015 pp. 258-263.

Chiang, W.C., Russell, R.A., Urban, T.L., 2011. Forecasting ridership for a metropolitan transit authority. Journal of Transportation Research Part A 45 (2011) 696–705.

Chow, L., F. Zhao, M. Li and X. Liu, 2005. "A Transit ridership model based on geographically weighted regression". Transportation Research Record: Journal of the Transportation Research Board, No. 1972, Transportation Research Board of the National Academies, Washington, D.C., 1972, pp. 105–114.

Chow, L. F., F. Zhao, X. Liu, M. Li and I. Ubaka, 2006. "Transit ridership model based on geographically weighted regression". Transport. Res. Rec. 105–114.

Chow, L. F., F. Zhao, H. Chi, and Z. Chen. 2010. "Sub-regional transit ridership models based on Geographically Weighted Regression". Transportation Research Board 89th Annual Meeting Compendium of Papers DVD, Washington, D.C.

Chu, X., 2004. "Ridership Models at the Stop Level". National Center of Transit Research, University of South Florida.

Corradino Group, Inc., 2008. "Hialeah Transit System Express bus Route and Enhanced Service". Submitted to the Hialeah Transit System.

Dargay, J and M. Hanly, 2002a. "The Demand for Local Bus Services in England". Journal of Transport Economics and Policy 36(1), 73-91.

Dargay, J and M. Hanly, 2002b. "Bus Patronage in Great Britain – Econometric Analysis". Transportation Research Record 1799, 97-106.

Dehghani, Y. and R. Harvey, 1994. "A Fully Incremental Model for Transit Forecasting: Seattle Experience". Transportation Research Board, Record # 1452, Washington D.C.

Dill, J., M. Schlossberg, L. Ma, and C. Meyer, 2013. "Predicting transit ridership at the stop level: The role of service and urban form". The 92nd Transportation Research Board Annual Meeting, Paper No. 13-4693, Washington, DC.

Duduta, N., 2013. "Direct Ridership Model of Mexico City's BRT and Metro Systems". Transportation Research Record: Journal of the Transportation Research Board, No. 2394. D.C., 2013, pp. 93–99.

Durning, M. and C. Townsend, 2015. "A Direct Ridership Model of Rail Rapid Transit in Canada". In Transportation Research Board 94th Annual Meeting (No. 15-5982).

Eash, R., K. Dallmeyer, and R. Cook, "Ridership Forecasting for Chicago Transit Authority's West Corridor Project," Transportation Research Record 1402, Transportation Research Board, National Research Council, Washington, D.C., 1993, pp. 40 – 42.

Estupiñán, N. and D. A. Rodríguez, 2008. "The relationship between urban form and station boardings for Bogota's BRT". Transportation Research Part A: Policy and Practice, 42(2), pp.296-306.

Florida Department of Transportation Freight, Logistics, and passenger Operations, 2016. "Guidebook for Florida STOPS Applications". Florida Department of Transportation, November 2016.

Frei, C. and H. S. Mahmassani, 2013. "Riding more frequently: Disaggregate ridership elasticity estimation for a large urban bus transit network". The 92nd Transportation Research Board Annual Meeting, Paper No. 13-3413, Washington, D.C.

Fredericksburg Area Metropolitan Planning Organization (FAMPO), 2007. "Framework for the Development of a George Washington Regional Transportation Authority (GWRTA)". George Washington Region Transit Policy Plan.

Furth, P. G. and H. N. M. Wilson, 1981. "Setting Frequencies on Bus Routes: Theory and Practice. Transportation Research Record, Journal of the Transportation Research Board, pp. 1-7.

Garcia-Ferrer, A., M. Bujosa, A. de Juan and P. Poncela, 2006. "Demand Forecast and Elasticities Estimation of Public Transport". Journal of Transport Economics and Policy, 40 (1), 45-67.

Gutiérrez, J., O. D. Cardozo and J. C. García-Palomares, 2011. "Transit ridership forecasting at station level: an approach based on distance-decay weighted regression". Journal of Transport Geography 19, 1081–1092.

Hazelton, M.L., 2010. "Statistical inference for transit system origin-destination matrices". Technometrics, 52(2), pp.221-230.

Hirsch, L.R., J. D. Jordan, R. L. Hickey and V. Cravo, 2000. "Effects of fare incentives on New York City Transit ridership". Transportation Research Record: Journal of the Transportation Research Board 1735 (-1), 147–157.

Horowitz, A. J., 1985. "Transit Ridership Forecasting Model: Reference Manual". Urban Mass Transportation Administration, U.S. Department of Transportation, Washington, D.C., 1985.

Horváth, B. 2012. "A Simple Method to Forecast Travel Demand in Urban Public Transport". Acta Polytechnica Hungarica, 9(4), 165–176.

Horváth, B., R. Horváth, and B. Gaál, 2014. “A new iterative method to estimate origin destination matrix in urban public transport”. In Proceedings of the Transport Research Arena Europe 2014, Paris, April 2014. Paris: IFSTTAR.

Hsu, Y. T., W. R. Lin, Y. C. R. Lai and T. C. T Kao, 2015. “Forecasting High Speed Rail Ridership Using Aggregate Data: A Case Revisit of High Speed Rail in Taiwan”. In Transportation Research Board 94th Annual Meeting (No. 15-4175).

Jones, M. 2013. “Spatial Analysis of Influences of Ridership on the Hiawatha Light Rail Transit System in the Minneapolis/St. Paul Metropolitan Area”. Volume 16, Papers in Resource Analysis. 12 pp.

