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Sensitivity Analysis of the Transit Boardings Estimation and Simulation Tool (TBEST) Model

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by

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ABSTRACT

Public transportation, although modest in the United States carrying about 2 percent trips, still serves millions of people as the main and only means of transportation. Recently released data set by Census, the 2006 American Community Survey (ACS) shows the main mode of travel for work commute is not surprisingly the automobile with over 86 percent and public transportation with nearly 5 percent users. Transit agencies strive to provide effective, convenient, and desirable transport. Because of the constant changes in our environment, being able to predict the response of riders to different network or system changes is extremely useful. Ridership can be described as a function of the amount of service supplied such as frequency, span of service, and travel time. One of the methods for estimating ridership forecasts and evaluating ridership response is to use the new state-of-art software TBEST. TBEST stands for Transit Boardings Estimation and Simulation Tool and is the third generation of such transit models sponsored by the Florida Department of Transportation (FDOT). Designed for comprehensive transit network and short term transit planning, it offers great benefits to its users. TBEST is a user friendly, yet very advanced transit ridership forecasting graphical software which is interfaced with ArcGIS. This paper evaluates different sensitivity tests and compares the results to known industry used elasticities. Because the current TBEST experience is modest, the results will provide users with a general idea of the model's sensitivity and help in the process of model refinements. Sensitivity tests such as service frequency, span of service, service allocation, and travel time will be carried out in a systematic order for all six time periods as defined by TBEST. Results showed that TBEST Model is overestimating and is highly sensitive to headway changes, specifically headway decrease. The opposite effect of almost no sensitivity is shown for the in-vehicle travel times.

CHAPTER 1 INTRODUCTION

1.1 Background

Public transportation, although modest in the United States carrying about 2 percent trips still serves millions of people as their main and sometimes only means of transportation. Recently released data set by the Census, the 2006 American Community Survey (ACS) shows the main mode of travel for work commute is not surprisingly the automobile with over 86 percent and public transportation with nearly 5 percent users. What are the general goals and objectives of transit agencies and what is needed to meet those? Transit agencies strive to provide effective, convenient, and desirable transport. Our environment is constantly changing on social, demographic, and economic level. An important area of research is looking into how those changes effect transit patronage. Being able to predict the response of riders to different network or system changes is extremely useful. Those changes can be modifications or improvements to the existing system or additions of completely new services. Resource allocation often depends on accurate information on these impacts. Florida Department of Transportation (FDOT), Public Transit Office (PTO) recently passed a rule, Public Transit 14-73.00 that requires all transit agencies to submit Transit Development Plans (TDP's). TDP is a ten year planning document which among others includes "an estimation of the community's demand for transit service using the planning tools provided by the Department, or a Department approved transit demand estimation technique with supporting demographic, land use, transportation, and transit data. The result of the transit demand estimation process shall be a ten-year annual projection of transit ridership.” This is one example where transit agencies are required to provide ridership forecasts in order to receive funding. One of the approved methods for accomplishing this task of ridership forecasting is to use TBEST. Section 1.2 discusses what TBEST is.

1.2 TBEST

TBEST stands for Transit Boardings Estimation and Simulation Tool. This third generation transit model is a better and improved version of the previous two – Integrated Transit Demand and Supply Model (ITSUP) and Regional Transit Feasibility Analysis and Simulation Tool (RTFAST). Developed by the FDOT Public Transit Office, to provide support completing their TDP’s, transit agencies can use TBEST as a tool to estimate their ridership forecasts. TBEST is user friendly, yet very advanced transit ridership forecasting graphical software which is interfaced with ArcGIS allowing transit agencies fairly easy manipulation of their network. As mentioned in section 1.1, being able to predict the ridership response to different system changes is important. Some typical system changes transit agencies and transportation planners are usually exploring are the service frequency, network coverage, fare pricing, span of service and speed. TBEST is capable of evaluating these variables and how the ridership is impacted by each of these individually or in combination. Unlike many other transit planning models, TBEST has the capability of simulating ridership at stop-level, thus providing more detailed, accurate analysis. Stop-level ridership can also be aggregated to route, segment, and system level. Transit ridership at the stop-level depends on a wide range of factors which TBEST incorporates. For example, direct versus transfer boardings, time of the day based analysis, socio-economic characteristics, network connectivity and others. TBEST User Guide describes each of these in detail and provides users with the complete TBEST methodology. More details on TBEST Model are provided in Chapter 3.

1.3 Objective and the Scope

How travel demand is affected by transportation changes has been a growing field of interest among transportation professionals. With this new software, we are a step closer to better and easier estimation and measurement of those changes. However, there are some caveats that need to be addressed. TBEST is new software and a planning tool, so the operation experience is modest. Although there have been previous versions, continuous evaluations and updates of the model will be necessary. The overall objective of this paper is to help improve the model and provide users a general idea of the model sensitivities. This will be achieved through a number of sensitivity tests. Polk County will be used as the case scenario. The results will be presented in terms of transportation elasticities or percent changes and will be compared to the known industry elasticities.

1.4 Methodology

This paper attempts to analyze the TBEST Model sensitivities. As of now, Pennsylvania DOT has already initiated forecasts with TBEST. In June 2007, two technical memos were produced. The first one described the network development for the two transit agencies used in this study, EMTA and Rabbit Transit. The second technical memo described the network calibration process. Completed in September, this Forecasting Short-Term Ridership report produced by Gannet Fleming for the

Pennsylvania Department of Transportation included four scenarios that were developedand analyzed for both the EMTA and Rabbit Transit. The alternatives included headway adjustments, extending routes, adding new routes, modifying the route types and others.

This paper uses Polk County as the base case for conducting a series of sensitivity tests with the TBEST Model. The series of tests can be grouped into four major categories: headway, service allocation, service span, and travel time changes. Different scenarios will be created for each of these categories for testing the sensitivity. The results will be analyzed and compared to known transit service frequency elasticities. Service allocation evaluation will include a series of model runs that will test how ridership responds to additional service versus service increases of the current system. Polk County currently does not offer Sunday service. As part of the span of service analysis, Sunday service will be added and the results evaluated. Ridership response to service span changes will also be evaluated by adding more arrivals during the night period. Each alternative scenario developed will be further discussed in Chapter 5.

1.4.1 Transportation Elasticities

Throughout the previous sections of this report there was much mention of the ridership response. How is this ridership response measured and quantified? "Law of Demand" is a concept describing a pattern when the price of the good decreases, its consumption increases, and vice versa. Economists measure price sensitivity using "elasticities". Elasticity is defined as the percent change in a consumption of a good, caused by a one percent change in its price. There are different forms or ways for calculating elasticity and those measures can be found throughout the transportation literature. Elasticities usually provide satisfactory results in assessing ridership response. However, elasticities need to be used with caution. In order for elasticity measures to be applicable in transportation, the change must be a relative one that involves quantifiable percent increase or decrease in the system. So elasticities cannot be used to assess the ridership response of a new bus system. If the elasticity value is 1, we refer to that as the unit elasticity. Elasticity values greater than one are called "elastic" which means the price or service change causes more than proportional change in consumption. Elasticity values less than one are referred to as "inelastic", meaning the price or service change causes less than proportional change in consumption.

Transportation literature typically contains three different methods in computing elasticities:

1) Point elasticity

2) Arc elasticity

3) Shrinkage ratio

Point elasticity is described as

$$\eta_p = \frac{dQ}{dP} x \frac{P}{Q}$$

where η_p is the elasticity at price P, and Q is the quantity demanded at that price.

The most frequent form used in transportation is the *Arc Elasticity*. Arc elasticity is defined as following:

$$\eta = \frac{\Delta \log Q}{\Delta \log P} = \frac{\log Q_2 - \log Q_1}{\log P_2 - \log P_1}$$

where η = elasticity value

Q1 and Q2 = demand before and after

P1 and P2 = price or service before and after.

When one value is zero, for example in the case of adopting or terminating free use of transit, the mid-point arc elasticity shown below must be used.

$$\eta = \frac{\Delta Q}{(Q_1 + Q_2)/2} / \frac{\Delta P}{(P_1 + P_2)/2} = \frac{\Delta Q(P_1 + P_2)}{\Delta P(Q_1 + Q_2)} = \frac{(Q_2 - Q_1)(P_1 + P_2)}{(P_2 - P_1)(Q_1 + Q_2)}$$

The third form is the shrinkage ratio. More recently, this method has been used in road value pricing studies. Instead of the shrinkage ratio, the term that's been used is "approximated point elasticity".

$$\eta = \frac{\Delta Q / Q_1}{\Delta P / P_1} = \frac{(Q_2 - Q_1)/Q_1}{(P_2 - P_1)/P_1}$$

When using elasticities, one needs to be cautious. Not only are there differences in nomenclature used throughout the literature, but there are also differences in results one can get using different formulas. When the percent change in transportation service is small, all the methods give approximately the same elasticity value. However, when there are large differences in service or fare changes, the results are very different. Figure 1 illustrates those differences when arc elasticity, shrinkage ratio, and point elasticity is used for an initial point price elasticity of -0.30 (Mayworm, Lago, and McEnroe, 1980).

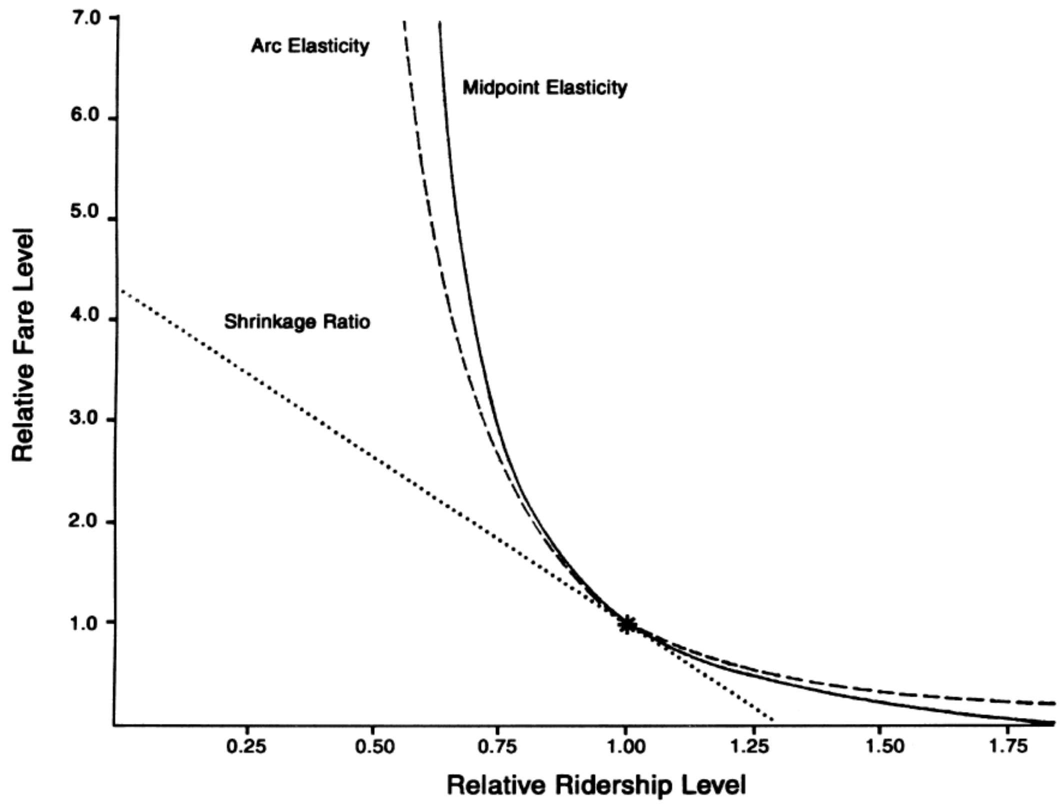

Figure 1 Different Transit Elasticities

1.5 Outline of the Thesis

This thesis contains six chapters. Chapter 1 provides the introduction of two areas: transit ridership response and the TBEST Model. The first section introduces the importance of accurately measuring transit ridership response and the transit ridership forecasting requirements for certain grants. Following that section is a brief introduction of the TBEST Model used in this paper and the sensitivity tests performed. Chapter 2 consists of literature review broken down into the literature review of transit ridership forecasting and transit service planning methods. The second part covers the research completed on the ridership response and reviews known transit industry elasticities. Chapter 3 discusses the TBEST Model structures, its features, and tools. Following the TBEST Model chapter, Chapter 4 will provide the description of the base case, the network development, and the model calibration and scaling. Chapter 5 discusses the alternative scenarios developed and tested and provides the results of the model runs and the calculated elasticities. Also, here the elasticities are compared to the known elasticities from the literature. Chapter 6 provides conclusions based on the model results. That chapter offers general conclusions and possible improvements for the TBEST Model.

CHAPTER 2 LITERATURE REVIEW

Literature review in this chapter consists of two parts. The first part covers the work done as it relates to the TBEST modeling approach. The second part of the literature is a review of research in the area of ridership response and transportation elasticities. Here some of the known industry elasticities are presented. The second part of this chapter is broken down into sections as it relates to this paper. Much research has been done in this area and it is difficult to cover the whole body of literature. TBEST Model methodology and framework will be discussed in detail in Chapter 3.

