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# Decision Support Tools For Bus Rapid Transit Corridor Planning

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DECISION SUPPORT TOOLS FOR BUS RAPID TRANSIT CORRIDOR  
PLANNING

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By

Luis D. Galicia

2010

## **DEDICATION**

To my beloved ones, my former family, present family and future family



DECISION SUPPORT TOOLS FOR BUS RAPID TRANSIT CORRIDOR  
PLANNING

By

LUIS DAVID GALICIA CABRERA, MASTER OF SCIENCE IN CIVIL ENGINEERING

DISSERTATION

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## **ABSTRACT**

Bus Rapid Transit (BRT) Systems have been gained popularity in the United States and worldwide as a cost-effective solution of mass transit. There are certain elements and characteristics that such a system should accomplish to be considered a BRT. However, a uniform definition, defined phases to be deployed, and a reliable methodology to estimate ridership are not well structured and clear yet. The purpose of this research was to help BRT stakeholders with an effective method to plan and assess BRT projects. The first goal of this research was to provide a comprehensive description of the essential characteristics of BRT based on the common features found in systems, currently in operation, worldwide. Secondly, this research suggested different stages of deployment based on the BRT experience in the U.S. As a final goal, the construction of an interactive model capable of looking at the technical fundamentals of transit theory, finance and economics, urban planning, traffic engineering, and infrastructure management was developed based mainly on spatial analysis using Geographic Information Systems, the System Dynamics theory and computational tools. The results of this research suggested the most important BRT features to contribute with a BRT definition, the set of features needed to implement an initial phase of a BRT corridor, and an accurate methodology to forecast BRT ridership at a corridor level. These results are aimed to help decision makers when conducting BRT feasibility and planning studies.

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# **CHAPTER 1 : INTRODUCTION AND OBJECTIVE**

The first chapter describes the background and motivation of this dissertation. After an exhaustive exploration of what constitutes a Bus Rapid Transit (BRT) and the available tools for its systematic planning, some relevant research gaps were found. These gaps led to the formulation of the research questions, objective and subsequently the different chapters included in this dissertation. This chapter concludes with this research's scientific contributions, its relevance as a basis for BRT planners and decision-makers, as well as the dissertation's limitations.

## **1.1 Background**

BRT Systems have recently gained popularity in the United States and worldwide as a cost-effective solution of mass transit. Successful examples such as Orange line in Los Angeles, Las Vegas MAX, Silver line in Boston, EMX in Eugene, Oregon have demonstrated ridership gains ([Diaz, et al., 2004](#)) ([Levinson H. , et al., 2003](#)) ([Kittelson & Associates, et al., 2007](#)). Since the first BRT system developed in Curitiba, Brazil, technical documents have shown that a BRT line or system requires coordinated improvements in transit system's infrastructure, equipment, operations, and technology ([Levinson H. , et al., 2003](#)) ([Wright, 2004](#)) ([Currie, 2006](#)) ([Diaz, et al., 2006](#)) ([Kittelson & Associates, et al., 2007](#)). Moreover, all this technical documents agree that the most important and reliable benefits of BRT compared to regular bus service are travel time savings and ridership attraction. Even though its tangible benefits and the fact that the BRT

concept has been implemented since the 70's ([Glennon, 1970](#)), a unified definition, phases to be deployed, and a reliable methodology to estimate BRT ridership are not well structured.

## **1.2 Research Questions**

The research gaps identified and described in the background section have motivated the formulation of the research questions and consequently the objective and limitations presented in the following sub-sections.

### **1.2.1 What is a Bus Rapid Transit System?**

The U.S. General Accounting Office (GAO) ([GAO, 2001](#)) describes BRT as a set of elements that includes “exclusive bus highways and lanes, High Occupancy Vehicle (HOV) lanes, technological and street design improvements, traffic signal prioritization, better stations and/or bus shelters, fewer stops, faster service, cleaner, quieter, and more attractive vehicles.” The Federal Transit Administration (FTA) ([FTA, 2006](#)) defines BRT as “an enhanced bus system that operates on bus lanes or other transitways in order to combine the flexibility of buses with the efficiency of rail”. In the BRT Planning Guide ([Wright, 2004](#)), BRT is presented as “a high-quality bus based transit system that delivers fast, comfortable, and cost-effective urban mobility through the provision of segregated right-of-way infrastructure, rapid and frequent operations, and excellence in marketing and customer service”. The Transit Cooperative Research Program (TCRP) Report 90 ([Levinson H. , et al., 2003](#)) defines BRT as “a flexible, rubber-tired rapid-transit mode that combines stations, vehicles, services, running ways, and Intelligent Transportation System (ITS) elements into an integrated system with a strong positive

identity that evokes a unique image”. The Transit Capacity and Quality of Service Manual (TCQSM) (Kittelson&Associates, et al., 2003) states that “BRT is a complete rapid transit system that combines flexible service and new technologies to improve customer convenience and reduce delays”. With such a variety of definitions for BRT systems, urban planners, city managers, decision makers, and other stakeholders involved in a local or regional public transit planning process might encounter difficulties when trying to plan, implement, or asses a BRT system and distinguishing its attributes from conventional bus services. If BRT really includes a wide spectrum of system types and features, how does one describe the BRT system concept?

### **1.2.2 How Many and What Type of Bus Rapid Transit Features Should be Deployed in Different Bus Rapid Transit Phases?**

Unlike rail systems, BRT projects rarely include the whole set of possible attributes in the first stage. Rather, they are gradually developed and implemented over the years. During the planning process of a BRT system, many operations and infrastructure design approaches are involved. In some cases, companies that are responsible for planning and implementation of these types of systems do not fully consider integrating an optimal set of elements at different phases (Kittelson & Associates, et al., 2007). Consequently, those systems may not be the most cost effective for maximizing the benefits to both the transit operator and the transit ridership.

### 1.2.3 How to Forecast Bus Rapid Transit Ridership?

Another questionable topic regarding the BRT planning process, and perhaps the most important element for designing a BRT system, is reliable ridership forecast. The FTA generally requests ridership forecasts for the base year, opening year, “maturity” year and horizon year (usually 20 years after the base year) for all “New Start” transit projects. New Starts projects are defined by the FTA as “any fixed guideway system which utilizes and occupies a separate right-of-way, or rail line, for the exclusive use of mass transportation and other high occupancy vehicles, or uses a fixed cantenary system and a right-of-way usable by other forms of transportation. This includes, but is not limited to, rapid rail, light rail, commuter rail, automated guideway transit, people movers, and exclusive facilities for buses (such as bus rapid transit) and other high occupancy vehicles (FTA, 2006). Moreover, it is necessary to provide peak and off-peak behavior by line segment and boarding/alighting patterns by station/stop (Kittelson & Associates, et al., 2007). However, the FTA has no standard methodology or guideline to estimate BRT ridership. The current interim guidance document by the FTA (FTA, 2007) is not clear regarding the method to use for BRT ridership forecast. Inaccurate ridership calculations could result in erroneous demand estimations that may put both, the overall BRT system performance and the entire local transportation network, at risk. These inaccurate estimations might also due to the lack of technical knowledge from stakeholders involved in the planning process. Geographic Information Systems (GIS) analysis and System Dynamics (SD) theory can be an effective combination of tools for transit planning in any urban or metropolitan environment. Moreover, these tools can supply decision makers a set of different and wider

perspectives that would help supporting or rejecting new spatial developments at the local, regional, state, or even national level.

### **1.3 Objective and Scientific Contributions**

This research has the objective of providing a useful set of tools for BRT planning and ridership forecasting. This work was divided in three main tasks. The first task provides a coherent description of the common features of a BRT system, its benefits, detriments, and proposed deployment phases. The second task develops a GIS-SD-based interactive model capable of forecasting BRT ridership. The final task was a case study that applied the suggested tools and methods. In Summary, the main pay-off of this research is to help BRT stakeholders with an effective set of tools to plan and assess BRT planning projects including BRT ridership forecast, which takes into consideration the system growth, upgrades and user preferences.

Starting with a definition of what could and what could not be considered as a BRT system might facilitate its distinction among other systems and serve as an initial point to assess the system's stages or phases.

The development of a GIS-SD model involves different BRT phases and intends to provide a solid justification to BRT decision makers, stakeholder, planners, and transit agencies for correctly assessing the benefit of BRT systems. The cost associated with each characteristic and their potential improvement in the level of service will help in the evaluation of the BRT

alternative against other alternatives (user benefits). These results are of immediate interest to transit agencies for deployment of cost-effective BRT systems.

The scientific contribution of this research is to offer a variety of technical tools for BRT planning. The construction of a GIS-SD interactive model capable of incorporating technical fundamentals of transit theory, economics, urban planning, traffic engineering, and infrastructure management, can help decision makers and city planners to redefine or restate important transit decisions that were originally analyzed by existing or traditional methodologies, which may not be suitable for this mode of transportation. This study will seek a systematic way to produce consistent demand estimates that leads to a sound BRT planning. Moreover, this work represents the first BRT planning tool ever done with a combination of GIS-SD model and an innovative onboard Origin-Destination (O-D) survey technique.

#### **1.4 Research Limitations**

A limitation of the research is the ridership forecast by stations/terminals (stop-level) or transfer points (disaggregated demand). Nevertheless, the case study included in this dissertation showed an adaptation of the proposed methodology that leads to ridership estimates at every stop, station, transfer center, or bus terminal.