Kain, J. F. and Z. Liu, 1999. “Secrets of success: assessing the large increases in transit ridership achieved by Houston and San Diego transit providers”. Transportation Research Part A: Policy and Practice 33 (7–8), 601–624.

Kerkman, K., K. Martens and H. Meurs, 2015. “Factors Influencing Stop Level Transit Ridership in the Arnhem Nijmegen City Region”. In Transportation Research Board 94th Annual Meeting (No. 15-2111).

Kikuchi, S. and D. Miljkovic, 2001. “Use of fuzzy inference for modeling prediction of transit ridership at individual stops”. Transportation Research Record: Journal of the Transportation Research Board, (1774), pp.25-35.

Koppelman, F., 1983. “Predicting Transit Ridership in Response to Transit Service Changes,” ASCE 109.

Kuby, M., A. Barranda and C., Upchurch, 2004. “Factors influencing light-rail station boardings in the United States”. Transportation Research Part A: Policy and Practice 38 (3), 223–247.

Lane, C., M. DiCarlantonio and L. Usvyat, 2006. “Sketch models to forecast commuter and light rail ridership: Update to TCRP report 16”. Presented at the 85th Transportation Research Board Annual meeting, Washington D.C.

Li, J., X. Ye and J. Ma, 2015. “Forecasting Method of Urban Rail Transit Ridership at Station-Level on the Basis of Back Propagation Neural Network”. In Transportation Research Board 94th Annual Meeting (No. 15-3012).

Li, Y. and M. J. Cassidy, 2007. “A generalized and efficient algorithm for estimating transit route ODs from passenger counts”. Transportation Research Part B: Methodological, 41(1), pp.114-125.

Ma, Z., J. Xing, M., Mesbah and L., Ferreira, 2014. "Predicting short-term bus passenger demand using a pattern hybrid approach". Transportation Research Part C: Emerging Technologies, Volume 39, Pages 148–163.

Miami-Dade County, Transportation and Public Works, Ridership Technical Report, Aug 2017.

Miami-Dade transit, Route details, Route 95 Express Broward Blvd. Accessed November 20, 2017. http://www.miamidade.gov/transit/routes_detail.asp?route=195

Miller, J., H. Goldstein and E. Seay, 2014. "An adaptation of the Incremental Logit Model for Forecasting Work Zone Diversion". Virginia Department of Transportation, Virginia center for Transportation Innovation and Research.

Mohammed, A., A. Shalaby and E. J. Miller, 2013. "Development of P-TRANE: GIS-Based Model of Bus Transit Network Evolution". Journal of Urban Planning and Development, 140(1), p.04013004.

Naesun, P., H. R. Yoon, and I. Hitoshi, 2003. "The feasibility study on the new transit system implementation to the congested area in Seoul". Journal of the Eastern Asia Society for Transportation Studies, 5.

National Cooperative Highway Research Program (NCHRP) Report 414. "HOV Systems Manual". Project G3-53 FY'95, National Academy Press, Wahington D.C. 1998.

National Cooperative Highway Research Program (NCHRP) Web-Only Document 86 (2006). "Estimating the Impacts of the Aging Population on Transit Ridership". Project number 20-65, DOI: 10.17226/22053.

Nelson D. O. and K. K., O'Neil, 1983, "Home-origin transit travel analysis model". Transportation Research Record 915, pp.24-30.

New York Department of Transportation, 2009. Transit Mode Selection Report (TMSR). Tappan Zee Bridge/I-287 Environmental Review.

Nickesen A., A. Meyburg, and M. Turnquist, 1983. "Ridership Estimation for Short-Range Transit Planning," Transportation Research B, v.17B, 1983.

Pendyala R. M, I. Ubaka and N. Sivaneswaran, 2002. "Geographic information system-based regional transit feasibility analysis and simulation tool". Transportation Research Record 1799: 42-49.

Peng, Zhongren, 1994. "A Simultaneous Route-level Transit Patronage Model: Demand, Supply, and Inter-route Relationship". Dissertations and Theses. Paper 1159.

Peng, Z, and J. K. Dueker, 1995. “Spatial data integration in route-level transit demand modeling”. Journal of the Urban and Regional Information Systems Association 7: 26–37

Peng, Z., Dueker, K.J., Strathman, J.G., Hopper, J., 1997. A simultaneous route-level transit patronage mode: demand, supply, and interroute relationship. Transportation 24, 159–181.

Peters, J., E. P. Han, S. Peeta, and D. DeLaurentis, 2014. “Analyzing the Potential for High-speed Rail as Part of the Multimodal Transportation System in the United States' Midwest Corridor”. International Journal of Transportation Science and Technology, 3(2), pp.129-148.

Preston, J., 1991. “Demand Forecasting for New Local Rail Stations and Services”. Journal of Transport Economics and Policy 25, 183-202.

Pulugurtha, Srinivas S. and M., Agurla, 2012. “Assessment of Models to Estimate Bus-Stop Level Transit Ridership using Spatial Modeling Methods”. Journal of Public Transportation, Vol. 15, No. 1.

Reich, S. L. and J. L. Davis, 2013. “Integrating Transit with Road Pricing Projects”. Final Report, Florida Department of Transportation. Prepared by USF center for Urban Transportation Research.

Resource Solutions Group (RSG), 2015. “STOPS: Simplified Trips-On-Project Software, User Guide version 1.5”. Prepared for the Federal Transit Administration.

Ryan, S. and L. F. Frank, 2009. “Pedestrian environments and transit ridership”. Journal of Public Transportation, 12(1), p.3.