2.1 Ridership Forecasting and Service Planning Methods

Budget preparation, allocation of resources, and better service planning are all reasons why one may want know the impacts on ridership from certain service changes. Literature on assessing ridership impacts dates back to the early 1980’s. The traditional four-step modeling process: trip generation, trip distribution, modal choice, and traffic assignment does not work for assessing and evaluating transit ridership at the route level because of accuracy issues (Multisystems 1982). This model was designed for large scale changes and it typically uses zonal level data. After realizing the difficulties in assessing the impacts of transit ridership with the four-step process, simpler models were developed. In 1984 Horowitz developed a simplified version of the four-step process.

After that some of the other early work has focused on route – level analysis. Here many of the problems of the four-step process are avoided, but there are still issues to be considered. These direct demand models use homogeneous land use and everything else along the route. This type of homogeneity is very unlikely to be the case. Just recently, transit ridership modeling and forecasting has been analyzed at the segment level (Peng et al. 1997; Kimpel et al. 2000). In their simultaneous route-level transit patronage model they incorporate transit demand, supply and inter-route effects in a simultaneous system. The results of this model indicate that simultaneity exists between transit demand and supply and that there is also a strong interrelationship among routes. And while this approach avoids both problems the previous two had, it still assumes homogeneity along the route segments. This study also shows that single-equation model overestimates the effects of service increases because it assumes that all ridership increase on a new route is new ridership. This model could be improved at the transit stop-level if reliable stop-level data is available. There is not much literature that shows the attempts of modeling and forecasting ridership at the stop-level. Kikuchi and Miljkovic in 2001 used fuzzy inference method to forecast ridership at the stop-level. The data used in this study was actual bus stops in Delaware.

2.2 Transportation Elasticities

In 1981, Lago, Mayworm and McEnroe summarized at that time the current state of knowledge on the transit service elasticities from demonstrations and demand models. In their *Transit Service Elasticities – Evidence from Demonstration and Demand Models* paper, they group the transit service elasticities into two broad categories. One is quasi-experimental, using data generated by a practical demonstration of an actual change. The other one is non-experimental, relying on some data where changes are part of historical data analysis. The quasi-experimental approach was used by Kemp (1979) in Atlanta and by Goodman, Green, and Beesley (1977) in San Diego. They used monthly data series. Among other things, they developed vehicle-mile elasticities. The aggregate elasticities for the San Diego area varied from +0.75 to +0.85. In Atlanta, the vehicle mile elasticities estimated by Kemp were +0.30. This difference can be attributed to more service being available and service expansion occurred over a much shorter time period. As with service frequency changes, these results suggest that the response to increase in vehicle-miles of service depends on the initial amount of service provided. Other factors such as fares, auto availability, and size of the urbanized area can be as equally important (Lago 1981). Table 1 shows San Diego vehicle-mile elasticities estimated by Goodman, Green, and Beesley in 1977.

Table 1 San Diego Vehicle-Miles Elasticities

Radial routes to CBD	+0.65
Central-city routes	+0.72
Suburban routes	+1.01

One of the most important factors affecting public transportation ridership is travel time. Measuring ridership response to travel-time changes is very difficult. Historically the only available travel-time elasticities came form mode-choice and transit-demand models. Therefore those travel-time elasticities should be used with caution. The only evidence for the in-vehicle travel-time response was obtained from an experiment in three cities. Table 2 displays these in-vehicle elasticities by time period.

Table 2 In-Vehicle Travel Time Elasticities by Time Period

Time Period	Elasticity		Project
Peak	-0.29 ± 0.13	(9 cases)	Miami, Seattle, Boston
Off Peak	-0.83	(1 case)	Seattle
Aggregate value	-0.35 ± 0.21	(10 cases)	All of the above

Source: Wattleworth (1978), A.M. Voorhees and Associates (1973), Dupree and Pratt (1973), and Ecosometrics, Inc. (1980).

Kraft and Domencich in 1970 observed higher elasticities during peak hours, especially for choice riders, in improved travel-time rather than reduction in fares. Mullen (1975) analyzed some bus demonstration data in England and found that off peak headway elasticities are significantly higher than peak-period elasticities. One of the most comprehensive pieces of literature covering traveler responses to different transportation system changes are the TCRP Report 95 series. Since 1977, this report has served as reference to many professionals. This part of the literature review will cover some of the elasticities presented in these reports. Also, Todd Litman produced two papers, *Transportation Elasticities – How Prices and Other Factors Affect Travel Behavior* and *Transit Price Elasticities and Cross Elasticities,* which will be reviewed later in this section. Very common service changes a transit agency makes are scheduling and frequency modification. The objectives can range from cost effectiveness to service quality. Service quality can be affected by either reducing passenger wait times or reducing wait time for transfers. Sometimes, however, transit agencies are forced reduce the frequency due to funding. There are several types of scheduling and frequency changes a transit agency can make. Service frequency changes, service hours changes, and frequency changes with fare changes are some of the types of modifications agencies can make. These types of changes usually do not involve bus routing and coverage.

Quantifying response of ridership to these changes is usually done using elasticities which was briefly introduced in the pervious chapter. We know that increased transit frequency is expected to result in increased ridership, and vice versa. Because of a wide variation in observed results it has been suggested that service frequency and ridership changes may not be able to be represented with a single numerical relationship (Holland 1974). More recent research indicated that frequency elasticities can be grouped in +0.3 or in +1.0 category. However, if one considers historical and current observations, the average service elasticity is around +0.5 (Pratt 2004). Historical data on service elasticities is presented in Table 3.

Table 3 Bus Route or Small System Headway Elasticities Observed in 1960's/70's

Massachusetts Demonstrations	Headway Elasticity	Months After Implementation
Boston-Milford suburban route (new headway approx. hourly)	-0.4	10-12
Uxbridge-Worcester suburban route (new headway hourly)	-0.2	7-9
Adams-Williamstown city route (new headway approx. hourly)	-0.6	1-3
Pittsfield city route (raised from 3 to 8 round trips daily)	-0.7	1-3
Pittsfield city route (raised from 10 to 15 round trips daily)	-0.6	1-3
Newburyport-Amesbury (depressed area) city route (new headway 30 min. peak/60 min. midday)	-0.4	6-8
Fall River (depressed area) city service (overall 20 percent service increase)	nil	4-6
Fitchburg-Leominster city route (new afternoon headway 10 min., to match morning)	-0.3	6-8
Boston downtown distributor, Phase 1 (new midday headway 5 min., to match peak)	-0.8	5-7
Boston downtown distributor, Phase 2 (new headway 4 min. base, 8 min. midday)	-0.6	8-10

Table 3 Continued

Boston rapid transit feeder route (new midday headway 5 min., to match peak)	-0.1	4-6
Other Contemporary Findings		
Detroit city route (new headway 2 min. peak, 3.5 min. midday)	-0.2	—
Chesapeake, VA, suburban service (new headway 35 to 42 min.)	-0.8	—
Stevenage, England (peak period/off peak; new headway 5 min.)	-0.4/-0.3	—
Madison, WI, circulator routes (Saturday/Sunday; new headway 20/30 minutes)	-0.2/-0.6	—

Sources: Massachusetts Demonstrations — Mass Transportation Commission et al. (1964). Massachusetts elasticity calculations — Pratt, Pedersen and Mather (1977). Other Findings — Holland (1974), Mayworm, Lago and McEnroe (1980).

Some general conclusions can be made about the frequency elasticities based on historical and current research. Elasticities tend to be higher in suburban systems than central cities. Also, it was observed that elasticities are significantly higher in areas where the frequency was originally low. Service hours changes are very different from frequency changes, but their effect is often not identified separately (Pratt 2004). Service hours changes include increasing or decreasing span of service where the service during the day is either shortened or lengthened. Another common change transit agencies implement is adding or eliminating days of service, usually Sunday operations. Bus headway elasticities discussed in Table 3 are also looked at in terms of the time of the day. Table 4 shows those results.

Table 4 Headway Elasticities by Time Period

Time Period	Number of Observations	Arc (Mid-point) Elasticity	Standard Deviation
Peak Hours	3	-0.37	±0.19
Off Peak Hours	9	-0.46	±0.26
Weekends	4	-0.38	±0.17
All Hours	7	-0.47	±0.21

We note that there is higher elasticity in the off-peak period. This can be attributed to lesser service frequencies in the off peak periods. Often, off peak period travel can be related to choice riders. Another factor that needs to be considered when looking at the service frequency changes is socio-demographics. Public transportation mostly serves those that are dependent on transit, also known as captive riders. Therefore, passengers that are most attracted by frequency improvements tend to be choice riders and mostly in the middle to upper income groups (Holland 1974). Two-year research on frequency and fare changes in the greater Dallas area reveled greater sensitivity to fares than service in the city center, and the opposite in the suburbs for both express and local service (Allen, 1991). In general, ridership appears to be more sensitive to fare changes than frequency changes where frequency is high, and opposite where service levels are low. Service restructuring of a transit system tries to improve the overall system effectiveness and productivity. Ridership surveys, transit planning models, and GIS application are some of the tools for measuring ridership response to service reconfiguration. Price Elasticities and Cross-Elasticities study by Todd Litman suggests that the elasticity of transit

ridership with respect to fares is lower for captive riders than choice riders. Also, elasticities are about twice as high for travel during off peak than during peak times. This paper also suggests that because of high variability and uncertainty it is better to use ranges rather than point value when using elasticity analysis. The evidence shows that fare elasticity is usually in the -0.2 to -0.5 range in the short run (first year), and increase to -0.6 to -0.9 over the long run (five to ten years). Table 5 summarizes general values found in this research.

Table 5 Recommended Transit Elasticity Values

	Market Segment	Short Term	Long Term
Transit ridership WRT transit fares	Overall	–0.2 to –0.5	–0.6 to –0.9
Transit ridership WRT transit fares	Peak	–0.15 to –0.3	–0.4 to –0.6
Transit ridership WRT transit fares	Off peak	–0.3 to –0.6	–0.8 to –1.0
Transit ridership WRT transit fares	Suburban Commuters	–0.3 to –0.6	–0.8 to –1.0
Transit ridership WRT transit service	Overall	0.50 to 0.7	0.7 to 1.1
Transit ridership WRT auto operating costs	Overall	0.05 to 0.15	0.2 to 0.4
Automobile travel WRT transit costs	Overall	0.03 to 0.1	0.15 to 0.3

Source: Todd Litman, 2004.

In most cases the fare change happens because of change in operating cost. Fare changes can also be used to increase or decrease ridership. For example, to alleviate peak periods or to shift/promote ridership to a less used period, one might implement a higher fare during those peak periods. The concept of transit pricing and fare changes is very simple, but the application can get complicated. The reason is because of so many different types of fares or fare categories available. There are many ways of purchasing the fare (single, multiple, or unlimited access). Another way of separating fares is in

1) Rider characteristics (student, military, disabled, etc.)
2) Trip characteristics (distance, duration, quality of service, and time period).

With all those options, most if not all transit agencies can have around 10 different fare categories for the same trip. A lot of the data on ridership response to fare changes is very old. Some of the newer research fortunately shows the same result as the old data.

If you reduce a fare, in order to complete the before-after analysis you would not only need to look at new ridership, but also those existing riders that used to use transit before the fare reduction. Getting this data may not be easy, as you would need to perform surveys, etc. The larger the city size, the smaller the elasticity. In other words, users are not as sensitive of fare changes in large cities compared to smaller cities, probably due to other options and choices. Table 6 presents elasticities with respect to some of the transit ridership factors, such as employment, population, headways, etc.

Table 6 Transit Ridership Factors

Factor	Elasticity
Regional Employment	0.25
Central City Population	0.61
Service (transit vehicle mileage)	0.71
Fare Price	-0.32
Wait Time	-0.30
Travel Time	-0.60
Headways	-0.20

Source: JHK, 1995; Kain and Liu, 1999

This table shows the elasticity of transit use with respect to various factors. We see that a 1 percent increase in regional employment is likely to increase transit ridership by 0.25 percent, while a 1 percent increase in fare prices will reduce ridership by 0.32 percent, all else being equal.

CHAPTER 3 TBEST MODEL

TBEST modeling software was briefly introduced in Chapter 1. This chapter will describe the model structure, model tools, methodology, and data requirements. TBEST was already introduced as the third generation transit planning tool developed by the Florida Department of Transportation that provides users short term transit planning capability, but it is much more than that. The research team consists of Ram Pendyala, Xuehao Chu, and Steve Polzin, together with Gannet Flaming support for the software development. TBEST forecasts ridership at the stop-level based on socio-demographics and accessibility to transit. Its user friendly ArcGIS interface allows for fast learning and use of the model. Some of the elements of TBEST are presented and described below.