## **1.5 Dissertation Structure**

The present dissertation has been structured in ten chapters. Chapter 1 introduces the main objective of this work, research questions, objective, scientific contribution, limitations and dissertation structure.

Chapter 2 Summarizes the literature review as well as the available planning tools for BRT systems currently in operation in the United States and worldwide. Furthermore, the second chapter reviews the current BRT ridership forecast methodologies, their advantages and disadvantages and followed by an extensive review of GIS tools applied to the BRT planning process.

Chapter 3 focuses on the methodology of this research. A step-by-step procedure, as well as, the different models and processes explanation and organization are described in this Chapter. Moreover, a set of tasks detailing each activity is included.

Chapter 4 provides a BRT definition base on a comprehensive revision of current systems in the U.S. The chapter summarizes the main components of a BRT system and its complementary corridor characteristics. It also proposes the deployment phases for BRT systems in the U.S.

Chapter 5 introduces the GIS systems and explores their current application in the transportation area. This chapter describes the BRT potential user's concept and the

corresponding data extraction by using the Business Analyst software. The Chapter concludes with a description of the method to extract data for any given corridor nationwide and presents results for four BRT systems currently in operation in the U.S.

Chapter 6 describes the methodology proposed to estimate the BRT rider's O-D pairs for a given corridor. The chapter also details an innovative survey technique capable of saving time and effort when transit demand models are not available. This data will be important to estimate the linked trips used at the case study chapter.

Chapter 7 offers a model that makes use of the SD theory for BRT ridership forecasting. This Chapter also includes a description of the methodology used to construct the main SD forecasting model. Included in this chapter are the analysis of model outputs, calibration and validation of the SD model. The model validation was completed using data for two BRT systems currently in operation: Las Vegas "MAX" and "Orange" line in Los Angeles. At the end of this chapter an explanation of a user-friendly interface model using SD software is presented.

Chapter 8 includes a brief section summarizing the results from the SD model, its validation, calibration and limitations.

Chapter 9 presents a case study to test the methodology proposed through this dissertation. The selected corridor is located in the city of El Paso, Texas and is currently one of the four potential BRT corridors seeking for federal funds for implementation. The chapter



illustrates a step-by-step implementation of the decision tools, including a proposed methodology to estimate BRT ridership demand along the corridor.

Finally, Chapter 10 discusses the answers to the research questions, concludes this work, and suggests future research recommendations.

## CHAPTER 2 : LITERATURE REVIEW AND AVAILABLE PLANNING TOOLS FOR BUS RAPID TRANSIT

The technical documents reviewed in this chapter include journal papers, reports, manuals, conference presentations and proceedings, handbooks, technical visits, web resources, and textbooks. Nevertheless, the most useful and up-to-date documents for this research were: the BRT Planning Guide 2004 and 2007 ([Wright, 2004](#)) ([Wright, 2007](#)), TCRP Report 90 ([Levinson H. , et al., 2003](#)) ([Levinson H. S., et al., 2003](#)) and Report 118 ([Associates, Consultants, & Dmjm+Harris, 2007](#)), TCQSM ([Kittelsohn & Associates, et al., 2007](#)), “Urban Transit” by Vuchic ([Vuchic, 2005](#)) and the remarkable book written by Sterman about the System Dynamic Theory ([Sterman, 2000](#)). More than 150 publications have been reviewed and only the cited ones are listed in the References section.

### 2.1 Bus Rapid Transit Systems Reviewed

From the literature reviewed, only the report entitled “Characteristics of Bus Rapid Transit for Decision-Making” ([Diaz, et al., 2004](#)) individually evaluates some of the BRT major elements in the United States. However, the authors keep using the BRT definition as stated by the TCRP report 90 ([Levinson H. , et al., 2003](#)) without questioning if the definition is suitable or not. The following table ([Table 2-1](#)) shows the list of BRT systems reviewed. The review focused on BRT infrastructure and operational features relative to regular bus service. With an understanding that BRT systems may evolve differently in the U.S. cities, the selected BRT systems reviewed are grouped into U.S. and non-U.S. systems ([Galicija,et al., 2009](#)).

**Table 2.1** List of BRT Systems Reviewed

<b>U.S. BRT Systems</b>		<b>Non-U.S. BRT Systems</b>	
<b>City</b>	<b>BRT System Name</b>	<b>City, Country</b>	<b>BRT System Name</b>
Albuquerque, NM	Rapid Ride	Adelaide, Australia	North East Busway
Boston, MA	Silver Line	Beijing, China	BRT Line 1
Eugene, OR	EMX	Bogota, Colombia	TransMilenio
Honolulu, HI	City Express	Brisbane, Australia	South East and Inner Northern Busway
Las Vegas, NV	North Las Vegas MAX	Curitiba, Brazil	BRT Curitiba
Los Angeles, CA	Metro Rapid	Hang Zhou, China	BRT Line B1
Miami, FL	BUSWAY	Jakarta, Indonesia	TransJakarta
New York, NY	Albany-Schenectady	Mexico City, Mexico	Metrobus
Orlando, FL	Lymmo BRT	Leon, Mexico	Optibus
Pittsburgh, PA	BUSWAY	Ottawa, Canada	Transitway
Kansas City, KS	MAX	Quito, Ecuador	Ecovía and Trole
Santa Clara, CA	VTA Rapid 522	Sydney, Australia	Liverpool-Parramatta Transitway
San Francisco, CA	Bay Area BRT	Sao Paulo, Brazil	BRT Sao Paulo
Virginia, VA	Capital Beltway Proposal	Santiago, Chile	Transantiago

Most of the BRT systems reviewed share common but not all BRT features. When designing a BRT system, the features should be selected according to project budget, local users, traffic and corridor characteristics, and combined to produce maximum ridership attraction and operating speed (Galicia, et al., 2009). Taking into consideration the BRT success in attracting ridership and the high right-of-way cost in U.S. cities, in this research the BRT features have been grouped into three deployment phases. The features recommended in the different phases are in increasing order of cost, engineering sophistication, and implementation time frames, but they also correspond to more positive effects on ridership attraction and operating speed. The phases may be implemented in sequential order for a BRT system to be sustainable.

The suggested features for different phases are included and explained in detail at the end of Chapter 4 of this dissertation.

## **2.2 Reviewed of Available Ridership Forecast Methodologies**

Concerning the BRT ridership forecast, the FTA includes in its “Interim Guidance and Instructions” (FTA, 2007) a summary of the acceptable methods for BRT ridership forecast. The existing methodologies suggested by the FTA are the multimodal traffic demand model, sketch planning methods (such as direct boarding) and elasticity-based methods. The following section offers a brief description of these methods, the necessary data for each one as well as their implications and limitations.

### **2.2.1 Travel Demand Model**

Among the approaches for estimating BRT ridership, the preferred method is the traditional four-step demand estimation process, also known as Travel Demand Model (TDM) (trip generation, trip distribution, mode split, and assignment). The method although effective, might represent a high-cost option in the BRT planning process since it requires a considerable number of human resources including transportation specialists.

Another concern is that the mode choice process implies the usage of a logit or incremental logit models and they need to be computed using coefficients for utility functions from available models in the area of study or “borrow” coefficients from other similar areas.

### **2.2.2 Direct Boarding Methods**

These methods are widely used in the absence of a TDM. The methodology has been used in urban areas of all sizes within the U. S. to evaluate transit alternatives. The method requires information such as socio-economic and work-place employment data, street configuration, transit routes and stop locations, Transit Analysis Zones (TAZs), and land-use data to estimate transit trips generated. Despite the fact that these methods are easier to implement than the TDM, they are suitable only for cases where the analyzed corridor does not have existing transit service at all.

### **2.2.3 Elasticity Based Methods**

Elasticity methods constitute an alternative to estimate ridership especially where BRT is overlaid on existing bus routes and for small-scale BRT investments. These methods are used to forecast ridership due to changes in service coverage or other bus parameters such as in-vehicle travel time, frequency, fuel costs, fare changes or branding. The TCRP Report 118 ([Kittelson & Associates, et al., 2007](#)) defines elasticity methods as the change in ridership corresponding to a 1% change in any of the following attributes: (a) fare, (b) travel time and (c) service frequency.

According to the definition of elasticity, each attribute's change will directly impact the transit demand. There are normally three different computations associated with elasticity methods: the shrinkage factor, the midpoint arc elasticity, and the log arc elasticity. The shrinkage factor is widely used to measure changes in ridership due to fare changes, while the

midpoint arc, as well as, the log arc elasticities are commonly used to measure travel time or frequency indistinctly.

One of the most important information for the implementation of these methods is the current base ridership data along the corridor of study. These can be obtained by field surveys or by knowing the boarding and alighting behavior. It is important to note that the base ridership reflects a portion of the total existing route or corridor ridership.

#### **2.2.4 Summary of Existing Methods**

The following table (Table 2.2) summarizes the existing methodologies for BRT ridership estimation and the level of convenience depending on cost and time of implementation.

**Table 2.2** Summary of Existing BRT Ridership Forecast Methodologies

<b>Methodology</b>	<b>Cost</b>	<b>Time</b>	<b>FTA Preference</b>
Travel Demand Model	High	Long	High
Direct Boarding Methods	Medium	Long	Medium
Elasticity Based Method	Low	Short	Low

### **2.3 Reviewed of Geographic Information System Tools to Estimate Transit Ridership**

There are few attempts to estimate transit ridership using GIS. However, they are limited to the regular transit system, i.e., there is no BRT or mass transit GIS application tool.