P. Ryus, J. Ausman, D. Teaf, M. Cooper and M. Knoblauch. “Development of Florida's transit level-of-service indicator”. Transportation Research Record: Journal of the Transportation Research Board, 1731 (2000), pp. 123-129

Sanko, N., T. Morikawa, Y. Nagamatsu, 2013. “Post-project evaluation of travel demand forecasts: Implications from the case of a Japanese railway”. Journal of Transport Policy 27 (2013) 209–218.

South Florida Commuter Services. “Park & Ride Lots report”. Florida Department of Transportation (FDOT), Accessed November 20, 2017. http://www.1800234ride.com/static/sitefiles/files/Park_and_Ride_Lots.pdf

Washington State Department of Transportation (WSDOT), 2015. “Transit Ridership Forecasting Methodology Report”. Sound Transit (ST3) regional High-Capacity Transit System Plan.

Stopher, P.R., 1992. “Development of a route level patronage forecasting method”. Transportation, 19(3), pp.201-220.

Taylor, B., D. D. Miller, H., Iseki and C. Fink, 2004. “Analyzing the determinants of transit ridership using a two-stage least squares regression on a national sample of urbanized areas”. In: 83rd Annual Meeting of the Transportation Research Board, Washington, DC.

TBEST4.4 user guide, papered by Center for Urban Transportation Research (CUTR), November 2016.

Texas A & M Transportation Institute, 2012. System Modification Strategies, Express Bus Service, Executive Summary. Available at: http://mobility.tamu.edu/mip/strategies.php

Thompson, G.L. and J. R. Brown, 2006. “Explaining variation in transit ridership in US metropolitan areas between 1990 and 2000: multivariate analysis”. Transportation Research Record: Journal of the Transportation Research Board 1986 (-1), 172–181.

Transit Cooperative Research Program Report 78, 2002. “Estimating the Benefits and Costs of Public Transit Projects: A Guidebook for Practitioners”. Transportation Research Board, National Research Council.

Transitfeeds, Miami-Dade County Transit. Accessed November 20, 2017. https://transitfeeds.com/p/miami-dade-county-transit/48

The US Department of Transportation, Federal Highway Administration, 2011. “UPA/CRD Annual Report, Miami, FL I-95 Express Lanes”, FHWA-JPO-11-044. http://www.ops.fhwa.dot.gov/congestionpricing/docs/fhwajpo11044/

Tsai, Ch., C. Mulley and G. Clifton, 2013. “Forecasting public transport demand for the Sydney Greater Metropolitan Area: a comparison of univariate and multivariate methods”. Australasian Transport Research Forum 2013 Proceedings 2 - 4 October 2013, Brisbane, Australia.

Umlauf, T., L. D. Galicia, R. L. Cheu, T. Horak and S. Perez, 2015. "Ridership Estimation for an Existing Transit Corridor with New Bus Rapid Transit Service". In Transportation Research Board 94th Annual Meeting (No. 15-0139).

United State Department of Labor, Bureau of Labor Statistics, Miami Area Employment report, August 2017.

https://www.bls.gov/regions/southeast/news-release/areaemployment_miami.htm

Usvyat, L., L. Meckel, M. DiCarlantonio and C. Lane, 2009. "Sketch model to forecast heavy-rail ridership". In 88th Annual Meeting of the Transportation Research Board, Washington, DC.

Valley Transportation Authority, 2007. "Express bus Service Design Guidelines". VTA Transit Sustainability Policy.

Verbas, I. and H. Mahmassani, 2013. "Optimal allocation of service frequencies over transit network routes and time periods: formulation, solution and implementation using bus route patterns". Transportation Research Record 2334, 50–59.

Wang, J., 2011. "Appraisal of factors influencing public transport patronage", NZ Transport Agency Research Report No. 434. 176 PP.

Wang, Y., H. Su, X., Wang, F., Gao, P.H., Hsu, R., Zhou, F.E., Zhang, and Y. Yong, 2012. "Transit-Oriented Development Correlates of Rail Transit Ridership in Metropolis of Shanghai". In Transportation Research Board 91st Annual Meeting (No. 12-4298).

Wu, C. and A. T. Murray, 2005. "Optimizing public transit quality and system access: the multiple-route, maximal covering/shortest-path problem". Environment and Planning B: Planning and Design 32 (2), 163–178.

Yoh, A. C., P. J. Haas and B. D. Taylor, 2003. "Understanding transit ridership growth: case studies of successful transit systems in the 1990". Transportation Research Record: Journal of the Transportation Research Board 1835 (-1), 111–120.

Yun, M.P. and X. W. Liu, 2014. "Commuter Mode Choice Forecast Considering Bus Rapid Transit under Planning: A Case Study of Yichang, China". Paper presented at the Transportation Research Board 93rd Annual Meeting, Washington, DC.

Zhang, R. and R. Xiao, 2007. "Study on the demand forecast method for the inter-urban public transport under the high-speed railways in Shanghai-Nanjing corridor".

Presented at International Conference on Competition and Ownership in Land Passenger Transport, 10th, 2007, Hamilton Island, Queensland, Australia.