3.1 Elements of TBEST

1) Direct and Transfer Boardings
2) Time of Day Based Analysis
3) Spatial Accessibility (Socio-Economic Characteristics)
4) Time-Space Network Connectivity
5) Competing and Complementary System Effects
6) GIS-Based Software Tool
7) Performance Measures

One of the distinctive features of the TBEST Model is the fact that it distinguishes between direct and transfer boardings. Transit passengers are either transferring of boarding directly at any given stop. Distinguishing between these two is important because it provides users better understanding of the trip linking that is occurring. Methodology for distinguishing between direct and transfer boardings is as follows. First, one should consider two stops, one with transfer opportunity and one without any transfer options. Using the data from the non-transfer stops, TBEST estimates the direct boardings model, then that model is applied to the transfer stops to estimate the boardings at the transfer opportunity stops. To estimate the transfer boardings, estimated direct boardings are subtracted from the total boardings. TBEST includes separate ridership estimation equations for each time of day and day of week. These times of day incorporated in TBEST are shown in Table 7. Different coefficients and equations were developed in order to account for the different ridership levels in different periods.

Table 7 Definitions of Time Periods in TBEST

Period No.	Period Name	Variable Description
1	Weekday morning peak period	6:00 – 8:59 AM
2	Weekday Off peak period	9:00 AM – 2:59 PM
3	Weekday evening peak period	3:00 – 5:59 PM
4	Weekday night period	6:00 PM – 5:59 AM (next day)
5	Saturday	12 midnight – 11:59 PM
6	Sunday	12 midnight – 11:59 PM

Various people characteristics can be attributed to different travel patterns. Such characteristics are age, income, auto availability, work status, race, etc. TBEST uses a circular buffer area around each stop to identify the market that has access to transit.

Figure 2 shows the TBEST Model user interface. Appendix A includes screenshots of the model's structure with descriptions.

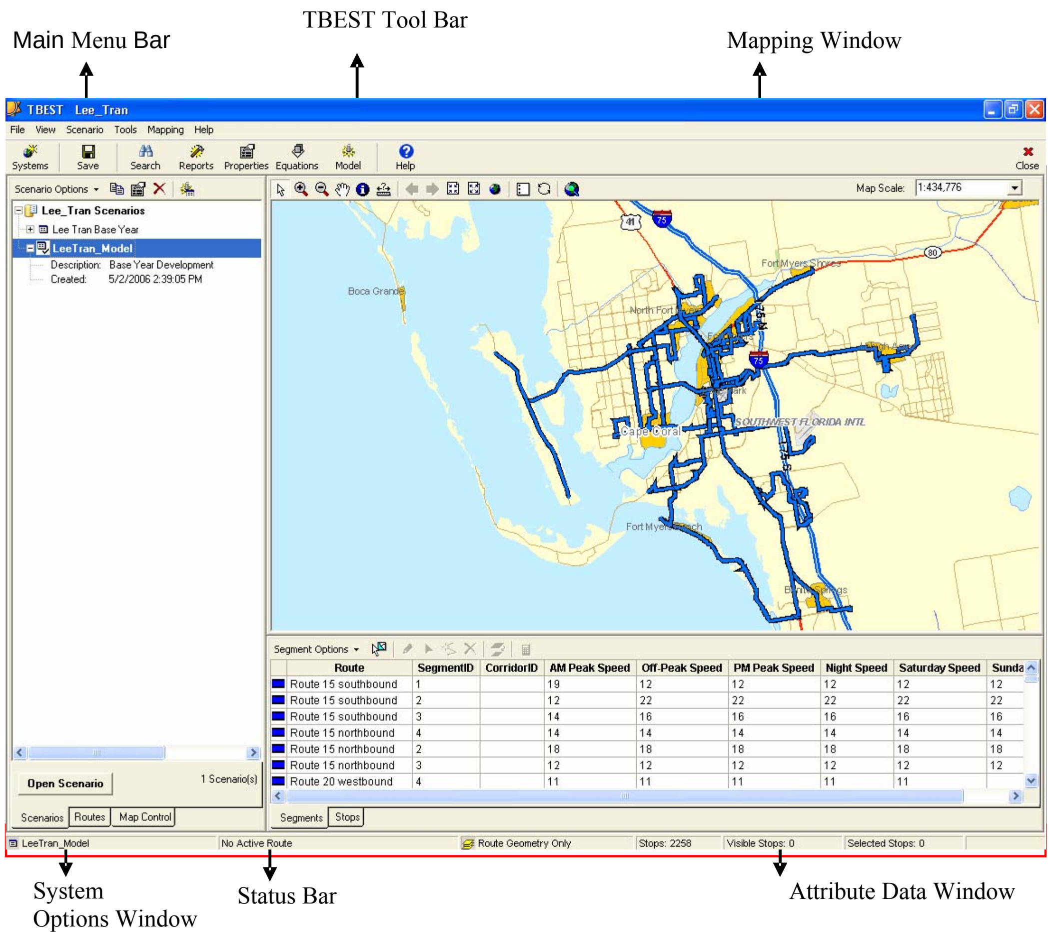

Figure 2 TBEST Model User Interface

There are a number of databases that TBEST needs to run:

1) 2000 Census data with pre-formatted SF1 and SF3 variables

2) 2000 InfoUSA employment data grouped by commercial, industrial, and service

3) 2000 GDT street networks

In addition, transit network and schedule data is stored in Microsoft SQL Server Express 2005. All Florida transit properties have already been coded and are ready for use.

3.2 Methodology

Section 3.2 provides the methodology used in TBEST and is based on the paper *A Framework of Modeling and Forecasting Stop-Level Transit Patronage* produced by Xuehao Chu, Steven E. Polzin, Ram Pendyala, and Ike Ubaka. As it was mentioned in the previous section, one of the key features of TBEST is that it distinguishes the direct boardings and transfer boardings. Therefore, the model structure consists of two sets of equations, direct and transfer. Direct boardings equation is as follows:

$$D_n^s = g\left(R_n^s, C^s, 0_{2n}^s, 0_{3n}^s, 0_{4n}^s, 0_{5n}^s, X_n^s\right), \quad n = 1,\ldots,N$$

where

s = index for any origin stop.
n = index for any time period.
N = number of time periods.
D_n^s = direct boarding at stop s during period n for the direction and along the route that define stop s.
R_n^s = number of bus runs departing 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.
0_{2n}^s = vector of accessibility to employment and population in the buffer areas of H_2 stops during period n.
0_{3n}^s = vector of accessibility to employment and population in the buffer areas of H_3 stops during period n.
0_{4n}^s = vector of accessibility to employment and population in the buffer areas of H_4 stops during period n.
0_{5n}^s = vector of accessibility to employment and population in the overlapped buffer areas H_5 stops and H_2 stops during period n.
X_n^s = vector of other stop and route characteristics during period n.

The methodology used here addresses three important features:

1) The model estimates and forecasts ridership at the individual stop-level

2) The model separates direct from transit boardings

3) Inter-relationship of the transit network is addressed by using the measure of accessibility to opportunities for potential activity

The big advantage new framework involving stop-level boardings is the ability to capture inter-relationship of the transit network and with that, providing more accurate evaluation of the impact to service changes. The framework proposes the individual stops being defined by spatial location, route association, and travel direction. There are two general component of the transit accessibility:

1) Access and egress to and from stops

2) Access from one stop to all other stops in the network

The standard accessibility measure is used where one adds up all the weighted opportunities across all accessible stops. This framework also uses impedance measured by cost of travel. Five measures of accessibility are used in this methodology. They include the measure of transfer potential from other routes at a subject stop, a measure of accessibility for three sets of accessible stops, and also a measure of accessibility for the shared buffer areas between stops. One should use Appendix A of the TBEST User Guide for more detailed and complete description of the framework and TBEST methodology.

CHAPTER 4 BASE CASE

4.1 Existing Conditions

This section will describe the existing conditions of Polk County in terms of demographics and transit services. It is always important to understand the base case in order to analyze the alternatives and the results one get from the alternative scenarios.

4.1.1 Demographics

Located in central Florida, Polk County population ranks number nine in the state with 541,840 residents in 2005. Since 2000, there has been an increase of 57,916 new residents. Figure 3 shows Polk County population from 1950 until 2005.

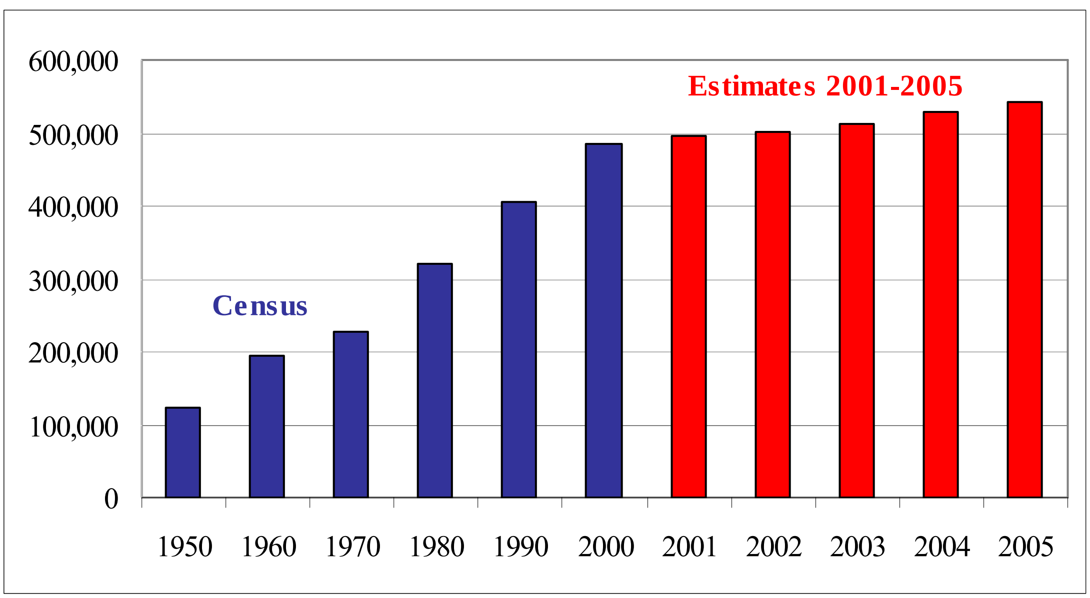

Figure 3 Polk County Population

The increase in population has been most likely due to affordable housing, and close proximity to the two major metropolitan areas, Tampa and Orlando. By 2030, University of Florida's Bureau of Economic and Business Research's (BEBR) shows projected growth in Polk County reaching 821,440 people. The two growing areas, Lakeland and Winter Haven are expected to merge and be identified as one in Census 2010.

4.1.2 Transit Services

The transit system in Polk County consists of three agencies, the Lakeland Area Mass Transit District (LAMTD), Winter Haven Area Transit (WHAT), and the Polk County Transit Services Division (PCTSD). LAMTD's Citrus Connection operates 21 routes and a downtown trolley route. WHAT consists of 9 routes. There are 7 routes that are operated by Citrus Connection and two routes operated by PCTSD. In addition PCTSD operates two rural routes. Those routes are route number 25 which provides service between Fort Meade and Bartow via Homeland and route 35, which operates from Frostproof to Eagle Ridge Mall through Lake Wales and Babson Park. Despite great coordination among these three different transit systems, duplicate administrative and operational functions, fragmented service, and complex roles and responsibilities are inevitable.

In 2004, the Polk County Regional Transportation Organization (RTO) was created. Some of the RTS goals are to try to implement a strategy for the transition to a regional or countywide transit authority. Consolidating the three existing transit service providers into one system will greatly benefit Polk County. Figure 4 shows the existing Polk County Transit System Organization chart. From this figure we see how complicated the system currently is.

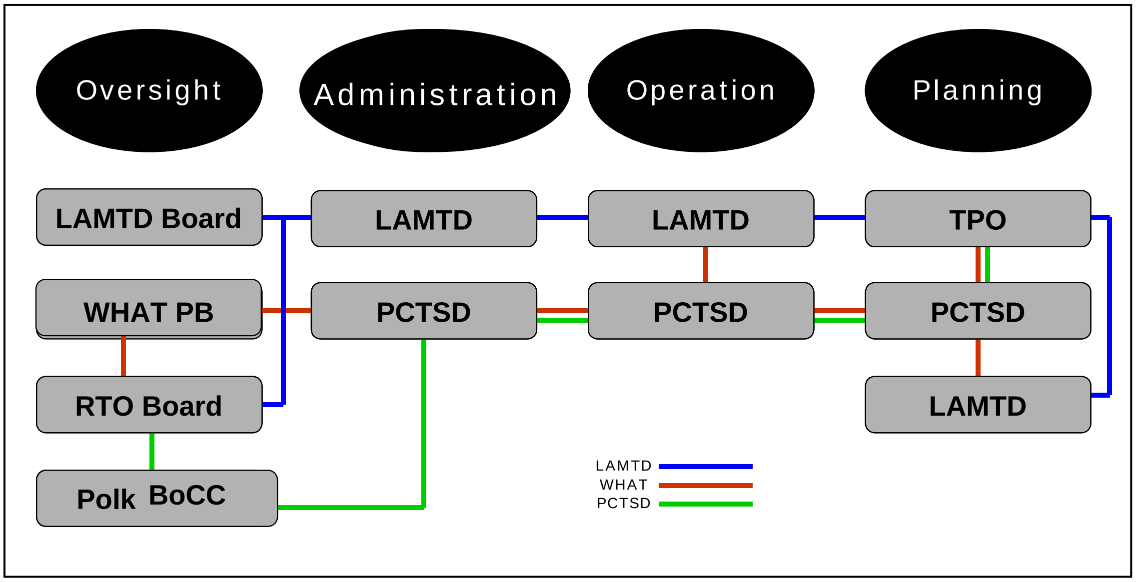

Figure 4 Polk County Transit System Organization Chart

4.2 TBEST Network Development

TBEST contains a 2006 pre-coded network for all Florida agencies. However, Polk County routes were coded as circulators when they were actually radial routes. In order to get the most accurate results, the correct network was developed. This was done by re-digitizing all the incorrect routes to radial types and then adding the stops in the correct locations.