### 2.3.1 TBEST

TBEST, which stands for Transit Boarding Estimation and Simulation Tool, uses GIS as interface to develop and integrate transit demand model and a regional transit feasibility analysis to estimate ridership at individual stop-level ([Florida Department of Transportation, 2009](#)). TBEST also simulates travel demand at individual stops accounting for the network connectivity.

TBEST can be considered as a “micro-level” model that provides very detailed information regarding ridership estimates at the stop-level. However, it can also be used to obtain a more aggregated route level, segment level, location-based, or system level measures through the aggregation of stop-level outputs. Moreover, this software provides results at specific times of the day (e.g. peak-hour periods) and different days of the week. One of the biggest limitations of the available (current) version of TBEST is that it has been calibrated using year 2000 census and ridership data from Portland, Oregon ([Florida Department of Transportation, 2009](#)). Therefore, users cannot directly apply this tool for other cities without a meticulous revision of the results and the establishment of local-condition constraints. Although this software has a great potential for bus ridership forecasting, its usage is still modest and more experiments (including re-estimation and re-calibration) needs to be performed on other U.S. transit systems before the public transportation community accepts this model as a reliable alternative to the traditional transit or TDM.

### 2.3.2 Transit Tools

Transit Tools is a set of products developed by Cambridge Systematics that offer state-of-the-art tools for transit market segmentation analysis, planning and potential transit share (Cambridge Systematics, 2010). This tool was designed to be used only with the ArcView platform (Environmental Systems Research Institute, 2010). Transit Tools is able to estimate transit ridership based on nearly a dozen of characteristics including: headway, walk access time, and in-vehicle time. A limitation however, is that this tool does not take into account typical endemic BRT features and corridor characteristics such as station or stop improvements.

The Potential Transit Share (PTS) tool, also included in Transit Tools, allows planners to identify potential transit users based on TAZs. Even though this tool is useful for a transit feasibility study, this approach was originally introduced by the Transportation Research Board in the document titled Transit Capacity and Quality of Service Manual (TCQSM) (Kittelson & Associates, et al., 2003) and shares the limitation of using census block or TAZ-level data for the analysis (which might not be the best approach to estimate ridership). The disadvantage of this methodology is the assumption of a uniform walking distance for all cases disregarding the geometric distribution of the TAZs. In other words, if a TAZ covers an extensive area and a group of households lays on the boundaries totally opposite to the corridor, these households will be taken into account even if the walking distance is longer than a realistic average (0.25 to 0.50 mile).



### 2.3.3 ArcGIS Business Analyst

Business Analyst (BA) desktop software ([Environmental Systems Research Institute, 2010](#)) is a combination of GIS analysis and visualization capabilities with an extensive data package. Users can gain a better understanding and timely information about the markets they are interested in, the customers' profile, as well as latent competitors. Although the software was initially developed for organizations and businesses to improve decisions about markets changes and economic factors, the potential for estimating BRT ridership is vast. This research proposes the use of BA software to obtain BRT potential ridership, a concept explained in detail further on Chapter 5.

## 2.4 Reviewed of System Dynamic Models Applied to Transportation

System dynamics is a modeling approach for users to perform simulation of dynamic systems that involve many variables with feedback loops, some of which the relationship may not be well defined. Having its roots in the computer aided modeling of systems with a high number of differential equations; SD has been mainly applied to the social and economic sciences. System Dynamics has developed to an independent research field related to Systems Thinking but includes the additional step of computer ([Bosshardt, 2009](#)).

Currently, there are several software programs that can facilitate the building and use of SD models. Examples of such tools are Vensim ([Ventana Systems Inc., 2009](#)), iThink, Stella ([isee systems, 2009](#)), Powersim ([Powersim, 2009](#)), and Simile ([Simulistics, 2009](#)) among others. System dynamics models can also be developed by using spreadsheets and programming languages.

Very few efforts to model transportation systems using SD have been reported. A study made by Emmi and Forster ([Emmi & Foster, 2003](#)) focused on the growth dynamics of North American metropolitan regions based on roadway expansion. This study used Stella software to develop the model structure. Other studies include the analysis of urban transportation systems made by Wang, et al. ([Wang, et al., 2008](#)). This analysis presents a SD model of urban transportation system and its response due to the policy changes. Using the Vensim software, the authors developed and applied a SD model simulating different policy scenarios.

A SD approach to land use and transportation system performance is the topic of a paper written by Haghani, et al. ([Haghani, et al, 2002](#)). The paper describes a SD approach to model simultaneous land use/transportation interactions based on casualty functions and feedback loops between a large number of physical, socioeconomic, and policy variables. The study is divided into two different parts: Part I describes the methodology used to develop the model and submodels, whereas Part II reports with the application of such models, comprehensive analysis, and final results.

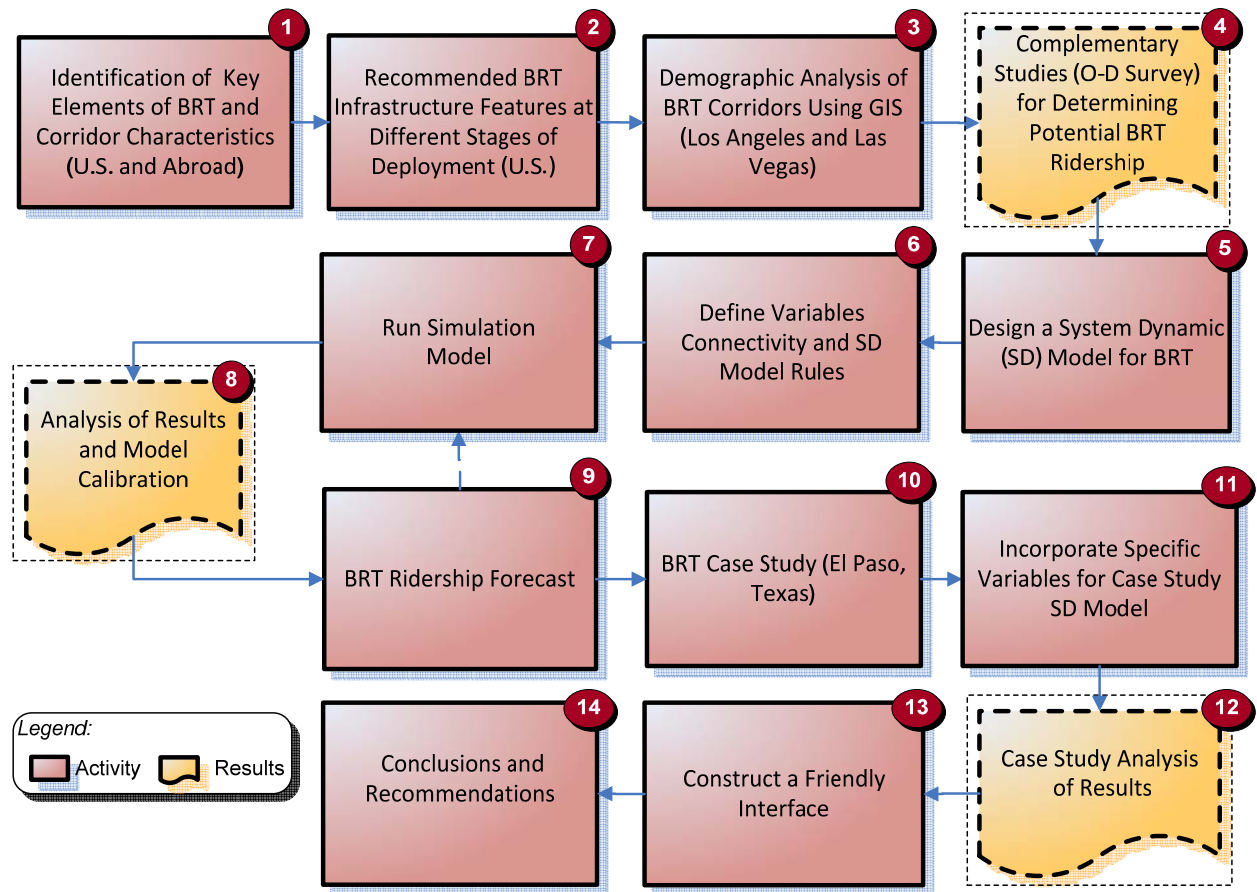
The research work entitled “Land Use Changes in Ciudad Juarez, Chihuahua: A System Dynamic Model” was also reviewed ([Peña & Fuentes, 2007](#)). The study presents a simulation using a SD model that dealt with demographic and urban growth that involves socio-economic and land use variables from the Mexican border city Ciudad Juarez, Chihuahua. The model structure was built using Stella software. The forecast results simulated the changes in land use demand for three different land uses (commercial, industrial and residential) for the upcoming years (2020) in Ciudad Juarez.

## **2.5 Summary**

This Chapter presented the literature review for every one of the research questions presented in Chapter 1. The comprehensive literature review performed in this Chapter allowed identifying a broad variety of existing BRT planning tools as well as the tools needed to improve, better perform, and tackle the BRT planning current challenges.