# APPENDIX A Summary of Ridership Forecasting Studies

Table 8 **Major Studies in Transit Ridership Forecasting**

| | Study | Service Type | Methodology | Independent Variables | Dependent Variable | Data Sources | Location of Study |
|---|---|---|---|---|---|---|---|
| 1 | Azar and Ferreira. 1995 | Bus | Ridership forecasting using GIS | • Length of the segment<br>• Population<br>• Number of employment<br>• Average speed of transit vehicles | A.M. and mid-day peak boarding | 1990 census data and 1990 TIGER line. | Boston, Massachusetts |
| 2 | Kikuchi and Miljkovic. 2001 | Bus | Ridership forecasting using fuzzy rule–based model | • Automobile ownership<br>• Number of households<br>• Average household income<br>• Bus stop condition<br>• Bus stop accessibility<br>• Commercial activities<br>• Quality of transit service | Daily ridership per station. (Passenger/station/day) | 1990 census data, Delaware DOT and Delaware Transit Corporation | Delaware, US |
| 3 | Chow et al. 2006 | Bus | Geographically weighted regression (GWR) model | • Land use and Accessibility<br>• Socioeconomic and demographic characteristic<br>• Transit level of service | Weekday boarding in each TAZ. | CTPP 2000 | Broward, Florida |
| 4 | Li et al. 2007 | Bus | OD matrix estimation based on boarding and alighting at stop-Level | • Boarding at each stop along the route. | Alightings count with probabilities | Unknown | Union, New Jersey |
| 5 | Ryan & Frank. 2009 | Bus | Regression model | • Transit level of service<br>• Built environment<br>• Socioeconomic | Daily boardings per station. (Passenger/station/day) | SANDAG Transit Passenger Counting Program, 2002. MTS service schedule. Land use shapefile 2003. Residential Acreage-SANDAG. | San Diego, California |
| 6 | Hazelton. 2010 | Bus | OD matrix estimation based on boarding and alighting at stop-Level | • Number of passengers boarding and alighting at each stop | Weekday O-D trip rate matrix. | AC Transit Database, 1997. | San Francisco, California |
| 7 | Chiang et al. 2011 | Bus | Regression Analysis, Neural Networks, and Autoregressive Integrated Moving Average (ARIMA) Model | • Standard fare for a fixed route.<br>• number of individuals receiving food stamps monthly<br>• Annual budget for Tulsa Transit's operating funds | Number of passengers per month. | Tulsa Transit. US Energy Information Administration. Food Research and Action Center. US Census Bureau. US Census Bureau's Small Area Income and Poverty Estimates (SAIPE). National Transit Database. | Tulsa, Oklahoma |
| 8 | Horváth. 2012 | Bus | OD estimation based on system features at stop-level | • Number of boarding and alighting passengers for each run in each stop | Time dependent O-D matrix | Full scope cross-section counting in the Hungarian city of Dunaújváros. | Dunaújváros, Hungary |
| 9 | Pulugurtha & Agurla, 2012 | Bus | stop-Level (DRM) using spatial proximity method (SPM) and spatial weight method (SWM). | • Demographic<br>• Socioeconomic<br>• Network characteristics<br>• Land use information in the vicinity of each bus stop | Average daily boardings per station (Passenger/station/day) | Charlotte Area Transit System (CATS) and City of Charlotte Department of Transportation (CDOT). | Charlotte, North Carolina |

| | Study | Service Type | Methodology | Independent Variables | Dependent Variable | Data Sources | Location of Study |
|---|---|---|---|---|---|---|---|
| 10 | Cardozo et al. 2012 | Bus | Direct ridership model (DRM) | • Number of bus lines<br>• Population and employment<br>• Street density and land use | Number of passengers boarding at each station per month | Transport Authority of Madrid, 2004. | Madrid, Spain |
| 11 | Horváth et al. 2014 | Bus | OD matrix estimation based on boarding and alighting at stop-Level or between stops | • Number of boarding and alighting passengers for each run in each stop | Corrected and calibrated O-D matrix | Unknown. | |
| 12 | Ma et al. 2014 | Bus | Interactive Multiple Model-based Pattern Hybrid (IMMPH) | • Real time information | Passenger demand for the 30-minute interval | Smart Card Data. | Jinan, China |
| 13 | Kerkman et al. 2015 | Bus | Direct ridership model (DRM) | • Frequency per direction<br>• Bus station<br>• Competitive bus-stops<br>• Bus terminus and Transfer stop<br>• Direct connections<br>• Benches<br>• Dynamic Information | Average daily boardings and alightings per station (Passenger/station/day) | General Transit Feed Specification (GTFS). | Nijmegen, Netherlands |
| 14 | Chakrabarti. 2015 | Bus | Regression Model at Stop-Level | • Population employment density<br>• Line population density<br>• Employment accessibility<br>• Income<br>• Transit availability<br>• Stops per mile and headway<br>• Line type and transit alternatives<br>• Position of stop w/ respect to line | Peak hour rout directional boarding for each station (i.e. Early AM, AM peak). (Passenger/station/Peak hour) | Archived Data Management System (ADMS). Census data from the 2007–2011 American Community Survey (ACS). Southern California Association of Governments (SCAG). | Los Angeles, California |
| 15 | Estupiñán, and Rodríguez. 2008 | BRT | Integrated supply and demand | • Station characteristics<br>• Physical Attributes<br>• Neighborhood Attributes<br>• Perceived characteristics | Daily boardings per station. (Passenger/station/day) | Local planning department and transit agency, Pedestrian Environment Data Scan (PEDS). | Bogotá, Colombia |
| 16 | Cervero et al. 2010 | BRT | Direct ridership model (DRM) | • Number of daily buses<br>• Number of perpendicular daily feeder bus lines<br>• Number of perpendicular daily rail feeder trains<br>• Distance to nearest BRT stop<br>• Park-and-ride lot capacity<br>• Population and employment density | Average daily boardings per station. (Passenger/station/day) | TCRP H-1 Database and Santa Monica Big Blue Bus (BBB) Database, 2008 | Los Angeles, California |
| 17 | Chen & Naylor. 2011 | BRT | Four-Step Model. | • Household survey information | Daily Boardings in 2030. Daily Linked Transit Trips in 2030. | Stated-preference survey of 819 households throughout Santa Clara County. | Santa Clara, California |
| 18 | Duduta. 2013 | BRT | Direct ridership model (DRM) | • Catchment size (distance in meters to nearest station) | Daily boardings per station | 2010 operational review report on Metrobus. Official statistics published | Mexico City, Mexico |