4.2.1 Routes

As it was mentioned above, LAMTD operates 21 routes plus a downtown trolley. WHAT has 9 routes, 7 of which are operated by LAMTD's Citrus Connection and 2 by PCTS. Table 8, 9, and 10 lists the routs that were coded into TBEST for LAMTD, WHAT, and PCTSD systems respectively.

Table 8 Lakeland Area Mass Transit District Route Network

Route Name	Description	Type
LAMTD 10	Shuttle	CIRCULATOR
LAMTD 11	East Main/Combee Road	CIRCULATOR
LAMTD CONNECTOR 12	Winter Haven to Lakeland via Auburndale	RADIAL
LAMTD CONNECTOR 12	Lakeland to Winter Haven via Auburndale	RADIAL
LAMTD 20	Grove Park/Crystal Lake	RADIAL
LAMTD 21	Edgewood	RADIAL
LAMTD CONNECTOR 22XL	Lakeland to Bartow	RADIAL
WHAT CONNECTOR 22XW	Bartow to Winter Haven	RADIAL
LAMTD 30	Cleveland Heights	RADIAL
LAMTD 31	South Florida Ave.	RADIAL
LAMTD 32	Medulla Loop/Lakeside Village	RADIAL
LAMTD 37	South Lakeland	RADIAL
LAMTD 40	Ariana/ Beacon	RADIAL
LAMTD 41	Central Avenue	RADIAL
LAMTD 42	West Memorial	RADIAL
LAMTD 50	Kathleen	RADIAL
LAMTD 51	Lakeland Mall	RADIAL
LAMTD 52	North Florida Avenue	RADIAL
LAMTD 53	Lakeside Village	CIRCULATOR
LAMTD 56	Kathleen/Mall Hill Rd.	RADIAL
LAMTD 57	Kidron/Flightline	RADIAL
LAMTD Citrus Trolley	Downtown Trolley	CIRCULATOR

Table 9 Winter Haven Area Transit Route Network

Route Name	Description	Type
WHAT 10	Northside	RADIAL
WHAT 12	Lakeland to Winter Haven via Auburndale	RADIAL
WHAT 15	Haines City	RADIAL
WHAT 20	PCC / Hospital	RADIAL
WHAT CONNECTOR 22XW	Bartow Express to Winter Haven	RADIAL
WHAT 30	Eagle Ridge Mall / Winter Haven	RADIAL
WHAT 40	Southside	RADIAL
WHAT 44	Southwest	RADIAL
WHAT 50	Westside	RADIAL

Table 10 Polk County Transit Services Route Network

PCTSD		
Route Name	**Description**	**Type**
PCTSD 25	Fort Meade to Bartow	RADIAL
PCTSD 35	Frostproof to Eagle Ridge Mall	RADIAL

4.2.2 Stops

Polk Transportation Planning Organization provided a bus stop inventory in the excel format. The inventory contained detailed information such as location, stop name, and the X and Y coordinates. From those X and Y coordinates it was possible to import the stops layer through GIS into TBEST. However, the stops needed to be coded into TBEST.

4.2.3 Network Attributes

Network attributes such as arrivals, travel time, service span, fare structure, and growth rates are all variables that needed to be input. The number of arrivals and service span was input for all time periods as defined by TBEST using the route schedules. TBEST calculates travel time by using the following equation. Travel time is calculated from stop to stop. Arrivals definition can be described by the following equation:

$$\text{Arrivals} = \left[\frac{60}{\text{Headway}}\right] \times \left[\text{Number of Hours in Defined Time Period}\right]$$

Table 11 shows the fixed route fares. Fare system/structure is the same for all three systems.

Table 11 Fare Structure for LAMTD, WHAT, and PCTSD Systems

Rider Type	Fares
Adult	$ 1.00
Children under 5	Free
Student (Grades 1-12)	$ 0.75
Senior	$ 0.50
Disabled	$ 0.50

Special generators are important in the sense that they can provide simple explanations for certain high or low ridership numbers. Special generators are stops that attract certain demographics. An example of those special generators and what TBEST uses are university, shopping mall, event center, park-n-ride, airport, and recreational park.

TBEST equations treat all of these the same way. A list of special generators was provided by the Polk Transportation Planning Organization. This was then added into the TBEST Model.

Table 12 Special Generators

Special Generator	Route
Lakeland Regional Medical Center - Lakeland Hills Blvd	LAMTD 51, 52
Polk Community College/USF/Travis Technical Center - US Hwy 98	LAMTD 22XL, 21
Kathleen High School - US Hwy 92 (Memorial Blvd)	LAMTD 42
Lakeland Government Center	LAMTD 10, 11, 52
Florida Metropolitan University	LAMTD 52
Florida Southern College	LAMTD 30
Polk Community College Winter Haven	WHAT 20
Winter Haven Hospital	WHAT 20
Gil Jones Government Center	WHAT 10, 15
Winter Haven High School	WHAT 30

4.3 TBEST Calibration and Scaling

After the network development was complete, the next step was to calibrate the model and save it as base year. TBEST Model calibration consists of five steps:

1) Entering stop-level observed ridership
2) Defining route collections
3) Entering collection-level observed ridership
4) Saving scenario as base year
5) Viewing collection-level calibration factors

The first step is to collect the raw data such as ridership for each individual route. In this case, Polk County provided the monthly route ridership data by weekday and Saturday for all three transit systems. The data was then organized in the form that is appropriate for the TBEST Model. After the necessary information was input into the model, the next step was to forecast the model using the default equations. Once the model run was complete, it was saved as "Base Year" and we were able to view our calibration results and scaling factors. TBEST scaling process was designed to automatically fit the calibrated model in order to replicate the actual ridership data and to adjust for items not captured by the model coefficients. The scaling factors are then applied to all stops along individual routes for all future forecasting scenarios and model applications. There are two types of scaling TBEST allows users to apply. One is called the special generator scaling and the other one route-level scaling. Special generator scaling is applied to unique stops that generate ridership that would not be reflected by the socio-demographics or service level data in the model. Examples of those unique stops are shown in Table 12. This calibration step of entering the unique stops into the model is optional. The results of the route-level scaling which was performed in this analysis are presented in the next section.

4.3.1 System Results

Table 13 shows the weekday observed versus TBEST estimated ridership by route as well as the scaling factor.

Table 13 Weekday Observed Versus TBEST Estimated Ridership by Route

Route	Observed	TBEST Estimated	Scaling Factor
CC_Route 10	153	38	4.08
CC_Route 11	311	106	2.95
CC_WHAT_Route 12	608	229	2.65
Route 25 (rural)	105	29	3.57
WHAT_Route 30	407	98	4.16
CC_Route 20	348	102	3.42
CC_Route 21	143	65	2.22
CC_Route 22XL	278	101	2.75
CC_Route 30	115	56	2.06
CC_Route 31	709	630	1.13
CC_Route 32	22	14	1.55
CC_Route 37	38	10	3.79
CC_Route 40	103	94	1.1
CC_Route 41	300	79	3.81
CC_Route 42	535	310	1.73
CC_Route 50	268	198	1.36
CC_Route 51	731	649	1.13
CC_Route 52	729	391	1.86
CC_Route 53	113	87	1.3
CC_Route 56	202	82	2.48
CC_Route 57	111	88	1.26
Route 35 (rural)	76	120	0.63
WHAT_Route 10	268	75	3.59
WHAT_Route 15	153	38	4.07
WHAT_Route 20	79	44	1.82
WHAT_Route 22XW	205	85	2.42
WHAT_Route 40	189	132	1.44
WHAT_Route 44	195	77	2.54
WHAT_Route 50	143	75	1.91

Figure 5 is a graphical presentation of the weekday observed versus TBEST Model estimated ridership.

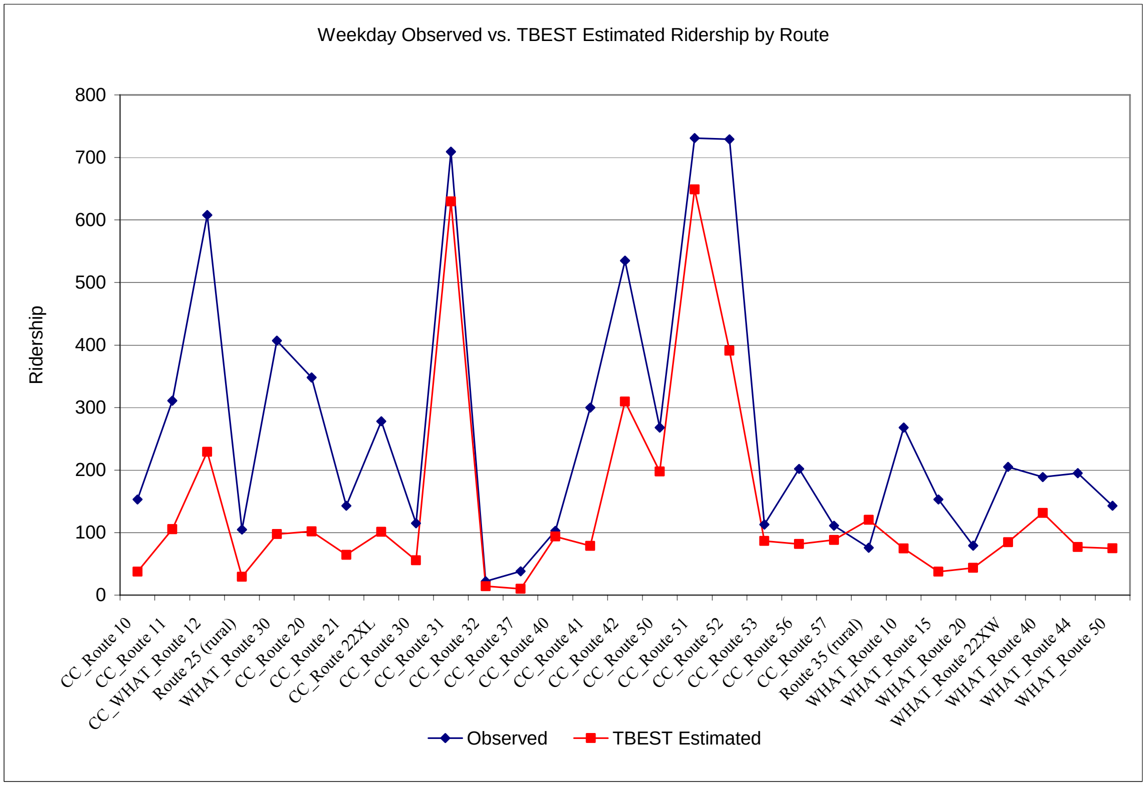

Figure 5 Weekday Observed Versus TBEST Estimated Ridership by Route

Table 14 shows the Saturday observed versus TBEST estimated ridership by route, as well as the scaling factor.

Table 14 Saturday Observed Versus TBEST Estimated Ridership by Route

Route	Observed	TBEST Estimated	Scaling Factor
CC_Route 10	107	28	3.77
CC_Route 11	185	66	2.81
CC_WHAT_Route 12	452	253	1.78
Route 25 (rural)	57	27	2.14
WHAT_Route 30	267	89	2.99
CC_Route 20	182	69	2.64
CC_Route 21	86	40	2.17
CC_Route 22XL	146	81	1.81
CC_Route 30	50	24	2.07
CC_Route 31	553	492	1.12
CC_Route 32	19	17	1.11
CC_Route 37	33	8	4.03
CC_Route 40	52	66	0.79
CC_Route 41	205	54	3.78
CC_Route 42	290	243	1.19
CC_Route 50	194	212	0.91
CC_Route 51	636	605	1.05
CC_Route 52	346	309	1.12
CC_Route 53	72	63	1.14
CC_Route 56	169	97	1.74
CC_Route 57	42	64	0.66
Route 35 (rural)	71	140	0.51
WHAT_Route 10	198	57	3.5
WHAT_Route 15	121	37	3.23
WHAT_Route 20	52	28	1.87
WHAT_Route 22XW	111	67	1.66
WHAT_Route 40	185	182	1.02
WHAT_Route 44	144	56	2.57
WHAT_Route 50	98	61	1.61

Figure 6 is a graphical presentation of the Saturday observed versus TBEST Model estimated ridership.