## CHAPTER 3 : RESEARCH METHODOLOGY AND DATA

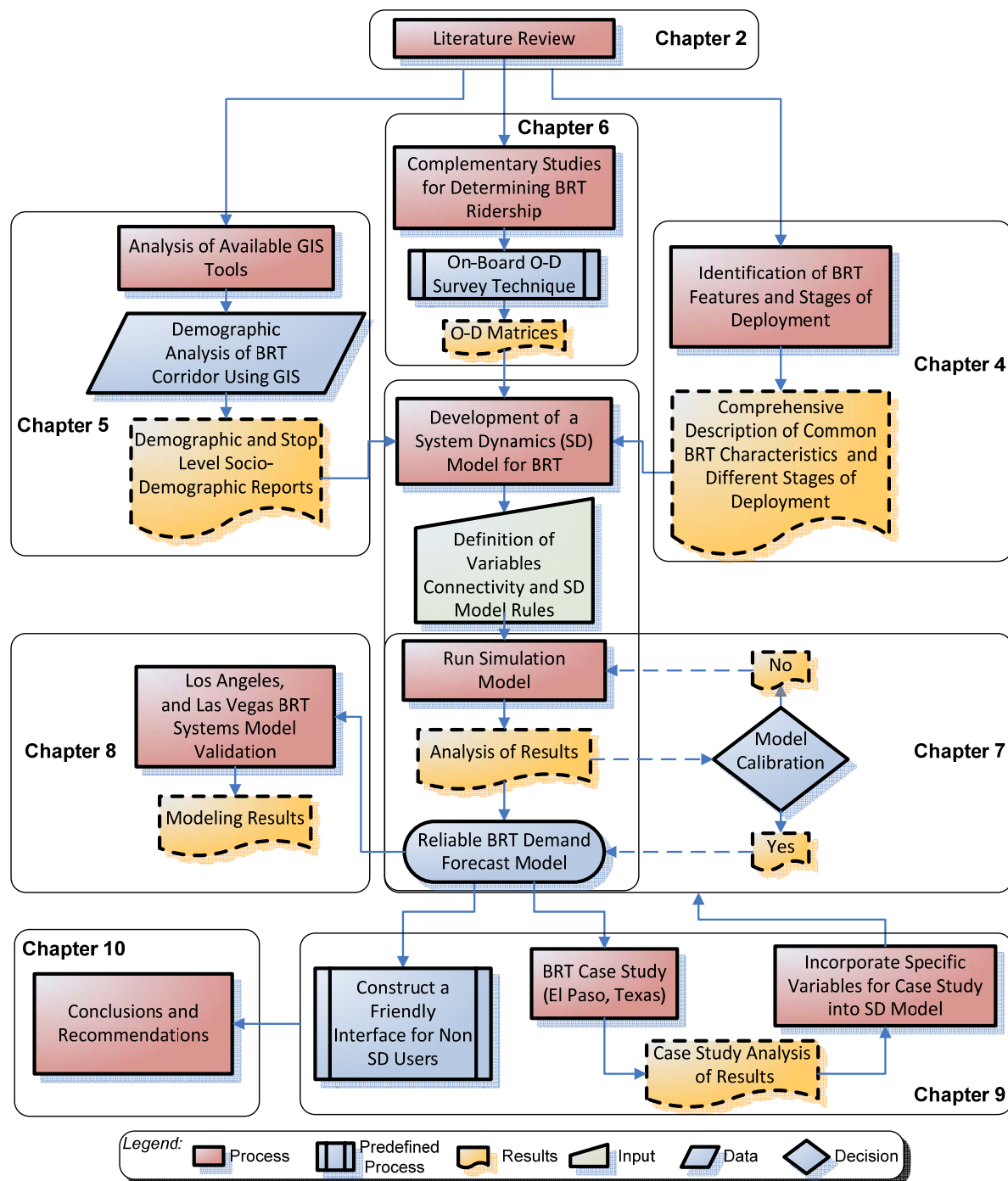
In order to conduct this research to meet the objective as stated in Section 1.3, a step-by-step methodology was constructed as it is shown in **Error! Reference source not found..** Several tasks were included as part of the entire process and were developed in a sequential order from tasks 1 to 14. Some tasks were considered key contributions in this dissertation and were written into chapters (e.g. tasks 1 and 2, 3, 4, 5, 10, and 14).



**Figure 3.1** Dissertation Research Methodology

A brief summary on every task is presented in the following sections. In order to avoid confusion on the methodological process the tasks were described in a sequential order as

illustrated in Figure 3.1. However in reality, some tasks were performed parallel to each other; Therefore, a flow chart (Figure 3.2). is also included for a better understanding of the entire process and the relationships of the tasks with dissertation chapters.



**Figure 3.2** Methodological Flow Chart

### **Task 1: Identification of Key Elements of Bus Rapid Transit**

The goal of this task was to conduct an assessment of all the existing features of BRT systems including its infrastructure and operation in the U.S. and worldwide. Additionally, this task included an analysis of the marginal changes (if any) of performance measures as a consequence of various BRT element implementations. Once the most common BRT elements and corridor characteristics were identified, the next step was to recommend the set of features suitable for BRT systems in the U.S.

### **Task 2: Recommendation of Bus Rapid Transit Features at Different Stages of Deployment**

As feature selection and design depend on the project budget, local user preferences, and traffic and corridor characteristics, form market packages in the different deployment phases. This Task's goal was to group those BRT elements analyzed in the previous step and propose a suitable setup for most U.S. cities based primarily on the ridership increase experience in other BRT systems currently in operation. Results of this task are presented in Chapter 4 and Appendix A of this dissertation.

### **Task 3: Demographic Analysis of BRT Corridors Using Geographic Information Systems**

This task first focused on the identification of three BRT systems in the U.S. Las Vegas MAX Line, and Los Angeles Orange Line. The convenience of data availability from the Regional Transportation Commission of Southern Nevada (RTC-Nevada) made Las Vegas Max BRT the most feasible system to work with. Another system Los Angeles “Orange Line” was also part of the analysis with some limitations about historic ridership data.

After the corridors of study were selected, an extensive collection of data was needed for modeling purposes. Data collection consisted of stop and corridor level. Due to the complexity of obtaining corridor and stop level demographic and economic indicators, all data was obtained from an extension included in ArcGIS software ([Environmental Systems Research Institute, 2008](#)). The data included demographic analysis of each selected corridor (MAX, Orange Line, and Silver Line), household and business units, total sales volumes of businesses, and total employment and corresponding increasing or decreasing historical behavior. Additional GIS data such as thematic maps, roadway geometry, transit network, BRT stops and terminals, and other regional planning data including BRT operational factors and implementation features, and ridership volumes were obtained from the regional and local mobility plans, transit agencies websites or directly contacting the local transit authorities.

Using the previously described GIS tools, the spatial distribution of population, household and business data, number of jobs per household, population age range, and employment was a considerable easy step. A first estimation of potential ridership was made by



buffering  $\frac{1}{4}$  mile area recommended by TCQSM (Kittelsohn&Associates, et al., 2003) and an additional  $\frac{1}{4}$  to  $\frac{1}{2}$  mile buffer (Planning Commission TOD Committee Fairfax County, VA, N/A). After completing the buffering analysis, the estimation produced by the GIS model was compared to statistical data to validate and calibrate the potential ridership model.

#### **Task 4: Complementary Studies (Origin-Destination Survey) for Determining Potential BRT Ridership**

This task has the goal of estimating corridor level Origin-Destination O-D matrices and identify the ridership coming from areas beyond the corridor's walking-distance. This task included the implementation of a state-of-the-art onboard O-D survey and the Iterative Proportional Fitting (IPF) process. These two techniques helped identify the transfer patterns between two different routes in a given corridor.

#### **Task 5: Development of System Dynamic Model for BRT**

The different stages of BRT deployment involve a set of elements that will influence and change the BRT system. In addition, the BRT systems change over time which makes their variables and the connections “dynamic” with respect to time. This task covers the analysis of the BRT system and subsystems taking into account the changes that might occur when a variable is affected by exogenous or endogenous factors over time.

The SD model was feed with all information collected during the data collection task. Additionally, all the BRT features and the relationships between them as well as the expected benefit or detriment were coded in Vensim ([Ventana Systems Inc., 2009](#)). A general model was built with the purpose of presenting an overall view of the system. SD modules, on the other hand, were built with a higher level of detail, including exogenous and endogenous variables. Once the modules structure was determined, a unit-check analysis of all variables involved in the overall SD-BRT model was completed.

#### **Task 6: Definition of Variables Connectivity and System Dynamics Model Rules**

The goal of this task was to explain in detail all the interrelations among the SD-BRT model variables identified in the previous task. Vensim software was used again to achieve this goal. The difference with the previous task is the definition of the mathematical relationship among variables.

A SD model has two main characteristics: (a) it can be dynamically simulated and (b) contains feedback structures ([Richardson & Pugh, 1981](#)). Feedback structures are defined as the transmission and return of information with special emphasis on the “returned information” since it will change the system behavior ([Haghani, et al., 2002](#)). As a result, a feedback loop will be a feedback structure involving two or more variables. These feedback loops can be either “positive” (self-reinforcing) or “negative” (equilibrating or self-correcting) ([Sterman, 2000](#)). The variables connectivity depended on the type of variable and mathematical relationship among them. Therefore, the SD-BRT model presented in this dissertation consisted mainly of three

different variable types: Level, Constant, and Auxiliary. Auxiliary variables were in fact the most used variable type during the SD modeling. Details on SD modeling variables are covered in detailed in Chapter 7.