| | Study | Service Type | Methodology | Independent Variables | Dependent Variable | Data Sources | Location of Study |
|---|---|---|---|---|---|---|---|
| | | | | • No. of connecting Microbus lines<br>• No. of connecting bus and BRT routes * dedicated lane<br>• Microbus terminal<br>• Number of Metro lines<br>• Direct line to the CBD<br>• Long distance station<br>• Station area density | (Passenger/station/day) | by the Metro de la Ciudad de Mexico for 2011. | |
| 19 | Yun & Liu. 2014 | BRT | Mode Choice Probability by Using a Nested Logit Model | • Gender and age<br>• Education background<br>• Personal monthly income | Mode Choice Probability | Stated Preference (SP) and Revealed Preference (RP) survey data. | Yichang, China |
| 20 | Umlauf et al. 2015 | BRT | Ridership forecasting using system dynamics (sd-brt) model | • Demographic data (Population, Household, Employment)<br>• O-D patterns on existing routes<br>• Proposed service features (vehicle capacity, headway, fare, etc.)<br>• Existing route network<br>• Existing transit service features | • Daily rout boardings<br>• Daily station boardings and alightings<br>• A stop-by-stop trip matrix | A transit O-D survey was conducted in 2012 in El Paso. The demographic data is mainly taken from ArcGIS Business Analyst for year 2011 and 2016. | El Paso, Texas |
| 21 | Preston, J. 1991 | LRT | Trip Rate Model (TRM), Direct Demand Model (DRM) and Disaggregate Mode Choice Model (MCM) | • Station usage as a function of the population within station catchment areas (for TRM)<br>• Number of trips from i to j, residents' population and workplace (for ASM).<br>• Walk and wait time (for MCM) | Demand for new rail stations and services | 1981 West Yorkshire Corridor Study. | Yorkshire, England |
| 22 | Naesun et al. 2003 | LRT | Ridership forecasting using four-step method | O/D by purpose. | Daily demand and maximum hourly demand during peak and non-peak hour for the years 2006, 2011, 2012. | 1997 Seoul Transport Census & Database and Stated Preference (SP) survey. | Seoul, South Korea |
| 23 | Zhang and Xiao. 2007 | High-speed Rail | Estimating OD Matrix Based on the Existing Transport System's Characteristics in Four-step Method. | The inter-urban public transport OD on the existing network | Inter-urban public transport OD in 2015 | China Railway Database. | Shanghai, China |
| 24 | Chen. 2010 | High-speed Rail | Two-stage least square regression model | • Average Fare<br>• Employment by type<br>• On Time Performance<br>• Gasoline Price<br>• Disposable Personal Income<br>• Month Dummy Variable<br>• Gross Domestic Product (GDP) | Monthly station boardings | Acela Express's ridership performance from its monthly report ranging from January 2004 to July, 2009 released on Amtrak's website. | Acela Express, USA |

| | Study | Service Type | Methodology | Independent Variables | Dependent Variable | Data Sources | Location of Study |
|---|---|---|---|---|---|---|---|
| 25 | Gutiérrez et al. 2011 | Metro Rail | Ridership Forecasting at Station-Level | • Service area characteristics<br>• Station characteristic | Monthly station boardings | Transport Authority of Madrid and Socioeconomic mobility survey, 2014. | Madrid, Spain |
| 26 | Wang et al. 2012 | LRT | Ridership Forecasting Using Multivariate Regressions at Station-Level. | • Density<br>• Diversity<br>• Design<br>• Destination accessibility<br>• Distance to transit<br>• Station characteristics<br>• Spatial location<br>• Socioeconomic characteristics | Daily station boardings (Passenger/station/day) | Shanghai Shentong Metro CO., Ltd, 2011. Field work, 2011. GIS data, 2011, Trip Survey, 2011. Shanghai Municipal Government, 2011. | Shanghai, China |
| 27 | Sanko et al. 2013 | LRT | four-step method | • OD matrix | Daily rout boarding | Nagoya Metropolitan Area household travel survey data, 1971. | Tokadai, Japan |
| 28 | Jones. 2013 | LRT | Regression model (Poisson) | • Population Density<br>• Residential Density<br>• Distance from LRT Stations | Ridership count per land use zone | On-board survey, 2010. Census data. land use data. | Minnesota, USA |
| 29 | Peters. 2014 | High-speed Rail | Ridership forecasting using four-step method | • Population<br>• fuel efficiency & Fuel price<br>• County-to-county demand | Annual ridership forecast | 1995 National Travel Survey. 2010 National Transportation Atlas Data. | United States' Midwest Corridor |
| 30 | Durning & Townsend. 2015 | Rapid Rail | Direct ridership model (DRM) | • Socioeconomics<br>• Station & service attributes<br>• Neighborhood, street network, and land use | Average daily station boardings (Passenger/station/day) | DMTI Spatial's Route Logistics package land use data. | Five Largest Cities in Canada |
| 31 | Hsu et al. 2015 | High-speed Rail | DRM, considering annual gross domestic product (GDP) | • Population & Employment<br>• Car ownership<br>• Aging population<br>• Travel cost & Travel Time<br>• Gross Domestic Product (GDP) | Annual ridership forecast | Taiwan High Speed Rail (THSR) dataset, 2007. | THSR service corridor, Taiwan |
| 32 | Li et al. 2015 | LRT | Back propagation neural network (BPMN) model | • Population<br>• Road density & Land use<br>• Number of shuttle bus lines<br>• Peak-hour train frequency<br>• Station type (terminal or not)<br>• Gross Domestic Product (GDP) | Daily station boardings | Ministry of Land, Infrastructure, Transport and Tourism of Japan, 2010. | Tokyo, Japan |
| 33 | Cheon et al. 2015 | LRT | Trip generation model (linier regression), four-step model. | • Trip purpose<br>• Area type<br>• Population<br>• Living and expropriated students<br>• Living and expropriated employees | Annual trip generation flow | 2012's socioeconomic. | Korea |
| 34 | Button et al. 2009 | Bus & Rail | Ridership Forecasting and Capital Cost Estimation Using Regression Model | • System Characteristics<br>• Type and Technology<br>• Time: The year in which system planning was completed with | • Ridership Forecast (Difference between forecasted and actual ridership) | Governmental reports, system evaluation reports, transit agency websites and transit agency contacts. | 47 US Transit System |