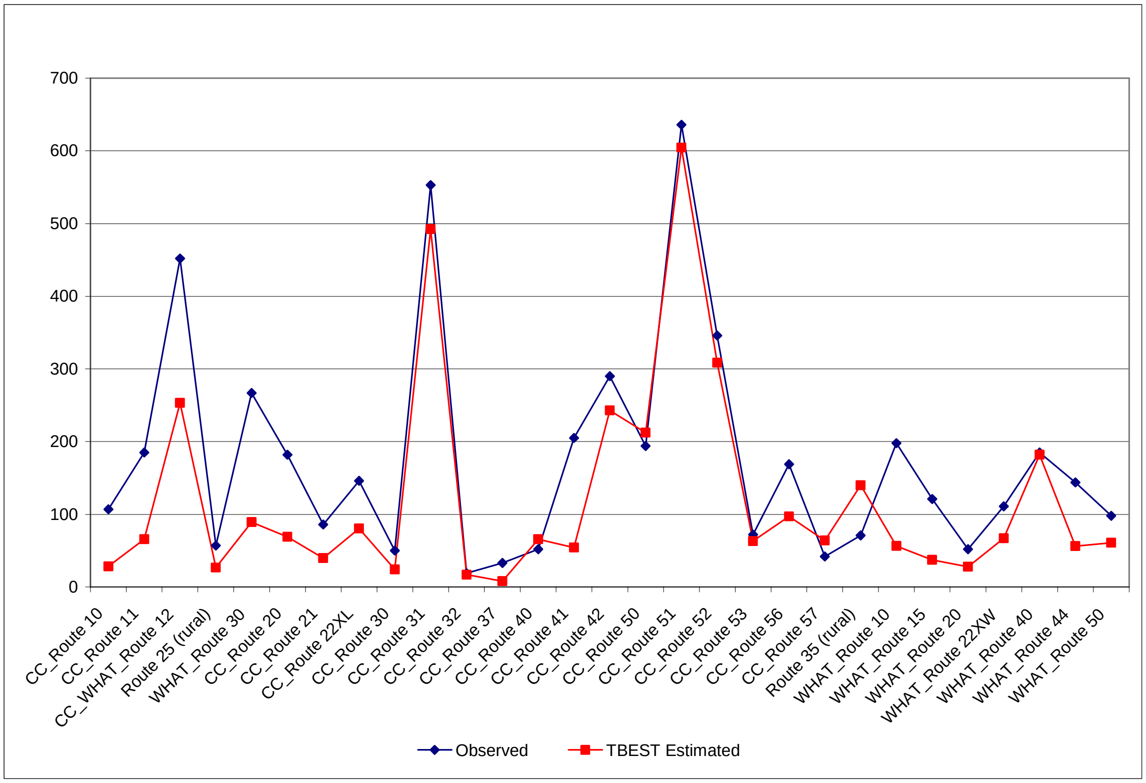

Figure 6 Saturday Observed Versus TBEST Estimated Ridership by Route

System results for both weekday and Saturday observed versus TBEST estimated ridership are shown in Table 15 and Figure 7. From the calibration summary Figure 7, we see that the TBEST Model estimates Saturday ridership better than the weekday.

Table 15 Calibration Summary

	Observed	TBEST Estimated	Scaling Factor
Weekday	7,637	4,097	1.86
Saturday	5,123	3,535	1.45

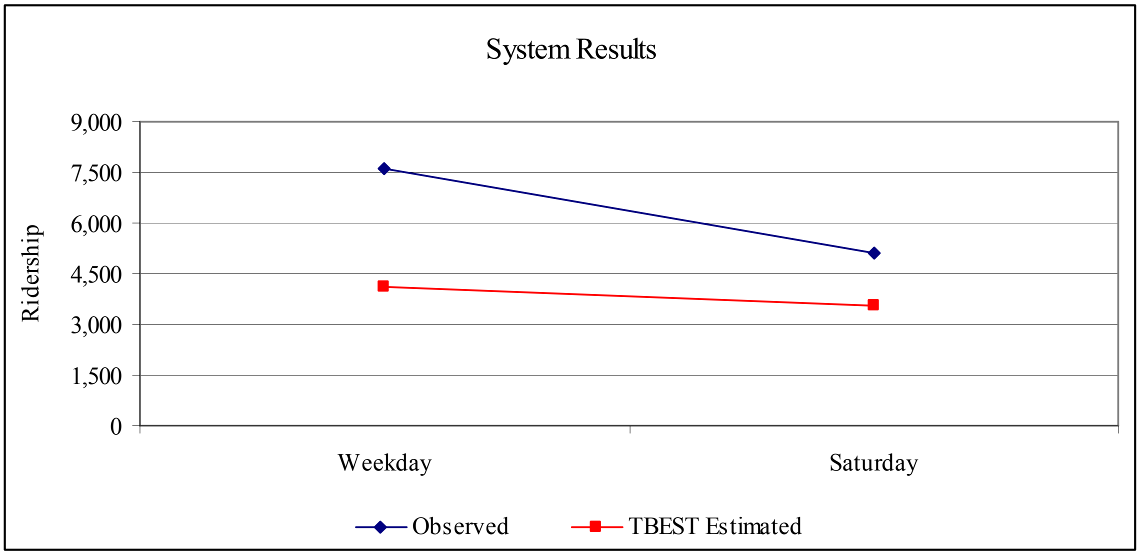

Figure 7 Calibration Summary

CHAPTER 5 ALTERNATIVE SCENARIOS AND MODEL RESULTS

5.1 Alternative Scenarios

Four major alternative scenario categories were created. Table 16 provides those scenarios their description. Alternative 1 involved various headway changes. Alternative 2 tested different service allocation changes. Service span analysis involved adding Sunday service and other assessment. Alternative number 4, similar to headway, involved various travel time changes and the ridership response analysis to those. Results of the alternative scenarios were compared to the base year as it was described in Chapter 4.

Table 16 Polk County Alternatives

Alternative	Description
1	Headway changes
2	Service allocation changes
3	Service span analysis - Sunday service addition
4	Travel time changes

5.1.1 Headway

Headway elasticities tend to vary significantly depending on different characteristics of routes, current level of service, etc. A series of model runs was set up altering the headway by various amounts for each time period, as shown in Table 17.

Table 17 Alternative 1 Headway Scenarios

Headway
Base
-60%
-50%
-40%
-20%
20%
40%
50%
60%
100%

Elasticities were calculated for the system and for all the individual routes. Appendix A contains some of the model outputs for each scenario created. Average headway elasticities were calculated and compared to different time periods. Table 18 and 19 show the weekday and Saturday system percent change of ridership for each time period for all nine scenarios.

Table 18 Weekday Ridership Response to Headway Changes by Time Period

	AM Peak		PM Peak		Off Peak		Night	
Headway	Ridership	% Δ	Ridership	% Δ	Ridership	% Δ	Ridership	% Δ
Base	1120		1760		4598		158	
-60%	7900	605%	10073	472%	23941	421%	764	384%
-50%	4669	317%	6244	255%	16046	249%	624	295%
-40%	3163	182%	4437	152%	11557	151%	525	232%
-20%	1868	67%	2843	62%	7316	59%	174	10%
20%	642	-43%	1032	-41%	3294	-28%	146	-8%
40%	498	-56%	891	-49%	2447	-47%	115	-27%
50%	496	-56%	889	-49%	2263	-51%	115	-27%
60%	474	-58%	857	-51%	2202	-52%	115	-27%
100%	404	-64%	756	-57%	1370	-70%	27	-83%

Table 19 Saturday Ridership Response to Headway Changes by Time Period

	Saturday	
Headway	Ridership	% Δ
Base	5123	
-60%	20938	309%
-50%	14452	182%
-40%	11007	115%
-20%	7005	37%
20%	3880	-24%
40%	3138	-39%
50%	2851	-44%
60%	2555	-50%
100%	1987	-61%

Figure 8 is a plot of ridership responses by time period to headway changes as described in Table 17. From this graph we see that the ridership is not as responsive to headway increases as it is with the headway decreases. This may be attributed to "captive" riders. Because transit users that have no or limited choice to any alternative modes, increasing the headway may not cause much decrease in ridership. Most of the literature described the elasticities being higher in the off peak periods. Off peak periods are associated with mostly recreational and choice travel. Table 20 presents the calculated elasticities for all time periods and comparison of elasticities for the weekday and Saturday period. Unexpectedly, we see higher elasticities in the peak periods than off peak.

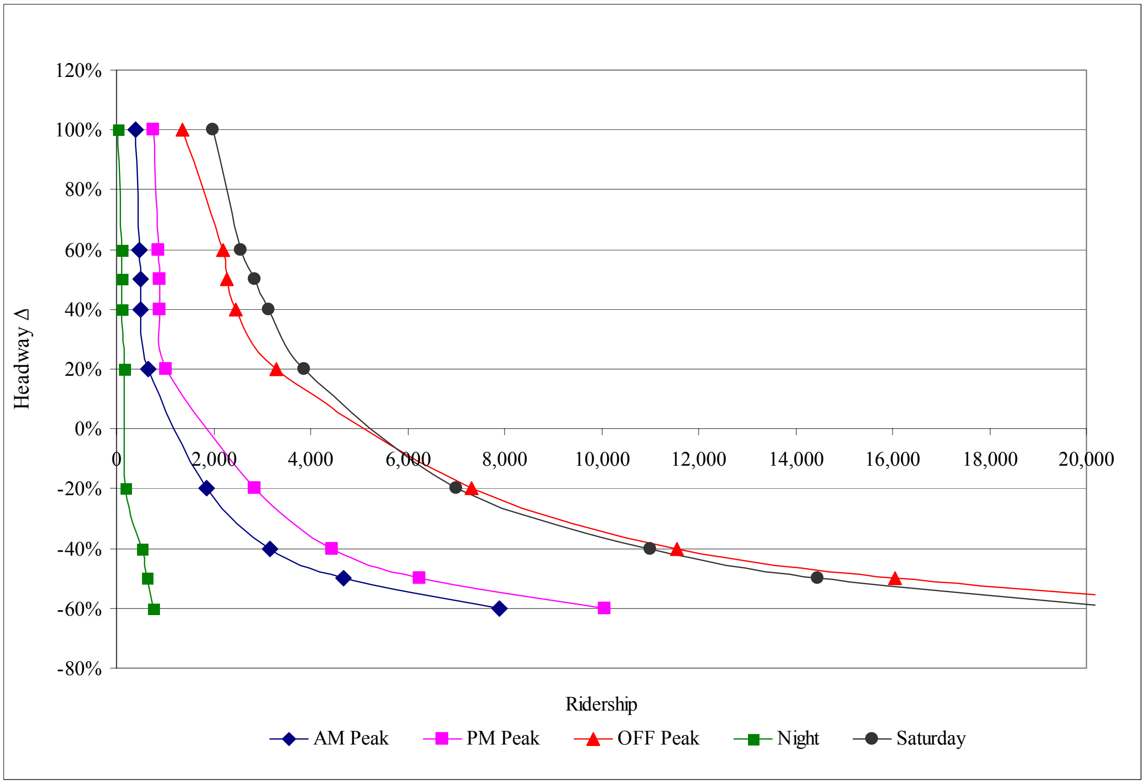

Figure 8 Ridership Responses to Headway Changes by Time Period

Table 20 System Elasticities by Time Period

Headway	AM PEAK	PM Peak	Off Peak	Night	Weekday	Saturday
Base						
-60%	-2.13	-1.90	-1.80	-1.72	-1.88	-1.54
-50%	-2.06	-1.83	-1.80	-1.98	-1.85	-1.50
-40%	-2.03	-1.81	-1.80	-2.34	-1.85	-1.50
-20%	-2.29	-2.15	-2.08	-0.42	-2.10	-1.40
20%	-3.05	-2.93	-1.83	-0.44	-2.20	-1.52
40%	-2.41	-2.02	-1.87	-0.95	-1.96	-1.46
50%	-2.01	-1.69	-1.75	-0.79	-1.75	-1.45
60%	-1.83	-1.53	-1.57	-0.68	-1.57	-1.48
100%	-1.47	-1.22	-1.75	-2.57	-1.58	-1.37

Another comparison was done by the current level of service. Current level of service was defined by three levels – high, medium, and low. High level of service was considered to be if the headway is between 30 and 40 minutes, medium if the headway is between 45 and 60 minutes, and low if the headway is more than 60 minutes. The case scenario, Polk County, had the lowest headway of 30 minutes and highest of 120 minutes. The headway is 60 minutes for over 80 percent of the stops. Current level of service by route as defined above is also presented in Appendix B, Table 29. Table below shows the number of stops in each service level category by time period.