Furthermore, in this task a subsystem involving three different deployment phases was developed. Each of the deployment phases embraced different levels of BRT configurations base on the results of task 1.

### **Task 7: Simulation Modeling**

The purposed of this task was to analyze the results from all simulations made by Vensim under different scenarios. This process helped moving to the next step of research: a calibration using existing BRT parameters from the case studies.

### **Task 8: Analysis of Results and Model Calibration**

After running the SD model, real data from transit agencies was used to validate the proposed model's results. A comparison between existing forecast methods (when available) and the SD BRT model was made. Furthermore, the preliminary results of the SD-BRT model simulation were analyzed so as to incorporate any possible change.

### **Task 9: Ridership Forecast**

A final total daily ridership for the base-year was obtained for each of the two corridors. This ridership was then forecast to the horizon year 2015.

### **Task 10 Bus Rapid Transit Case Study (El Paso, Texas)**

As an application case, the SD-BRT model was applied to a proposed BRT line in El Paso, Texas. Results of this case study were compared to the ones obtained by a previous transit study.

### **Task 11 Incorporate Specific Variables for Case Study**

Although this task was planning to be performed in the process, the final results presented in Chapter 9 showed that such specific variables were not necessary.

### **Task 12 Case Study Analyses of Results**

Total Daily Ridership, Peak and Off Peak hour analysis of results were included in this task.

### **Task 13 Construct a Friendly Interface**

As a final product of modeling BRT ridership conditions, an easy-to-use interface was developed. This tool will avoid confusions among those decision makers who are not familiar with SD modeling and/or Vensim software. The model was built in user-friendly environment using the software's available tools, so that a Vensim license is not be required for the users to run it and get results ([Ventana Systems, Inc., 2008](#))

### **Task 14 Conclusions and Recommendations**

This task included a summary of all recommendations and final remarks found through the entire research.

## **CHAPTER 4 : BUS RAPID TRANSIT FEATURES AND STAGES OF DEPLOYMENT**

As previously mentioned, the diversity of BRT definitions makes it difficult for system designers, transportation engineers and transit planners to explain the BRT concept to policy makers and the general public. This chapter proposes and recommends a more comprehensive and symbolic characterization of BRT systems and phases of deployment in the U.S.

### **4.1 Common Bus Rapid Transit Features**

BRT features (also known as elements) are physical and operational characteristics that make BRT systems stand out from regular bus services. The features vary among the BRT systems in different cities. They depend on factors such as local policy preference, customer needs, land use, weather, financial resources, etc ([Deutsche Gesellschaft für Technische Zusammenarbeit \(GTZ\), 2006](#)). The common BRT features may be grouped into infrastructure and operational features. The infrastructure features are those related to the physical facilities along corridor. They include:

- Guideway
- Stations and shelters (terminal or boarding facility)
- Park-and-ride facilities
- Surrounding land use (also known as transit oriented development)

These features are normally under the jurisdiction of the local infrastructure provider. The BRT operational features include:

- Vehicles
- Route coverage and service frequency
- ITS technologies applied to BRT
- Fare collection
- Operating speed methods

The operational features are generally controlled by the service provider(s).

#### **4.1.1 Infrastructure Features**

##### **4.1.1.1 Guideway**

The most potentially significant but costly BRT infrastructure feature is provision of dedicated or exclusive lanes. The lanes may be at grade or grade separated. Collectively, they are referred to as guideway. Guideway helps improve operating speed, schedule reliability and headway control between BRT vehicles. Guideways appear more frequently outside the U.S. Its implementation in the U.S. is rare because of the high cost of right-of-way acquisition. Thus, limited length exclusive tunnels (e.g., the Metro Bus Tunnel in Seattle, WA), combinations of dedicated lanes and mixed flow or contra-flow lanes (e.g., in Boston, Massachusetts) appear more feasible. Engineers must be innovative to come out with relatively low cost guideway

designs that will fit into the local street configurations. At least some of the advantages of exclusive guideway can be provided through less costly innovations such as bus-on-shoulder bypasses, short dedicated guideway segments and signal priority systems.

#### **4.1.1.2 Stations and Shelters**

Other than guideway, stations and shelters are the most visible infrastructure along BRT corridors. Their architecture, accessibility and comfort play a vital role to determine the BRT quality of service ([Kittelson&Associates, et al., 2003](#)) ([Diaz, et al., 2006](#)) Stations and shelters should be planned for not only existing BRT users, but also to attract users from other modes of transportation. Standards for transit facility appearance, cleanliness and inspection programs must be established. In general, BRT systems provide high quality shelters with passenger information systems. A passenger survey in Santa Clara, California ([Dahlgren & Morris, 2003](#)) found that an ideal station or shelter is a cleaned, well-maintained and patrolled place that also provides accurate schedule information. Thus, shelter and stations may not necessarily be equipped with the latest technologies.

The design of shelters must also consider passenger accessibility between the shelter and the vehicle, and between the shelter and the sidewalk. The BRT systems in several Latin American cities (such as Curitiba, Goiania and Sao Paulo, Bogota, Quito, Mexico City and Leon) have adopted the platform mode for boarding and alighting. The platform mode eliminates any difference in elevation between the station and bus platforms, and significantly reduces the dwell time. However, the construction of shelters with platforms increases the cost of the entire project.



#### **4.1.1.3 Park-and-Ride Facilities**

Park-and-ride facilities enable users to access the BRT stations by other modes. In cities where car is the dominant mode of transportation, park-and-ride facilities may encourage BRT use. Park-and-ride facilities are more common in the non-U.S. systems, for examples, in Brisbane and Bogota. Moreover, planners may design park-and-ride amenities to include commercial activities ([Deutsche Gesellschaft für Technische Zusammenarbeit \(GTZ\), 2006](#)) ([Currie, 2006](#)). The construction cost for park-and-ride facilities must be evaluated against investments for other BRT infrastructures or provision of better feeder bus service

#### **4.1.1.4 Transit Oriented Development**

Transit Oriented Development (TOD) refers to the proper planning or integration of transit stations/terminals with commercial activities. This will not only reduce the number of trips a traveler makes per day ([Deutsche Gesellschaft für Technische Zusammenarbeit \(GTZ\), 2006](#)), but also produce revenue from the lease of commercial space. In general, TOD increases land/property value along the corridor, as experienced in Brisbane, Bogota, San Francisco and Washington D.C ([Wright, Bus Rapid Transit: Planning Guide, 2004](#)). The opportunity to develop commercial spaces is a trend and is becoming part of the strategies to contribute to BRT project funds.

## **4.1.2 Operational Features**

### **4.1.2.1 Vehicles**

BRT systems usually use vehicles that are distinct from regular bus service. They often have high-capacity, low-floor, ergonomic-seats and multiple-wide-doors. These designs contribute to improved ride quality, comfort, and reduction in dwell time. The use of articulated buses appears common. Nonetheless, articulated buses are recommended only when high capacity is desired without the need of increasing the frequency of service along the line (Kittelson&Associates, et al., 2003). The design of vehicle should be considered together with the station and shelter designs.

Low-floor vehicles can reduce boarding time (Levinson H. , et al., 2003). (Levinson H. S., et al., 2003) Asian and Latin American cities with a high passenger demand opt to use high-floor vehicles for better ride quality (better mechanical suspension).

### **4.1.2.2 Route Coverage and Service Frequency**

The TCQSM describes route coverage as the area covered by a particular route within walking distance (400 m for a bus stop, or 800 m from a terminal) (Kittelson&Associates,et al., 2003). Area coverage by BRT systems is necessary to attract ridership. However, extensive area coverage may lead to frequent stops and longer travel time.

Service frequency is, indeed, one of the measures of transit service quality. A high frequency implies lower average wait times for customers. This feature usually attracts ridership and is a key component in the total travel time ([Kittelson&Associates, 2003](#)). In the U.S., BRT service headways range from 3 to 20 minutes while in Latin American countries the headways vary from less than a minute (Sao Paulo and Porto Alegre) to 10 minutes depending on the time of day. In countries with high passenger demand such as Kuming (China) and Seoul (Korea), the average headway during the day is continuously less than a minute ([Wright, Bus Rapid Transit: Planning Guide, 2004](#)).

In terms of capacity, which is dependent on the combined effect of vehicle capacity, route coverage and service frequency, BRT vehicles or fleets can also be competitive with rail-based mass transit systems. One of the greatest misconceptions of BRT systems is that they are unable to reach high capacity operation. Wright ([Wright, Bus Rapid Transit: Planning Guide, 2004](#)) reported that Bogota's BRT moves around 36,000 passengers per hour per direction and the Sao Paulo BRT transports up to 30,000 passengers per hour per direction. Both systems use high-capacity articulated vehicles. In U.S. the highest capacity can be found in the Lincoln tunnel in New York with a capacity of 25,000 passengers per hour per direction ([Vuchic, 2005](#)). BRT systems in the U.S. usually have lower passenger demand which leads to lower design capacities compared to systems in Asian and Latin American cities ([Cain, et al., 2007](#)).