| | Study | Service Type | Methodology | Independent Variables | Dependent Variable | Data Sources | Location of Study |
|---|---|---|---|---|---|---|---|
| | | | | 1972 as the base.<br>• Pickrell Effect: Indication of whether system planning was completed before or after 1992. | • Capital Costs (Difference between estimated and actual capital costs) | | |
| 35 | Blum et al. 2010 | Bus & Rail | hybrid demand estimation (HDE) algorithm | • Transit network<br>• Passenger counts<br>• Survey zones | Fine-grained O-D matrix | Household travel survey. | Mumbai, India |
| 36 | Chakraborty & Mishra. 2012 | Bus & Rail | Ordinary least squares (OLS) regression model | • Combination of demographic, socioeconomic, network, and land use characteristics | Daily station boardings (Passenger/ day/ station) | 2000 Census Transportation Planning Package (CTPP). Quarterly Census Employment and Wages (QCEW). | Maryland, USA |
| 37 | Chakraborty & Mishra. 2013 | Bus & Rail | Finding Significant and Robust Predictors of Transit Ridership | • HH and employment density<br>• Drive alone density<br>• HH without cars & Income<br>• Number of school enrollment<br>• Accessibility to transit stop<br>• Health care square feet<br>• Housing square feet<br>• Total freeway distance<br>• Recreation square feet<br>• Dinning square feet<br>• Average free flow speed | Annual ridership for 2030 | Maryland Department of Planning's (MDP) Property dataset, 2000. | Maryland, USA |
| 38 | Dill et al. 2013 | Bus & Rail | Regression model | • Transit service characteristics<br>• Transportation system (e.g. street connectivity, bike lanes, etc.)<br>• Land use<br>• socio-demographics | Daily station boardings (Passenger/ day/ station) | TriMet, 2008. US Census data from 2005-2009 and American Community Survey (ACS). | Oregon, USA |
| 39 | Frei & Mahmassani. 2013 | Bus & Rail | Transit Demand Variation Estimation at the Stop-Level Using Log-Log Model | • Land use<br>• Socio-demographic<br>• Boardings at stops<br>• Time periods<br>• Headway at stops<br>• Walk Score of stops | Transit demand variation at the stop level for a 30-minute interval of a day. | Chicago Metropolitan Agency for Planning (CMAP). Land use data at parcel level, 2005. City of Chicago census, 2010 and Illinois Department of Employment Security. | Chicago, USA |
| 40 | Tsai et al. 2013 | Bus & Rail | Univariate ARIMA Model and a Multivariate Dynamic Partial Adjustment Model (PAM) | Monthly boarding from 2007 to 2011. | Future demand for a number of policy scenarios from 2011 to 2026 in five-year intervals. | Bureau of Transport Statistics (BTS), 2007 to 2011. | South Wales, UK |

# APPENDIX B Existing Tools

## B.1. TBEST

### B.1.1. Overview of the Software Structure

The unit of analysis in TBEST is a Transit System. Transit systems could be downloaded for existing transit routes all over the United States, or could be created by the user. A transit system analysis is referenced by three major properties:

- Extent (by pre-defined County)
- Distribution data: All Transit System files are packaged within one single file titled as "Distribution File" which includes SQL server databases, GIS files, reports, etc.
- Socioeconomic data: Socioeconomic data input, which usually comes from census or other relevant sources. Two major types of SED input data are used: population, and employment. Different scenarios could be defined when analyzing a transit system.
    - For population, TBEST requires three Census file types from the Census:
        - SF1 Census Attribute Table
        - American Community Survey (ACS) 5-Year Estimates
        - Census Block-level polygon shape file
    - For Employment, two options are used:
        - InfoUSA point data
        - Zonal employment data

TBEST transit system contains different transit scenarios. Each scenario contains a transit network and attributes which define the socioeconomic and travel behavior within the transit system service area. Scenarios are created to represent existing conditions or to represent proposed current year or future year service modifications. Specific general or localized growth factors are used for target future years.

### B.1.2. Route/Segment/Stop Design

Route properties include route type (Radial, Circulator, Crosstown, Express, Rapid or BRT), Technology (Bus, Heavy Rail, People Mover, Street Car, Light Rail, or Other), route name and directions. Segment attributes include Route, Length, in-vehicle travel times on different Times-of-day, and segment geometry.

For stops, three different types of attributes are considered:

- Stop Definition Attributes. Each stop within the network has reference "operational" attributes such as a stop name, description, and time point. During a GTFS Network Import, TBEST will automatically populate these operational variables. The Time Point column will be populated only if the GTFS is formatted for network segmentation.