Table 21 Number of Stops in Each Service Level Category

	AM Peak	Off Peak	PM Peak	Night	Saturday
High	405	364	364	100	364
Medium	1609	1393	1650	1658	1464
Low	81	338	81	0	265

Tables 22 and 23 present the elasticities calculated and sorted based on the current level of service. Here we see more familiar results when comparing to literature. Higher elasticities can be usually observed where the initial service is low. However decreasing headway by 50 percent indicates higher elasticities where the initial service is high. The elasticities are visibly higher where the original service was low when decreasing headway by 50 percent.

Table 22 Decreasing Headway – Elasticities Based on Current Level of Service

Decreasing Headway by 50%						
Original LOS	Route	AM Peak	PM Peak	Off Peak	Night	Saturday
High	CC_Route 31	-2.35	-1.86	-1.86	-2.11	-1.52
Medium	CC_Route 50	-2.00	-1.94	-1.74	-2.04	-1.37
Low	CC_Route 32	-1.90	-1.78	-1.81	-	-1.53

Table 23 Increasing Headway – Elasticities Based on Current Level of Service

Increasing Headway by 50%						
Original LOS	Route	AM Peak	PM Peak	Off Peak	Night	Saturday
High	CC_Route 31	-1.89	-1.66	-1.79	-1.65	-1.45
Medium	CC_Route 50	-2.45	-1.87	-1.85	-0.03	-1.17
Low	CC_Route 32	-3.20	-2.82	-1.89	-	-1.53

5.1.2 Service Allocation

Service allocation analysis was performed as Alternative 2. Two routes were selected – Route CC_Route_31 and the express route 22XL. In one alternative, Route_31 was copied and named Route_31A. Only half the service of the Route_31 was placed on the Route_31A. Another alternative was created where the Route_31 was copied with the exact same amount of service. The results were then compared to increasing the service frequency by 20, 40, 50 and 100 percent. The same procedure was done with the express Route_22XL. Table 24 displays these results.

Table 24 Service Allocation and Frequency Analysis

	AM Peak		Off Peak	
	Ridership	% Δ	Ridership	% Δ
Base	1120		4598	
20 % Frequency Increase	1733	55%	6092	32%
40 % Frequency Increase	2051	83%	8049	75%
50 % Frequency Increase	2250	101%	9481	106%
100% Frequency Increase	4670	317%	16046	249%
Route 31A added with half service of Route 31	1234	10%	5105	11%
Route 31A added with full service of Route 31	1442	29%	6040	31%
Route 22XL_A added with half service of Route 22XL	1143	2%	4615	0.4%
Route 22XL_A added with full service of Route 22XL	1199	7%	4674	2%

Table 24 Continued

	PM Peak		Night	
	Ridership	% Δ	Ridership	% Δ
Base	1760		158	
20 % Frequency Increase	2674	52%	174	10%
40 % Frequency Increase	2953	68%	211	33%
50 % Frequency Increase	3154	79%	521	230%
100% Frequency Increase	6244	255%	624	295%
Route 31A added with half service of Route 31	1927	9%	215	36%
Route 31A added with full service of Route 31	2247	28%	256	62%
Route 22XL_A added with half service of Route 22XL	1808	3%	163	3%
Route 22XL_A added with full service of Route 22XL	1890	7%	163	3%

One would expect the same results when comparing the 50 percent frequency increase with the increase of the additional route that is added. However, we see very different results. In the AM Peak period, 50 percent frequency increase produced over 100 percent increase in ridership. However, the route addition produced only 10 percent increase for the Route 31 and an even smaller increase of 2 percent for the express route 22XL. Figure 9 displays those results.

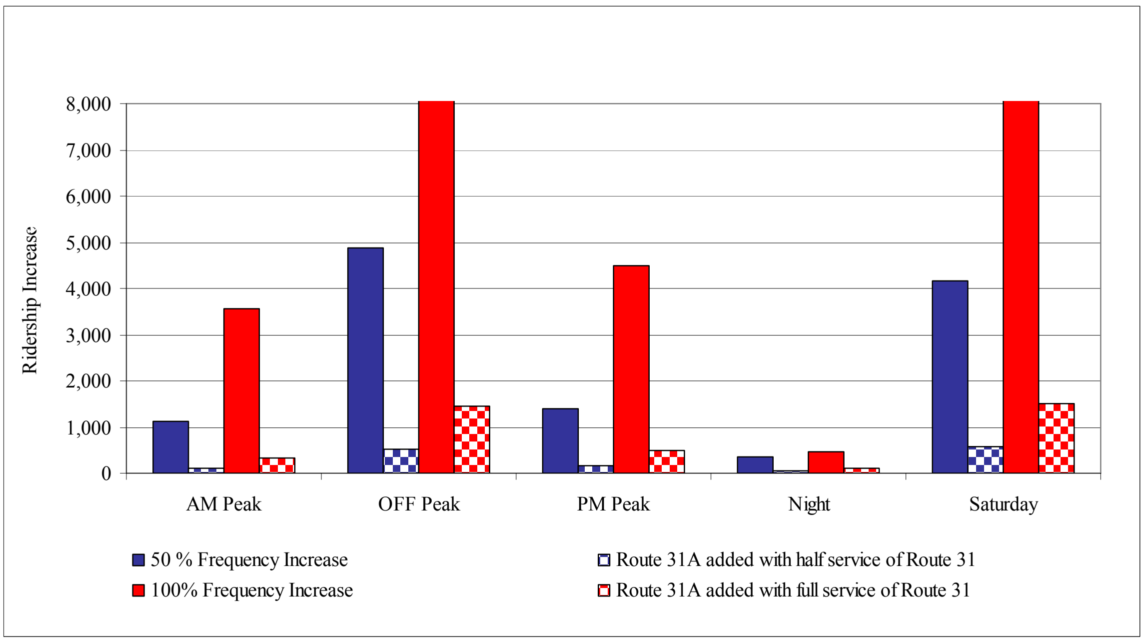

Figure 9 Service Allocation Analysis Route 31

5.1.3 Span of Service

Polk County currently operates from Monday through Saturday. For the span of service analysis, Sunday service was introduced. Sunday service scenario that was added replicated the Saturday service in terms of arrivals and speed. After the model run, the results produced an additional 3,297 riders. Another scenario was created, increasing the service span and arrivals for the night period. The number of arrivals at each stop was increased to 3. The speed for the night period was input the same as the off peak period. The headway was set to 40 minutes.

Table 25 Night Service Span Increase

	AM Peak	Off Peak	PM Peak	NIGHT
Base	1120	4598	1760	158
NIGHT Service Increase	559	2535	910	472
% Δ	-50%	-45%	-48%	199%

These changes produced results shown in Table 25. The night period produced an increase of almost 200 percent while during all other periods the ridership decreased by nearly 50 percent. Further analysis of applying the same amount of service increase to other time periods and then comparing the results would be beneficial.

5.1.4 Travel Time

One of the most important factors affecting public transit ridership is the travel time. Eight scenarios were created to test the sensitivity of travel time. This involved increasing and decreasing ridership by 10, 20, 30, and 50 percent for all time periods. Tables 26 and 27 show the ridership response to travel time changes for weekday and Saturday period.

Table 26 Weekday Ridership Response to Travel Time Changes by Time Period

Travel Time	AM Peak		Off Peak		PM Peak		Night	
Base	1120		4598		1760		158	
-50%	1184	5.7%	4692	2.1%	1869	6.2%	169	7.0%
-30%	1162	3.7%	4654	1.2%	1814	3.1%	161	2.1%
-20%	1142	2.0%	4639	0.9%	1796	2.0%	161	1.8%
-10%	1130	0.9%	4618	0.4%	1778	1.0%	160	1.1%
10%	1110	-0.9%	4580	-0.4%	1742	-1.0%	158	0.0%
20%	1101	-1.7%	4560	-0.8%	1724	-2.0%	157	-0.7%
30%	1097	-2.0%	4547	-1.1%	1710	-2.9%	156	-1.1%
50%	1072	-4.3%	4509	-1.9%	1680	-4.6%	153	-3.2%

Table 27 Saturday Ridership Response to Travel Time Changes by Time Period

Travel Time	Saturday		Weekday	
Base	5123		7637	
-50%	5228	2.0%	7914	3.6%
-30%	5180	1.1%	7791	2.0%
-20%	5162	0.8%	7737	1.3%
-10%	5144	0.4%	7686	0.6%
10%	5104	-0.4%	7590	-0.6%
20%	5086	-0.7%	7542	-1.2%
30%	5070	-1.0%	7510	-1.7%
50%	5039	-1.6%	7412	-2.9%

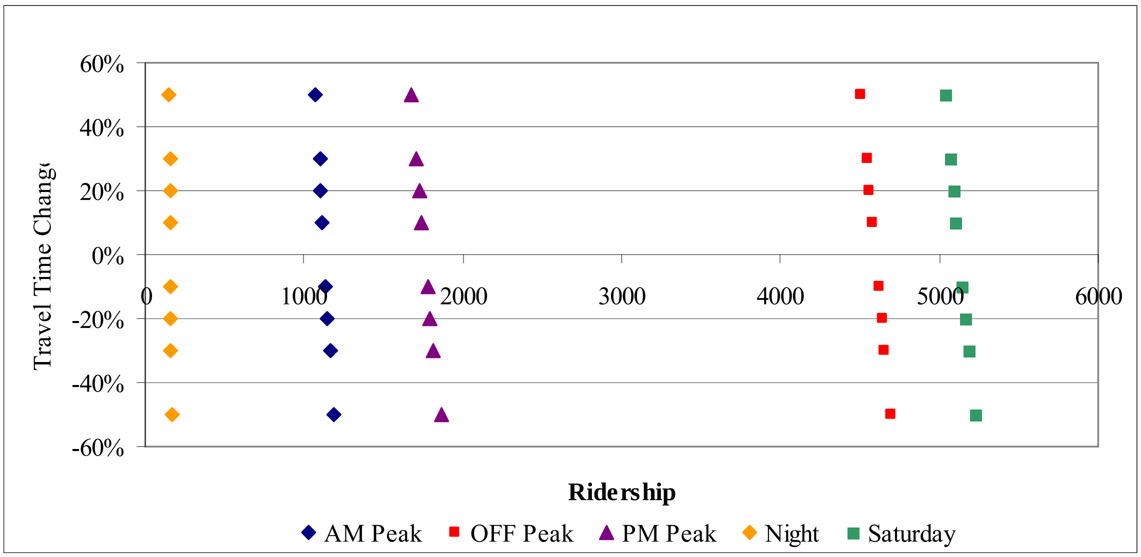

Figure 10 Ridership Response to Travel Time Changes by Time Period

TBEST Model results for travel time variations show almost no sensitivity at all. Elasticities were calculated using the approximated point elasticity formula. Table 28 shows the results and we can see that the elasticity is very low. The travel time analyzed in this section involved using only in-vehicle time. However total trip times includes access, wait, in-vehicle, transfer, and egress time. One can expect that headway and out-of-vehicle time elasticities to be similar. Literature suggests that evidence on the out-of-vehicle time elasticities (walk, wait, and transfer) as it relates to in-vehicle time is inconsistent. Quarmby (1967) estimated out-of-vehicle time elasticities to be two to three times higher than in-vehicle time elasticities.

Table 28 Travel Time Elasticities

Travel Time	AM Peak	Off Peak	PM Peak	Night	Saturday	Weekday
-50%	-0.11	-0.04	-0.12	-0.14	-0.04	-0.07
-30%	-0.12	-0.04	-0.10	-0.07	-0.04	-0.07
-20%	-0.10	-0.04	-0.10	-0.09	-0.04	-0.07
-10%	-0.09	-0.04	-0.10	-0.11	-0.04	-0.06
10%	-0.09	-0.04	-0.10	0.00	-0.04	-0.06
20%	-0.09	-0.04	-0.10	-0.03	-0.04	-0.06
30%	-0.07	-0.04	-0.10	-0.04	-0.03	-0.06
50%	-0.09	-0.04	-0.09	-0.06	-0.03	-0.06

CHAPTER 6 CONCLUSIONS AND FURTHER RESEARCH

6.1 Conclusions

Being able to quantify the ridership response to different service changes is an important area in transportation planning. Weather budget or service planning related, transit agencies will always look for better ways to analyze their network and transit system. This paper introduced new planning software that is capable of capturing those ridership responses, TBEST. With TBEST, we are a step closer to better and easier analysis of the ridership response, ridership forecasting, and network modeling. TBEST was used to produce general sensitivity of the model and to compare the results to transit elasticities shown in the literature. Sensitivity analysis was performed in four different areas. Headway, travel time, service span, and service allocation were analyzed. Some of the transit elasticities were described in the literature review and can be summarized as following.

1) Average service elasticity is around -0.5
2) Ridership response to service changes is inelastic
3) Off peak period ridership is more responsive than peak period
4) Higher elasticities tend to occur in the low service areas
5) Ridership is more responsive in headway improvements than travel time improvements

Based on these few observations, there are number of conclusions that can be drawn from the results.