#### **4.1.2.3 Intelligent Transportation Systems Technology Applied to BRT**

Intelligent Transportation Systems (ITS) technology are being more commonly implemented in European, North American countries and Australia than in developing countries. BRT systems in developing countries are still limited in ITS suplications because of the capital and operating cost ([Wright, Bus Rapid Transit: Planning Guide, 2004](#)). ITS technologies mainly contribute to the image, safety and operating speed ([Kittelson&Associates, 2003](#)) ([Diaz, et al., 2006](#)) ([Currie, 2006](#)) ([Sakamoto, 2007](#)) but is not an essential feature for a successful BRT system. The BRT systems in Bogota, Quito, Beijing, Mexico City and all Brazilian systems are successful examples that have not implemented or have very limited ITS technologies.

Bus Signal Priority (BSP), real-time passenger information systems and Automatic Fare Collection (AFC) are examples of typical ITS applications in BRT systems. Implementation of BSP has grown rapidly among the U.S. transit systems. Real-time passenger information systems increase productivity of passengers while waiting for buses, avoid crowding at stations, and enhance the image of the shelters ([Kittelson&Associates, et al., 2003](#)). One of the newest ITS technologies for BRT is lane assist systems being implemented in the BRT systems in Orlando and Minneapolis. Lane assist permits BRT vehicles to operate at higher operating speeds with improved safety ([Kulyk & Hardy, 2008](#)). Precision docking technology (implemented in Las Vegas, but more popular in European cities) reduces the dwell time.

#### **4.1.2.4 Fare Collection Methods**

Automatic fare collection (AFC), although originated in other transit systems, has become a regular feature of BRT systems worldwide. Advanced AFC with a common smart card allows integration of several modes in one single system which offers customer convenience ([Deutsche Gesellschaft für Technische Zusammenarbeit \(GTZ\), 2006](#)). In surveys carried out among transit users in Hong Kong, Taipei, New Delhi, London, Oslo, Copenhagen, Washington, D.C., San Francisco, Chicago, Rome, Bangkok, Seoul and Istanbul, smart cards were noted as being effective in promoting ridership, increasing customer satisfaction, improving boarding time and increasing ease of access ([Boushka, 2006](#)). AFC usually generates important data for demand forecasting and operational planning ([Hidalgo, et al, 2007](#)).

#### **4.1.2.5 Operating Speed**

Operating speed depends on many factors such as guideway, number of stops, dwell time, etc. When the TransMilenio (in Bogota) was first implemented, the operating speed went from approximately 15 km/h to 26.7 km/h ([Cain, et al., 2007](#)). In Seoul, the operating speed of BRT has improved over time (from 33% in 2004 to 100% in 2006) as users become more familiar with the system ([Deutsche Gesellschaft für Technische Zusammenarbeit \(GTZ\), 2006](#)). Operating speed has a direct impact on ridership attraction. As the name implies, BRT service should be “rapid”.

### **4.1.3 Other Related Features**

#### **4.1.3.1 Environmental**

A single BRT vehicle may replace as many as 50 automobiles along a corridor, thus reducing the total emissions ([Deutsche Gesellschaft für Technische Zusammenarbeit \(GTZ\), 2006](#)). Environmentally friendly vehicles are often highlighted as a branding feature of BRT systems. This is particularly important to the U.S. cities who seek federal funding (from FTA) to start BRT services.

#### **4.1.3.2 Safety**

Guideway and intersection geometric treatments may improve the overall corridor safety to better than pre-BRT levels. The corridor designs that eliminate conflicts between BRT buses and other vehicles or pedestrians usually produce safety benefits. Seoul and Bogota have seen reductions in the number of accidents by 27% and 93% respectively, compared to pre-BRT conditions ([Deutsche Gesellschaft für Technische Zusammenarbeit \(GTZ\), 2006](#)).

#### **4.1.3.3 Recommended Deployment Phases**

The above BRT features are those most commonly found in operational systems. However, not all the features must appear for a system to be called BRT. As feature selection and design depend on the project budget, local user, traffic and corridor characteristics, the authors have

grouped the feature combinations in three deployment phases. The infrastructure features are listed in [Tables 4.1](#) while the operational features are listed in [Tables 4.2](#). The three phases are named limited, moderate and aggressive phases, in increasing order of system cost, ridership attraction and operating speed. One may view the recommended features in Tables 2 and 3 as market packages in the different deployment phases. Note that, not all the features listed in each of the phases in [Tables 4.1](#) and [4.2](#) must be followed strictly. Planners can estimate the ridership along the projected corridor and compare that number with the ridership presented at each phase column title. Therefore, the suggested set of features can be read in the corresponding columns. For instance, if a projected corridor is expecting 21,000 passengers per day, the suggested set of features will be read from the second column (Phase 2).

The three deployment phases may be implemented progressively, starting from limited phases when funds are limited and ridership is uncertain. The limited phase consists of features that can be implemented in relatively short time, at relatively low costs. This set-up is particularly suitable for most U.S. cities because of the initial low ridership and high right-of-way cost. Once the limited phase BRT has gained acceptance by policy makers and users, and with increasing ridership and experience, the system may be upgraded to the moderate or directly to the aggressive phases. That is, the sequence of deployment does not need to be in sequential order. If the right-of-way and funds are readily available, a transportation agency may opt to implement the aggressive phase directly without having to go through the first two phases. Note also that, it is also possible to upgrade one feature, for an example, AFC at a time. Therefore the shift from one deployment phase to the next may take place gradually over time.

**Table 4.1** Recommended BRT Operational Features at Different Stages of Deployment

INFRASTRUCTURE FEATURES		PHASE 1 (3,000 to 9,300 pax/trip/day)	PHASE 2 (3,500 to 26,000 pax/trip/day)	PHASE 3 (120,000 to 1,450,000 pax/trip/day)
GUIDEWAY AND LANE IMPROVEMENT				
Mixed Flow		x		
Dedicated guideway			x	x
Contra-flow way		x	x	x
Grade separated exclusive guideway	Below grade			x
	At grade			x
	Aerial			x
Queue jumper		x	x	
Overpass lane				x
Median lane runway			x	x
Curb lane		x		
Curb extension		x		
STATIONS				
Enhanced shelters with seats and lighting		x	x	
Air conditioning/heater			x	x
Level Platforms			x	x
Other Amenities (route & schedule, vending machines, telephones)				x
Pedestrian crosswalks with signal		x	x	
Pedestrian bridge access				x
Automatic passenger counter			x	x
PARK-AND-RIDE FACILITIES				
Open lot parking		x	x	
Multi-Level Parking			x	x
Transfer areas (inside buildings)			x	x
Bicycle parking		x	x	x
Taxi stands		x	x	x
SURROUNDING LAND USE				
Sidewalk condition improvements		x	x	x
Security systems near stations			x	x
Mixed land use near station		x	x	x
Commercial activities around station			x	x
Clustered business facilities (integrated building)				x



**Table 4.2** Recommended BRT Operational Features at Different Stages of Deployment (cont.)

OPERATIONAL FEATURES	PHASE 1 (3,000 to 9,300 pax/trip/day)	PHASE 2 (3,500 to 26,000 pax/trip/day)	PHASE 3 (120,000 to 1,450,000 pax/trip/day)
<b>VEHICLES</b>			
40'-60' articulated	x	x	
80' double articulated			x
Diesel, CNG or electric vehicle	x	x	x
Hybrid vehicle		x	x
Low-floor vehicles		x	x
Multiple entrance-exit doors			x
Wi-Fi service			x
<b>INTELLIGENT TRANSPORTATION SYSTEM</b>			
Transit signal priority	x	x	x
Automatic vehicle location		x	x
Real-time information system (at stations)		x	x
Real-time information system (on board)			x
Collision warning			x
Precision docking			x
Lane assist system			x
Automatic steering- guidance system			x
Automatic speed and spacing control system			x
Voice and video monitoring			x
<b>FARE COLLECTION</b>			
Onboard fare collection	x	x	
Pre-board fare collection	x	x	x
Cash payment	x		
Magnetic strip cards		x	
Smart cards		x	x
<b>SERVICE AND OPERATION</b>			
Marketing identity	x	x	x
Reduced number of stops	x	x	x
Route length extension		x	x
Increased overage area with multiple routes			x
High service frequency		x	x
Feeders system		x	x
On-time performance monitoring		x	x
<b>OPERATING SPEED</b>			
Operating Speed <20 mph	x		
Operating Speed >20 and <30 mph		x	
Operating Speed >30 mph			x

## 4.2 Summary

This chapter has reviewed and summarized the infrastructure and operational features of BRT systems worldwide. Most of the BRT systems reviewed share common but not all BRT features. When designing a BRT system, the features should be selected according to project budget, local users' preferences and traffic and corridor characteristics combined to produce maximum ridership attraction as well as a competitive operating speed. Taking into consideration the limited evidence of BRT success, ridership and high right-of-way cost in U.S. cities, the BRT features have been grouped into three deployment phases. The features recommended in the different phases are in increasing order of cost, engineering sophistication, and implementation time frames, but they also correspond to more positive effects on ridership attraction and operating speed. The phases may be implemented in sequential order for a BRT system to be sustainable.

## **CHAPTER 5 : DEMOGRAPHIC ANALYSIS OF BUS RAPID TRANSIT CORRIDOR USING GEOGRAPHIC INFORMATION SYSTEMS**

The GIS systems application to transportation, as defined by Miller and Shaw ([Miller & Shaw, 2001](#)) is the principles and applications of geographic information technologies to transportation problems. GIS-T is a branch of GIS dedicated entirely to the transportation area. The GIS tool selected for the analysis of this section was ArcGIS Business Analyst (BA). The BA implements spatial analysis on demographics, market and socio-economic data that offers reliable BRT user profile information at practically any location in the United States.