- Time Period Specific Service Characteristics and Special Generators. TBEST includes three stop attributes (Arrivals, IVTT, Headway) which vary based on network Time Period.
- Socioeconomic Variables. To determine the socioeconomic conditions around each stop, TBEST utilizes the source socioeconomic data defined for the scenario to calculate and assign the walk access demographics (Population, Employment, Households, and Income) around each stop in the system. The TBEST ridership estimation procedure will calculate these variables and then use them within the model to assess the market for riders at a stop location and to determine the destination trip attractions through network accessibility computations.

### B.1.3. Model Structure

TBEST provides forecasts or predictions of stop-level boardings. Thus, ridership in the context of TBEST is defined as the number of boardings at each transit stop. In particular, models estimated by TBEST have two features:

1) TBEST incorporates separate equations for estimating and distinguishing between **Direct** boardings and **Transfer** boardings at each stop location.

2) TBEST includes separate ridership estimation equations for each **time of day** and **day of week.**

The basic assumption in TBEST model estimation is that boarding in each stop is affected by both **Neighbor** stops and **Accessible** stops. Neighboring stops are other stops within its buffer or whose buffers overlap with its buffer. Four different types of neighbor stops (N0 through N3) are defined. Definition of five accessible stops (S0 through S4) is based on the potential to reach or be reached by the analyzed stop or any of its neighboring stop groups [Detailed definitions could be found in the manual].

**Direct Boarding**

$D_n^s = g(C^s, A_{1n}^s, A_{2n}^s, A_{3n}^s, A_{4n}^s, X_n^s), n = 1, \dots, N$

where

s = index for any origin stop

n = index for any time period

N = number of time periods

$D_n^s$ = direct boardings at stop $s$ during period $n$ for the direction and along the route that define stop $s$.

$C^s$ = vector of buffer characteristics for stop $s$. These characteristics include the amount of population and employment as well as their characteristics. s C
$A_{1n}^s$ = vector of accessibility to employment and population in the buffer areas of $S1$ stops during period $n$.
$A_{2n}^s$ = vector of accessibility to employment and population in the buffer areas of $S2$ stops during period $n$.
$A_{3n}^s$ = vector of accessibility to employment and population in the buffer areas of $S3$ stops during period $n$.
$A_{4n}^s$ = vector of accessibility to employment and population in the overlapped buffer areas $S3$ stops and $S1$ stops during period $n$.
$X_n^s$ = vector of other stop and route characteristics during period $n$.

**Transfer Boarding**

$T_n^s = t(P_{0n}^s, A_{1n}^s, A_{2n}^s, A_{3n}^s, A_{4n}^s, Y_n^s), n = 1, \dots, N$
where
$T_n^s$ = transfer boardings at stop $s$ during period $n$ for the direction and along the route that define stop $s$.
$P_{0n}^s$ = transfer potential from upstream boarding at $S0$ stops toward stop $s$ during period $n$.
$Y_n^s$ = vector of other stop and route characteristics for period n.

**BRT Adjustments**

TBEST includes model sensitivity to an array of BRT characteristics. The variability of specifications for BRT systems has resulted in the development of a specific methodology to modify BRT demand forecasts to reflect the variety of BRT features prescribed for any given BRT system. BRT features that are specified as part of a method for determining the ridership benefits of BRT implementation are:

1) Vehicle characteristics such as floor height, aerodynamics, alternative fuel, etc.
2) Station attributes such as shelter, real time information, fare vending, etc.
3) Travel Way, such as exclusivity, signal preemption, visual distinctiveness, etc.
4) Branding/Marketing,

Each of these features contains characteristics which can be evaluated in terms of level of implementation on the BRT line. TBEST enables the user to input a score on a scale of 0 to 5 which best describes the level of implementation of each characteristic on a BRT route. From the user scoring, the TBEST model will apply the calculated BRT route adjustment factor to the estimated boardings.

### B.1.4. Model Outputs

TBEST provides a number of different outputs including:

**Stop/Route/Segment/Pattern/Regional Analysis**

Includes a summary of in-bound and out-bound transfer opportunities, direct and transfer boardings customized by any of the attributes above.

**Route Level Performance Measures**

1. Direct Boardings
2. Transfer Boardings
3. Total Boardings
4. Revenue Service Trips
5. Route Miles
6. Revenue Service Miles
7. Revenue Service Hours + (Revenue Service Hours * % In-Service Layover Time)
8. Total (direct + transfer) Passenger Boardings per Service Mile
9. Total (direct + transfer) Passenger Boardings per Service Hour
10. Total (direct + transfer) Passenger Boardings per Service Trip
11. Average Boardings/Stop Visit = total (direct + transfer) boardings on route ÷ number of stops on route ÷ number of service trips on route.

**Scenario Summary**

Takes summary span, time period, routes to summarize, and operating cost and layover parameters as input and provides summary of different variables in the scenario including: Boardings, population, household, income, employment, network, service, performance, and cost. It also enables comparison between two separate scenarios.

**TDP Summary**

It summarizes key performance indicators among different transit systems and geographical areas. Performance indicators include:

- Population Access
  - Total population
  - Service area population
  - Percent population served of total population
  - Passenger trips per population served
- Employment Access

- Total Employment
- Total Employment Served
- Percent employment served

- Service Characteristics
    - Estimated annual service miles
    - Average system speed
    - Average system headway
- Productivity
    - Estimated annual ridership
    - Boardings per service mile
    - Boardings per service hour
- Efficiency
    - Estimated scenario operating cost
    - Operating cost per service mile
    - Operating cost per passenger trip

**Route Headway Report**

The TBEST Route Headway Summary report displays the calculated route direction headway for each TBEST time period within the open scenario.