First alternative involved headway analysis. From the results obtained, we see that TBEST overestimates ridership response. The headway elasticities calculated do not compare with the literature. Unreasonably high ridership increase occurs when the headway is decreased by even only 40 percent. In other words, decreasing headway from 60 minutes to 36 minutes resulted in 182 percent ridership increase in the AM peak period and over 200 percent ridership increase in the night period. Literature also suggests that the ridership is more sensitive to off peak periods then peak periods. The elasticities calculated by time period contradict that phenomenon. However, many factors such as the socio-demographics, land use, and accessibility can influence these results. Further analysis of the headway elasticities revealed that increasing the headway does produce higher ridership response in the low service areas as shown in the literature. However, we see the opposite effect when decreasing the headway. This may be attributed to high area with captive riders.

Service span analysis involved adding Sunday service. This produced additional ridership of over 3,000 passengers. Additional analysis was performed by increasing the span if service the night period. An increase of almost 200 percent riders was observed. Literature does report that there are high responses to extended evening service, especially after the PM peak period. This may be due to the assurance to riders in case they are stranded at work due to a late meeting, that the transit service is available to them in those situations. To better understand the model sensitivity to service span, further analysis of applying the same amount of service increase to other time periods and then comparing it to the results obtained for the night period is necessary.

Service allocation analysis involved increasing the frequency and adding a route with half the service of the route that it is mirroring. Same or similar response is expected as we are adding the same amount of service different way. TBEST however, produced unreasonable results of ridership being far more responsive to frequency improvements than route additions. Frequency increase of 50 percent produced ridership increase of over 100 percent whereas the route addition produced only 10 percent increase for route 31 and only 2 percent for the express route XL.

Travel time sensitivity analysis was also performed. The results obtained show very little ridership response to travel time. Decreasing the travel time by 50 percent produced an increase of 7.0 percent in the night period and 5.7 percent during the AM peak period. Measuring ridership response to total travel time as well as in-vehicle travel time is difficult. Therefore the literature and evidence on these is modest. The literature that does exist on in vehicle travel time ridership response, however, shows an aggregate value of -0.35. TBEST results do not compare to this, as the elasticities obtained are much lower.

6.2 Further Research

TBEST is capable of providing ridership response to different service changes. Based on the sensitivity results provided in this paper, TBEST overestimates and shows unreasonable estimates for the ridership response to headway changes. The elasticities are significantly higher than what the literature suggests. Travel time has shown almost no sensitivity, which contradicts the literature. All the results, however, do provide a predictable pattern in terms of increase or decrease of ridership to certain service changes.

Much of the analysis was time consuming. In addition to lengthy model run times, the ridership output reports available to download are individual reports by time period. Having six time periods and multiple scenarios can lead to time consuming and cumbersome data collection and formatting. A possible software improvement suggestion would be to add a similar to batch model function. A batch reports function where a user could select the time periods to download in one spreadsheet would be beneficial for data analysis purposes. Common use function in many computer applications is the undo function. TBEST does not have this, therefore saving often is critical. Also high performance computers are recommended, especially for larger transit systems. Transit systems similar in size, socio-demographics, and network to Polk County can expect same or similar results.

The objective of this paper was to provide users a general idea of the model sensitivities and to help further improvement of the model. This was achieved by the sensitivity analysis performed on some of the variables. In order to further improve the model, additional testing and sensitivity analysis is needed. Because of unreasonable results especially in the frequency area, the equations and coefficients of the model need to be altered. Model methodology and direct boarding equation were introduced in Chapter 3. However, for satisfactory results one needs full understanding of the model equations and coefficients in order to alter them. A new series of the model sensitivity analysis would then need to be performed.

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APPENDICES

APPENDIX A TBEST Model

Appendix A contains the screenshots from TBEST showing many opportunities of the model.

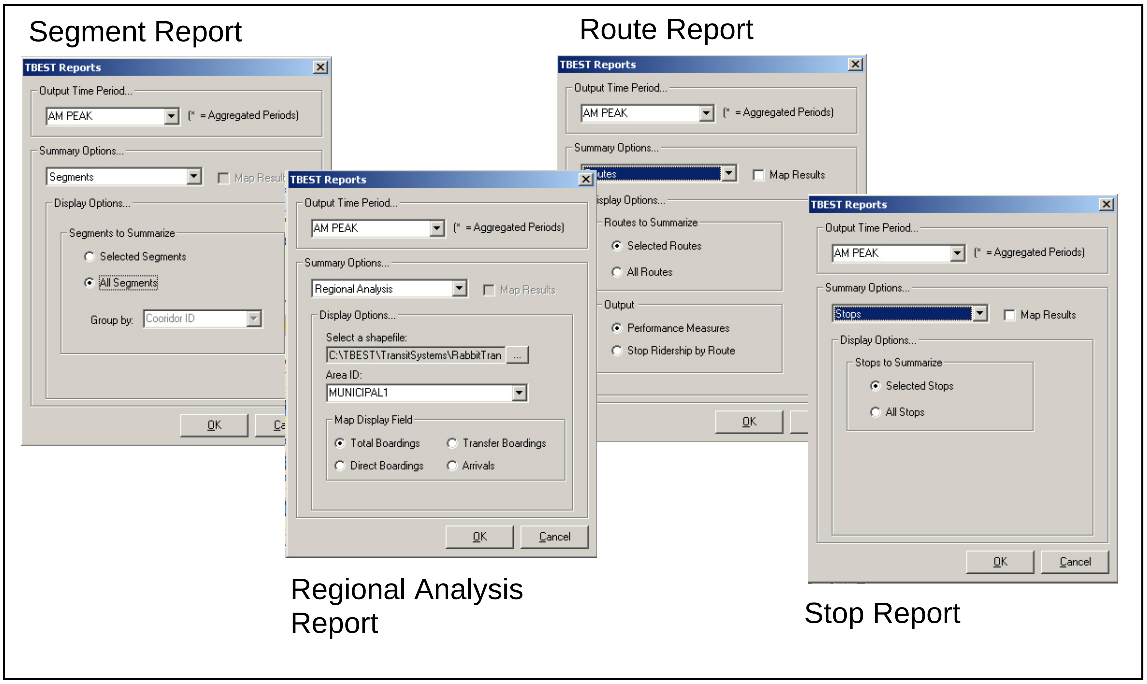


Figure 11 Different Types of Reports

APPENDIX A (Continued)

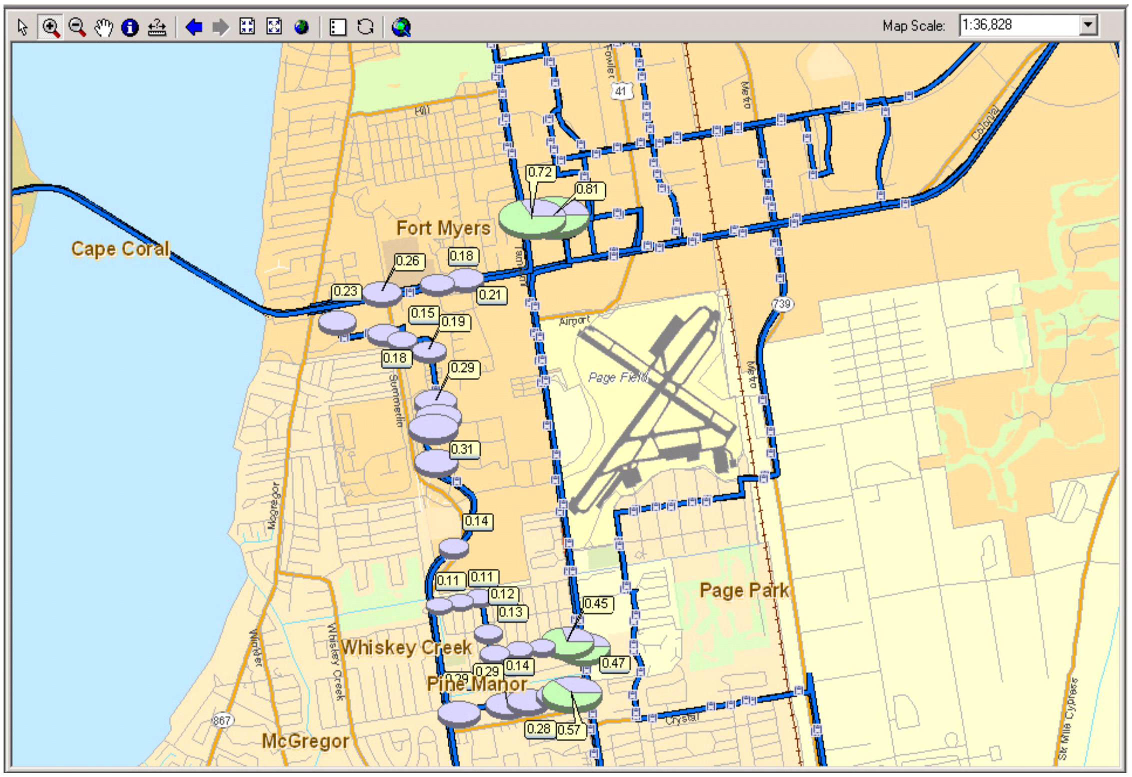
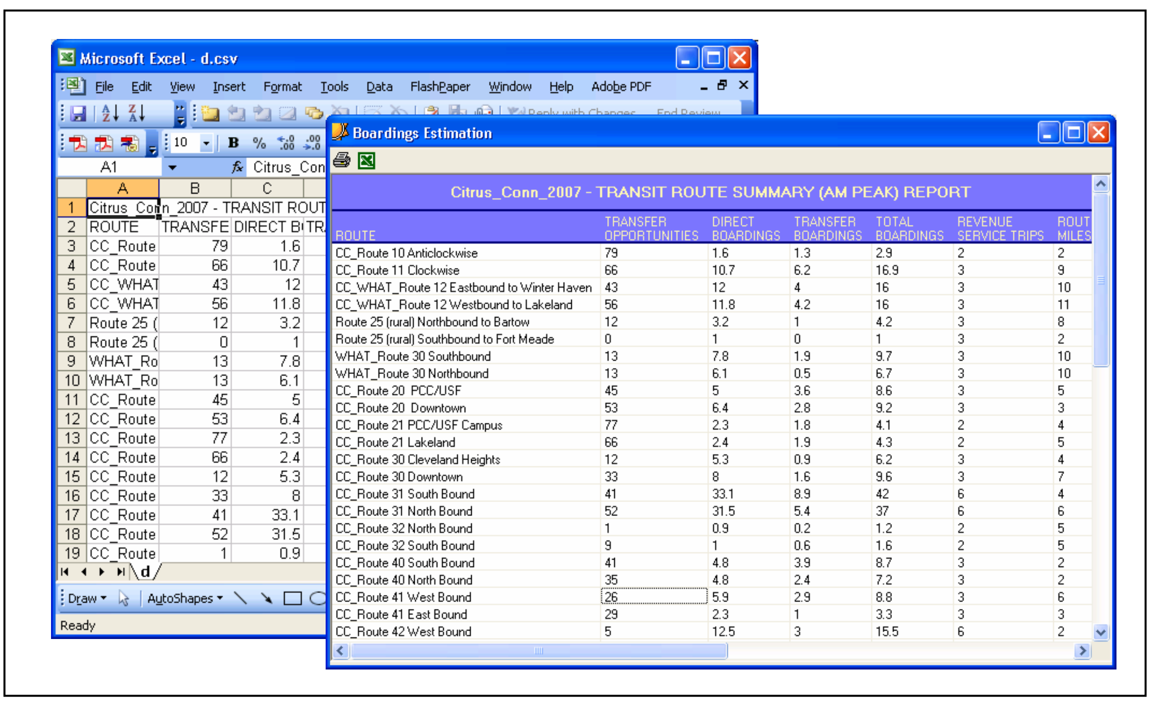


Figure 12 Mapped Ridership Output Sample



Citrus_Conn_2007 - TRANSIT ROUTE SUMMARY (AM PEAK) REPORT

ROUTE	TRANSFER OPPORTUNITIES	DIRECT BOARDINGS	TRANSFER BOARDINGS	TOTAL BOARDINGS	REVENUE SERVICE TRIPS	ROUT MILES
CC_Route 10 Anticlockwise	79	1.6	1.3	2.9	2	2
CC_Route 11 Clockwise	66	10.7	6.2	16.9	3	9
CC_WHAT_Route 12 Eastbound to Winter Haven	43	12	4	16	3	10
CC_WHAT_Route 12 Westbound to Lakeland	56	11.8	4.2	16	3	11
Route 25 (rural) Northbound to Bartow	12	3.2	1	4.2	3	8
Route 25 (rural) Southbound to Fort Meade	0	1	0	1	3	2
WHAT_Route 30 Southbound	13	7.8	1.9	9.7	3	10
WHAT_Route 30 Northbound	13	6.1	0.5	6.7	3	10
CC_Route 20 PCC/USF	45	5	3.6	8.6	3	5
CC_Route 20 Downtown	53	6.4	2.8	9.2	3	3
CC_Route 21 PCC/USF Campus	77	2.3	1.8	4.1	2	4
CC_Route 21 Lakeland	66	2.4	1.9	4.3	2	5
CC_Route 30 Cleveland Heights	12	5.3	0.9	6.2	3	4
CC_Route 30 Downtown	33	8	1.6	9.6	3	7
CC_Route 31 South Bound	41	33.1	8.9	42	6	4
CC_Route 31 North Bound	52	31.5	5.4	37	6	6
CC_Route 32 North Bound	1	0.9	0.2	1.2	2	5
CC_Route 32 South Bound	9	1	0.6	1.6	2	5
CC_Route 40 South Bound	41	4.8	3.9	8.7	3	2
CC_Route 40 North Bound	35	4.8	2.4	7.2	3	2
CC_Route 41 West Bound	26	5.9	2.9	8.8	3	6
CC_Route 41 East Bound	29	2.3	1	3.3	3	3
CC_Route 42 West Bound	5	12.5	3	15.5	6	2