Despite BA has not yet been fully considered as part of the GIS-T branch, this chapter shows how this tool can be easily used to estimate population along a BRT corridor avoiding the process of requesting information from regional or local agencies.

### **5.1 Introduction to Geographic Information Systems**

Geographic Information Systems (GIS) has been adapted as a very useful and powerful tool for spatial analysis and, in the past two decades, for urban planning. With the development and improvement of computer-aided programs, database processors and graphics, the spatial analysis has become accessible.

In general, GIS are computerized systems for the storage, retrieval, manipulation, analysis, and display of geographically referenced data. It is commonly applied to geographically orientated data processing tasks, and often refers to the integration and use of computer-aided design, computer cartography, database management, and remote sensing information systems (ESRI, 2001).

## **5.2 ArcGIS Business Analyst**

One of the most popular GIS software package in used today is ArcGIS (Environmental Systems Research Institute, 2010). BA is an ArcGIS extension that allows the analysis of site locations, customers, markets, trade areas, and business competitors. This powerful extension let users to build models, visualize them on a map, and analyze the results (Environmental Systems Research Institute, 2010). Business Analyst uses a combination customer demographics and geography to locate areas defined by users and analyze demographic characteristics (Environmental Systems Research Institute, 2008). It integrates data from reliable data providers which makes this tool a powerful demographic and business analyzer. Business Analyst uses a geographic analysis that links store locations with the associated information and presents results in a map or document. Data and providers included in this tool are:

- Demographic Data— offers more than 1,500 demographic data variables including current-year estimates and five-year projections. These data variables also include current-year estimates for employee population, population by occupation/industry,

disposable income, and consumer expenditures all at the state, county, ZIP Code, census tract, and block group geography levels.

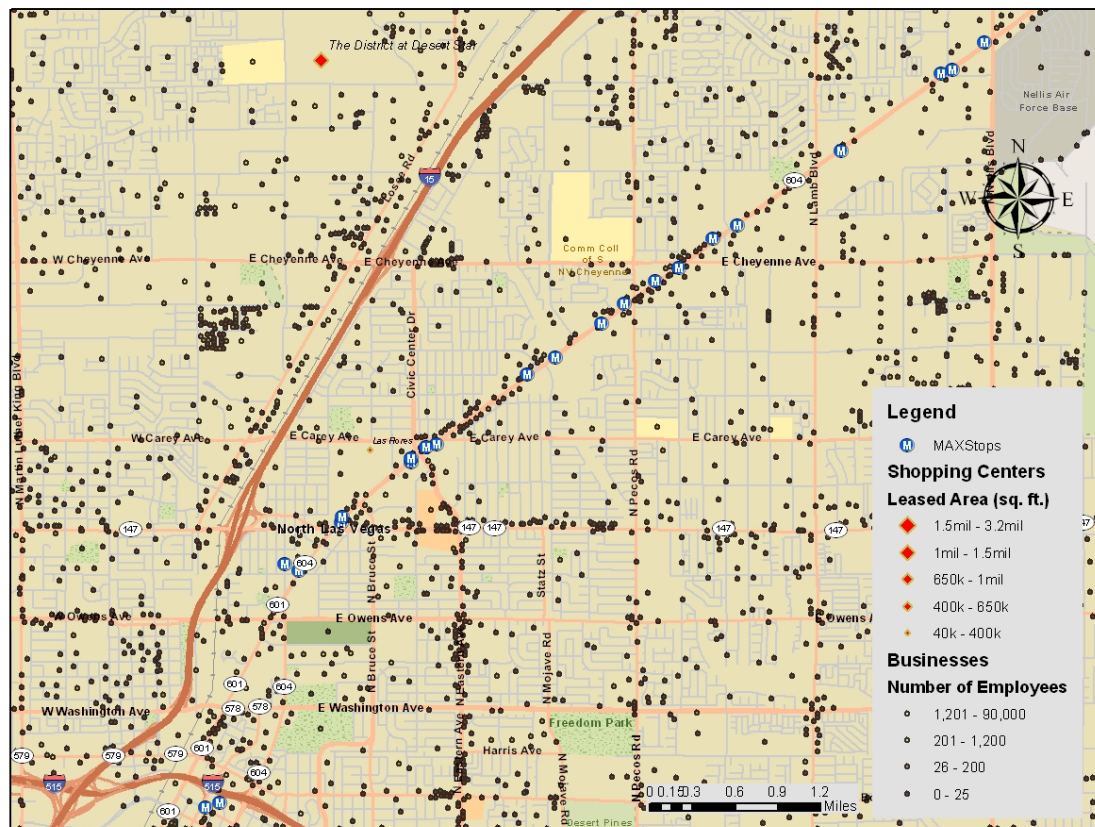
- Business Data—a national data for approximately 11 million U.S. businesses ([infoUSA, 2010](#)), including data by industry, sales volume, location, name, employees, and more.
- GlobeXplorer®— a collection of high-quality aerial and satellite imagery ([DigitalGlobe, 2010](#)).
- Street Information—a set of detailed street data from contains more than 14 million addressed street segments in the U.S. ([Tele Atlas, 2010](#)).

In addition, BA includes the Business Objects™ Crystal Reports®. This tool included in BA allows viewing, printing, and exporting reports to a variety of popular formats. The BA extension also includes several analysis tools such as trade area and market analysis, customer profiling, store site selection, among others.

In this research work, the advantages of using BA as an outstanding demographic and geographic analyzer were exploded by substituting business stores for BRT stops or stations. This process was applied to estimate potential BRT ridership and is explained in the following section.

### 5.3 Business Analyst Estimation of Population along the BRT Corridor

As mentioned in Chapter 3, this research uses BA as a tool to estimate potential BRT ridership by analyzing the population around bus stops, stations and terminals. This analogy is based on the idea that BRT is, as retail stores, offering a service to the public with specific clients (passengers) that will be attracted according to the location (stop distance/walking distance) and amenities (BRT features). The following figures show the businesses and shopping centers included in BA (2010) for Las Vegas MAX area (Figure 5.1) and the BRT service accessibility locations (stops) along the Las Vegas MAX BRT line.



### 5.3.1 Service Coverage Area

Service coverage is a measure of the area within walking distance of transit service. This area is defined by the TCQSM as the “air distance within 0.25 mile (400 m) of a bus stop or 0.5 mile (800 m) of a busway or rail station. Any location within 0.25 mile (400 m) of the area served by deviated fixed-route bus service is also considered to be covered.” This analysis can be completed relatively fast by using the buffer tool included in the ArcGIS package. The buffer appends the demographic and customer profile data from BA and gives the corresponding report. This process saves time and effort when comparing to traditional methodology of extracting data from the Transportation Analysis Zones (TAZs) and adjusted to be within the air distance recommended by the TCQSM

There are several hypotheses about what is or what should be the right walking distance. Dittmar and Ohland ([Dittmar & Ohland, 2004](#)) define a distance between 500 and 1,000 feet as an optimal walking distance from the transit stop to the place of employment and between ¼ and ½ mile from the transit stop to a residential place. The Maryland’s Mass Transit Administration ([Maryland Department of Transportation, 1988](#)) recommends 1500 feet (0.28 mile) as the “adequately served” walking distance and recommends “closer spacing” for high-density areas. The New Jersey Transit ([New Jersey Department of Transportation, 1994](#)) defines reasonable walking distance as the “willingness to walk 5-15 minutes to get to or from a transit stop, corresponding to ¼ to ½ mile, but varies based on topography, sense of safety and security,

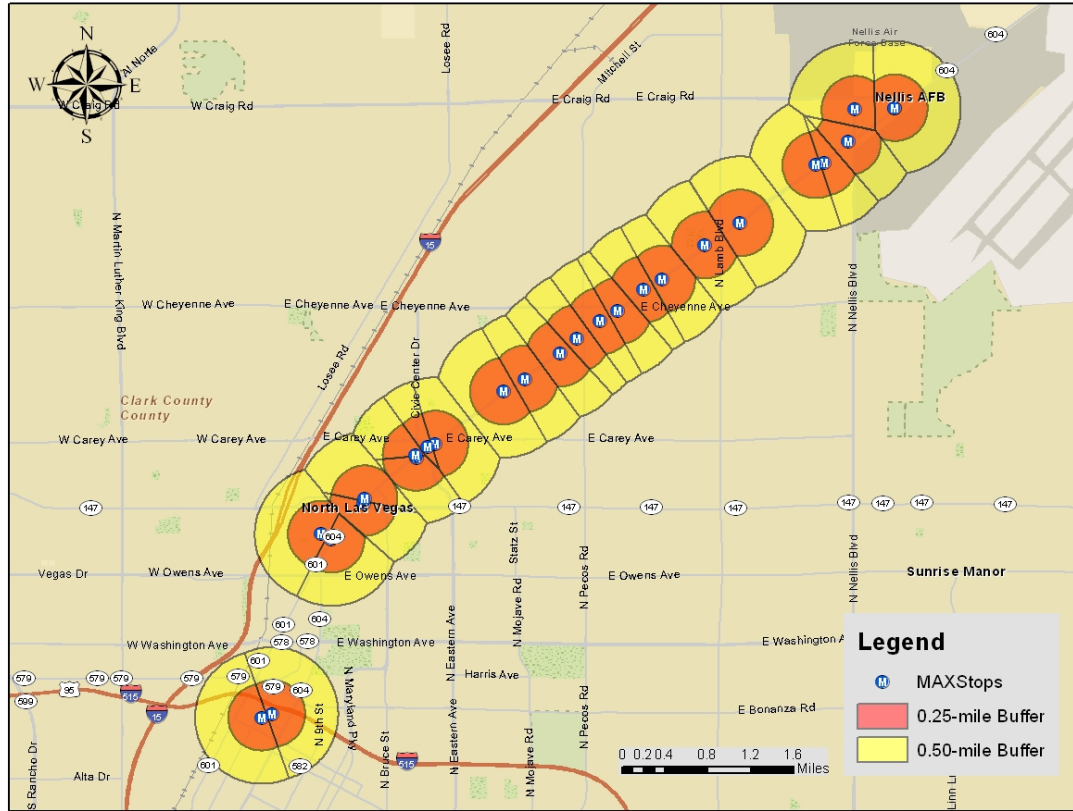
presence of interesting activity.” Table 5.1 illustrates a summary of the recommended walking distance for other three jurisdictions.