**Route Level Validation Factors**

TBEST validation factors are created during the transit system validation process and are applied during a TBEST ridership estimation model by multiplying the calculated factor against the TBEST ridership estimation forecast. Validation factors are the multiplier that will match TBEST predicted ridership to the validation observed ridership.

**Market analysis based on SED or Land Use**

TBEST enables the analysis to be customized by different socio-demographics or land use types.

**Title VI Analysis**

TBEST can provide system equity analysis based on how much it benefits the minority, low income people, individuals with limited English capabilities, etc.

## B.2. STOPS

STOPS is a series of programs designed to estimate transit project ridership. The term "simplified refers to the fact that STOPS bypasses some of the steps in the time-consuming process of developing and applying a regional travel demand model. In particular,

- Estimates of total origin-to-destination travel are derived from Census data rather than elaborate trip generation and destination choice procedures. This avoids the need to calibrate these tools to the degree of accuracy required to estimate transit ridership.
- Representations of transit levels-of-service are derived from timetable information, bypassing the need to develop detailed transit networks in the planning environment. Timetable information is already available at most agencies and is much more accurate than the representations of travel time and frequencies contained in typical planning networks.
- The model calibrates itself to represent current conditions. This means that the months, and sometimes years, that are spent developing and documenting effective forecasting tools can be avoided.

### B.2.1. Overall Model Structure

The core function of the STOPS model is to develop a regional mode choice model, which particularly forecasts the share of transit trips between any two zones within the study area. Just like any other multi-modal forecast model, STOPS consists of three parallel procedures:

- Highway supply:
  Includes OD distances and highway skims. STOPS does not directly process information on highway attributes and instead relies on estimates of zone-to-zone highway travel times and distances obtained from regional travel forecasting model sets maintained by Metropolitan Planning Organizations (MPOs). Since MPO models might not still use the same geographic (zone) system used in the CTPP, STOPS includes a procedure to convert MPO geography to CTPP geography.
- Transit supply:
  Transit network characteristics are used to build zone-to-zone level of service (skim) matrices and load transit trips to determine ridership by route and station. Unlike traditional forecasting models, STOPS does not use elaborate hand-coded networks. Instead, STOPS takes advantage of a recent advance in on-line schedule data—the General Transit Feed Specification (GTFS). This data format

is a commonly-used format for organizing transit data so that on-line mapping programs can help customers find the optimal paths (times, routes, and stop locations) for their trips. STOPS includes a program known as GTFPath that generates the shortest path between every combination of regional origin and destination. This path is used for estimating travel times (as an input to mode choice) and for assigning transit trips (an output of mode choice) to routes and stations.

- Travel demand:
  STOPS uses Year 2000 CTPP JTW (Journey to work) data to estimate zone-to-zone demand for travel (i.e., travel flows) as an input to the models that determine the mode of travel. This data is adapted to represent current and future years by using MPO demographic forecasts to account for zone-specific growth in population and employment. A traditional nested logit mode choice model is used to determine the proportion of trips utilizing transit stratified by access mode and transit sub-mode. Results of mode choice are summarized in a series of district-to-district flow tables.

### B.2.2. Input parameters

**Scenario Setup**

This step identifies project corridor, states and MPO regions being involved in the project (as GIS layers), the geography types being analyzed (e.g. traffic analysis zones TZ, census Block Groups BG, or Census Tracts CT), and the years being modeled (either the current year or a forecast year). Usually three different scenario types are modeled:

- Existing scenario: The existing scenario represents the existing transit system and is used with current year socioeconomic data to calibrate the local application of STOPS to observed current year ridership. The resulting calibration is applied to all other scenarios.
- No-build scenario: The no-build scenario represents the future year network that is to be used as the basis of comparison for the project for any statistic requiring information on incremental impacts of the project (e.g., Vehicle Miles of Travel). The no-build scenario includes the existing system together with relevant transit elements that are already committed for construction and operation.
- Build scenario: The build scenario represents conditions after the project fixed guideway transit system is constructed and in operation.

**Station Locations**

Includes station name, code, location, sequence, daily boardings (used for station calibration level), stop type (9 different categories providing details on station physical situation and purpose), and penalty values for different types of access or transfers.

**CTPP and Census Data**

Includes CTPP boundary (shape) files, CTPP JTW data, and census block files.

**MPO Data**

STOPS uses data from the local Metropolitan Planning Organization (MPO) to represent:

- Current and projected future-year population and employment to "grow" the 2000 CTPP JTW tables to represent current and future conditions
- Zone to zone automobile travel times and distances

**Transit Agency Schedule and Supplement Data**

The General Transit Feed Specification (GTFS) is used to represent existing and scenario-specific transit services. GTFS consists of a series of files that, together, represent the stops, routes, and scheduled operation of a transit system. In this section, all operation attributes including time schedule, frequency, headway, transfers, route type, etc. are input to the software.

In many cities, GTFS files for the current transit schedule are available on-line for public use. In cases where the transit feed is not publicly available, it might be obtained from the agency's scheduling department. Even if the agency does not generate a feed, the agency's scheduling software may be able to generate a GTFS file set for use in STOPS.

### B.2.3. Model Outputs

- Transit productions and attractions within each district based on household auto ownership
- Transit productions and attractions within each district based on station group
- Distribution matrix based on origin and destination station groups
- Comparing transit ridership in different scenarios
- Impacts on auto PMT (person miles traveled)
- Summary of transit trips by sub mode, access mode, and auto mode