Figure 13 Model Output Summary Reports Sample

APPENDIX A (Continued)

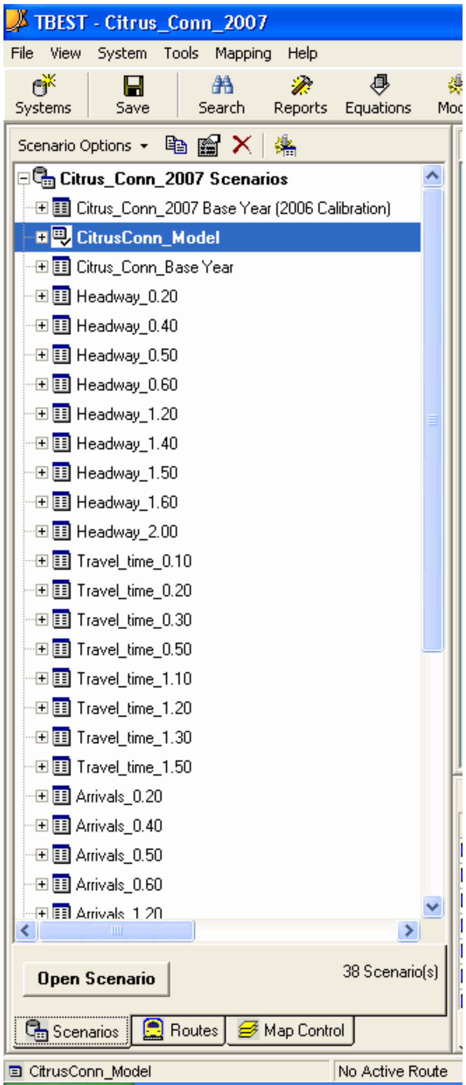


Figure 14 Alternative Scenario List

APPENDIX B TBEST Model Output Results

Appendix B presents some of the results obtained from the model output. Table 29 shows the current level of service for Polk County, which was used in Chapter 5.

Table 29 Current Level of Service by Route

	AM Peak	Off Peak	PM Peak	Night	Saturday
CC_Route 10	60	60	60	60	60
CC_Route 11	60	60	60	60	60
CC_WHAT_Route 12	60	60	60	60	60
Route 25 (rural)	60	60	60	0	60
WHAT_Route 30	60	60	60	60	60
CC_Route 20	60	60	60	60	60
CC_Route 21	60	90	60	0	100
CC_Route 22XL	45	90	45	60	60
CC_Route 30	60	120	60	0	96
CC_Route 31	30	30	30	40	31
CC_Route 32	90	120	90	0	120
CC_Route 37	60	60	60	0	60
CC_Route 40	60	60	60	0	60
CC_Route 41	60	60	60	60	60
CC_Route 42	30	30	30	60	31
CC_Route 50	60	60	60	60	60
CC_Route 51	30	30	30	60	30
CC_Route 52	30	30	30	60	31
CC_Route 53	60	60	60	60	60
CC_Route 56	60	60	60	60	60
CC_Route 57	60	60	60	60	60
Route 35 (rural)	60	60	60	0	60
WHAT_Route 10	60	60	60	60	60
WHAT_Route 15	60	60	60	60	60
WHAT_Route 20	60	60	60	60	60
WHAT_Route 22XW	60	60	60	60	60
WHAT_Route 40	60	60	60	60	60
WHAT_Route 44	60	60	60	60	60
WHAT_Route 50	60	60	60	60	60

Table 30 AM Peak Ridership Response to Headway by Route

Route	Base	Alternatives							
	1	0.2	0.4	0.5	0.6	1.2	1.4	1.5	1.6	2
CC_Route 10	12	12	26	45	67	12	3	3	3	3
CC_Route 11	50	85	148	209	357	23	22	22	22	21
CC_WHAT_Route 12	85	145	238	351	630	41	39	39	38	38
Route 25 (rural)	18	31	47	66	114	8	8	8	8	8
WHAT_Route 30	68	115	177	250	431	30	30	30	30	30
CC_Route 20	61	105	186	270	463	29	28	28	27	27
CC_Route 21	19	19	42	72	109	19	5	5	5	5
CC_Route 22XL	82	124	244	327	505	47	39	38	19	19
CC_Route 30	33	60	101	150	270	15	15	15	15	14
CC_Route 31	89	150	278	453	753	63	41	41	41	25
CC_Route 32	4	5	10	16	25	4	1	1	1	1
CC_Route 37	7	8	16	27	40	7	2	2	2	2
CC_Route 40	18	31	49	71	120	8	8	8	8	8
CC_Route 41	46	81	133	196	344	22	22	22	21	20
CC_Route 42	86	147	237	354	585	57	38	38	38	22
CC_Route 50	34	60	96	135	230	13	13	13	13	12
CC_Route 51	74	130	220	341	596	50	33	33	33	20
CC_Route 52	111	189	303	454	753	77	52	52	51	31
CC_Route 53	2	2	8	8	8	2	2	2	2	0
CC_Route 56	28	49	76	106	180	13	13	12	12	12
CC_Route 57	15	28	53	78	135	6	6	6	6	6
Route 35 (rural)	3	3	6	11	16	3	1	1	1	1
WHAT_Route 10	36	53	92	139	237	23	15	15	15	15
WHAT_Route 15	26	44	67	94	161	12	12	12	12	12
WHAT_Route 20	6	7	15	25	38	6	2	2	2	2
WHAT_Route 22XW	29	51	79	114	198	13	13	13	12	12
WHAT_Route 40	23	40	62	88	153	10	10	10	10	10
WHAT_Route 44	33	58	91	129	224	16	16	16	16	16
WHAT_Route 50	23	40	64	92	159	11	11	11	11	11
Total System	1120	1868	3163	4670	7900	642	498	496	474	404

Table 31 Off Peak Ridership Response to Headway by Route

Route	Base	Alternatives							
	1	0.2	0.4	0.5	0.6	1.2	1.4	1.5	1.6	2
CC_Route 10	87	145	216	297	438	63	42	42	42	25
CC_Route 11	171	285	425	588	875	124	83	83	83	50
CC_WHAT_Route 12	376	627	947	1321	1979	271	181	181	178	107
Route 25 (rural)	66	110	164	227	337	48	32	32	32	20
WHAT_Route 30	238	395	595	828	1238	173	115	115	115	69
CC_Route 20	204	339	511	717	1101	146	99	98	92	57
CC_Route 21	68	102	186	236	353	41	41	41	20	20
CC_Route 22XL	90	134	246	313	467	54	53	53	26	26
CC_Route 30	35	59	91	129	216	17	17	17	17	16
CC_Route 31	459	688	1184	1667	2511	330	271	222	222	133
CC_Route 32	11	19	28	39	65	6	5	5	5	5
CC_Route 37	16	27	39	54	90	8	8	8	8	8
CC_Route 40	63	106	158	218	320	45	30	30	30	18
CC_Route 41	177	297	446	620	923	127	86	85	85	51
CC_Route 42	322	485	836	1190	1816	233	188	155	155	93
CC_Route 50	175	294	433	583	835	125	83	83	83	49
CC_Route 51	495	714	1177	1624	2337	369	310	261	260	169
CC_Route 52	463	693	1170	1641	2463	334	274	224	223	135
CC_Route 53	80	134	199	272	396	58	39	38	38	23
CC_Route 56	123	207	311	428	624	88	59	59	58	35
CC_Route 57	70	117	175	243	362	50	34	33	33	20
Route 35 (rural)	49	70	91	115	153	40	31	31	31	22
WHAT_Route 10	163	278	421	593	892	115	75	75	75	45
WHAT_Route 15	87	145	216	299	446	63	43	43	43	26
WHAT_Route 20	57	94	146	204	305	41	28	28	28	17
WHAT_Route 22XW	132	219	332	464	697	96	65	65	63	38
WHAT_Route 40	123	207	311	431	642	89	60	60	60	35
WHAT_Route 44	112	186	282	395	591	81	55	55	55	31
WHAT_Route 50	86	142	221	311	468	62	42	42	42	25
Total System	4598	7316	11557	16046	23941	3295	2448	2263	2202	1370

Table 32 AM Peak Ridership Response to Travel Time by Route

Route	Base	-10%	-20%	-30%	-50%	10%	20%	30%	50%
CC_Route 10	12	12	12	12	12	12	12	12	12
CC_Route 11	50	51	51	53	55	48	47	47	45
CC_WHAT_Route 12	85	86	87	89	91	84	83	83	81
Route 25 (rural)	18	18	19	19	19	18	18	18	18
WHAT_Route 30	68	68	69	69	70	67	67	67	66
CC_Route 20	61	61	62	63	65	61	60	60	59
CC_Route 21	19	19	19	19	19	19	19	19	18
CC_Route 22XL	82	83	84	86	87	82	81	81	75
CC_Route 30	33	33	36	36	37	33	32	32	32
CC_Route 31	89	89	90	92	93	89	88	89	86
CC_Route 32	4	4	4	5	5	4	4	4	4
CC_Route 37	7	7	7	8	8	7	7	7	7
CC_Route 40	18	18	18	18	18	17	17	17	17
CC_Route 41	46	47	47	48	49	46	45	45	44
CC_Route 42	86	86	87	87	90	85	85	84	82
CC_Route 50	34	34	35	36	37	33	33	33	32
CC_Route 51	74	74	76	77	79	73	72	71	70
CC_Route 52	111	111	112	114	116	110	108	108	105
CC_Route 53	2	2	2	2	2	2	2	2	2
CC_Route 56	28	28	28	29	29	28	27	27	27
CC_Route 57	15	15	15	16	17	15	15	15	15
Route 35 (rural)	3	3	3	3	3	3	3	3	3
WHAT_Route 10	36	36	36	36	37	36	36	36	36
WHAT_Route 15	26	26	26	26	27	26	26	26	25
WHAT_Route 20	6	6	7	7	7	6	6	6	6
WHAT_Route 22XW	29	30	30	31	31	29	28	28	28
WHAT_Route 40	23	23	23	24	24	23	22	23	22
WHAT_Route 44	33	34	34	35	35	33	33	33	32
WHAT_Route 50	23	24	24	24	24	23	23	23	23
System Total	1120	1130	1142	1162	1184	1110	1101	1097	1072

Table 33 Off Peak Ridership Response to Travel Time by Route

Route	Base	-10%	-20%	-30%	-50%	10%	20%	30%	50%
CC_Route 10	87	86	86	86	84	87	87	87	87
CC_Route 11	171	172	173	173	177	170	168	168	166
CC_WHAT_Route 12	376	377	379	381	384	374	373	371	368
Route 25 (rural)	66	67	67	67	67	66	66	66	65
WHAT_Route 30	238	238	239	240	242	236	236	235	231
CC_Route 20	204	204	205	205	205	204	204	204	203
CC_Route 21	68	68	69	69	69	68	68	68	68
CC_Route 22XL	90	90	90	90	90	90	90	90	89
CC_Route 30	35	35	35	36	36	35	35	35	34
CC_Route 31	459	459	462	461	463	458	456	455	452
CC_Route 32	11	11	11	11	12	11	11	11	11
CC_Route 37	16	16	16	16	16	16	16	16	16
CC_Route 40	63	63	63	63	63	63	63	63	63
CC_Route 41	177	178	179	179	180	176	175	175	173
CC_Route 42	322	327	328	330	337	320	317	317	312
CC_Route 50	175	176	177	178	181	174	173	172	171
CC_Route 51	495	499	502	505	512	493	489	488	483
CC_Route 52	463	466	467	469	472	461	458	457	452
CC_Route 53	80	81	81	82	82	80	79	79	78
CC_Route 56	123	124	124	125	127	123	122	121	120
CC_Route 57	70	70	70	70	70	70	69	69	69
Route 35 (rural)	49	50	50	50	50	49	49	49	49
WHAT_Route 10	163	164	169	169	169	163	163	162	161
WHAT_Route 15	87	88	88	88	89	87	87	86	86
WHAT_Route 20	57	57	57	57	57	57	57	57	56
WHAT_Route 22XW	132	132	133	133	134	132	131	131	129
WHAT_Route 40	123	123	123	124	124	122	122	122	121
WHAT_Route 44	112	112	113	113	114	112	111	111	110
WHAT_Route 50	86	86	86	86	87	86	85	84	84
System Total	4598	4618	4639	4654	4692	4580	4560	4547	4509