**Table 5.1** Recommended Walking Distance for other Jurisdictions

<b>Jurisdiction</b>	<b>Walking Distance Referred</b>
Mid-America Regional Council (Kansas City, Missouri)	1500 ft (0.28 mile)
Snohomish County Trans. Authority (Snohomish City, Washington)	1000 ft (0.19 mile)
Regional Plan Association (NY, CT, NJ Tri-metro area)	0.25 mile

After the comprehensive review of an acceptable walking distance and the experience in different cities, the distance used throughout this research work was set from a  $\frac{1}{4}$  (0.25) to  $\frac{1}{2}$  (0.50) mile. The first ring (buffer area) has a ratio of 0.25, mile while the second ring is the result of a 0.50-mile ratio ring subtracted from the 0.25 mile ring. [Figure 5.2](#) shows the resulting of the  $\frac{1}{4}$  -mile and  $\frac{1}{2}$ -mile buffer rings for the Las Vegas MAX BRT stops.

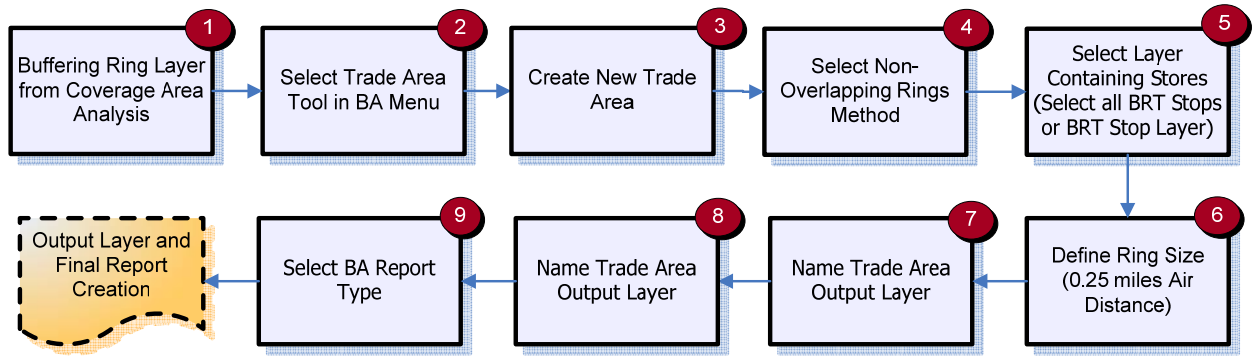




**Figure 5.2** Service Coverage Area Las Vegas MAX

### 5.3.2 Creating Trading Areas

Once the coverage areas are created, the following step is to create the trading areas. In this process the store layer is interchanged by the BRT stop layer and the analysis of trade area delimitation is performed. The buffering created for the coverage area analysis is now appended with the BA demographic data. BA offers the advantage of a Trade Area Wizard that helps users to create a new layer containing the demographic and marketing data. [Figure 5.3](#) summarizes the steps to create a trade area (demographic report).



**Figure 5.3** BA Trade Area Creation Process (Extraction of Demographic Data)

### 5.3.3 Demographic Reports

For each one of the rings, BA extracts the total and projected population. The complete report includes several variables. However, for the purpose of this research, only preferred demographic variables were selected. The following figure (Figure 5.4) illustrates a sample output report for a specific ring along the Las Vegas MAX BRT Corridor. The available reports in version 2008 of BA included: population, age, household, race, age by sex profile, demographic, market profile, retail expenditure, general, and executive reports.



## Las Vegas MAX Bus

## Age Profile

Description 0 - 0.25 Miles

Area	Whole Layer (MAX)	Nam	Whole Layer (MAX)	Description	Whole Layer (MAX)	
Summary		2000	2008	2013	2008-2013 Change	2008-2013 Annual Rate
Population		22,179	24,625	27,902	3,277	2.53%
Households 0.25		7,235	8,033	9,096	1,063	2.52%
Average Household Size		2.99	3.00	3.01	0.01	0.07%
Median Age		27.1	27.3	27.4	0.1	0.07%
Median Male Age		27.7	28.2	28.2	0.0	0.00%
Median Female Age		26.4	26.4	26.4	0.0	0.00%
Total Population by Age						
		2000		2008		2013
		Number	Percent	Number	Percent	Number
Total		22,179	100%	24,626	100%	27,903
0-4		2,515	11.3%	2,817	11.4%	3,246
5-9		2,329	10.5%	2,310	9.4%	2,577
10-14		1,674	7.5%	1,909	7.8%	1,967
15-19		1,556	7.0%	1,888	7.7%	2,061
20-24		2,097	9.5%	2,316	9.4%	2,880
25-29		2,164	9.8%	2,293	9.3%	2,549
30-34		1,901	8.6%	1,901	7.7%	2,016
35-39		1,645	7.4%	1,681	6.8%	1,723
40-44		1,485	6.7%	1,541	6.3%	1,673
45-49		1,226	5.5%	1,448	5.9%	1,618
50-54		968	4.4%	1,231	5.0%	1,452
55-59		757	3.4%	1,025	4.2%	1,316
60-64		607	2.7%	774	3.1%	1,019
65-69		432	1.9%	537	2.2%	668
70-74		331	1.5%	371	1.5%	445
75-79		231	1.0%	248	1.0%	290
80-84		134	0.6%	176	0.7%	204
85+		127	0.6%	160	0.6%	199

**Figure 5.4** Demographic Report Sample (Age Profile)  
Along Las Vegas MAX BRT

The BA general reports include base year (2008) population, a projected population for 2013, and a projected annual five-year growth rate. This annual growth rate varies from stop to

stop and in some cases can reach negative numbers. For this reason, an average annual growth rate that included all the stops along a given corridor was calculated ([Table 5.1](#)).

#### **5.4 Total Population along the Corridor**

The buffering analysis previously described was repeated for several BRT corridors in the U.S. The intention to this exercise was to obtain the total population along the corridor as well as the growing rate reported in BA to subsequently “feed” the SD-BRT model developed in Chapter 7 and finally estimate the potential BRT ridership. The following table ([Table 5.1](#)) summarizes the results for the selected BRT corridors included in the analysis.

**Table 5.2** Total Population Report

<b>Total Population along the Corridor (Report)</b>				
<b>0.25- mile Non-overlapped Rings</b>				
<b>BRT Corridor</b>	<b>Location</b>	<b>2008 Total Population</b>	<b>2013 Projected Population</b>	<b>2008-2013 Growth Rate (%)</b>
LV MAX	Las Vegas, NV	24,626	27,903	2.53010562827
Orange Line	Los Angeles, CA	21,489	22,451	2.53010562827
Mesa St	El Paso, TX	13,478	13,756	0.41252411337
<b>Total Population along the Corridor (Report)</b>				
<b>0.25 to 0.50-mile Non-overlapped Rings</b>				
<b>BRT Corridor</b>	<b>Location</b>	<b>2008 Total Population</b>	<b>2013 Projected Population</b>	<b>2008-2013 Annual Growth (%)</b>
LV MAX	Las Vegas, NV	46,516	51,902	2.31576231834
Orange Line	Los Angeles, CA	78,659	81,626	0.75439555550
Mesa St	El Paso, TX	21,257	21,997	0.69624123818

## 5.5 Summary

This Chapter described the usage of ArcGIS BA as a tool to obtain demographic data along any given corridor in the United States. Base-year and projected population are key variables for ridership forecasting. Reports generated by BA allow estimating the total and projected population by stop or corridor level. BA offers the advantage of extracting reliable demographic information in a relatively simple manner and avoiding data request to governmental or private agencies.

## **CHAPTER 6 : COMPLEMENTARY STUDIES FOR DETERMINING POTENTIAL BRT RIDERSHIP**

Corridor and stop level data are important factors to estimate potential BRT ridership. However, this information does not include O-D patterns or passenger trip distribution. In addition, ridership coming from areas beyond the corridor's walking-distance buffer cannot be determined. This chapter includes an innovative survey technique that captures the trips generated outside the walking-distance areas that may influence the ridership patterns for a given corridor.

### **6.1 Onboard Origin-Destination and Intercept Transit Surveys**

Onboard O-D surveys are vital for transit agencies since they allow the agencies to identify customer trip characteristics, travel behavior, demographic characteristics, and customer attitudes about the transit service (Schaller, 2005). Onboard and intercept surveys (type of survey where surveyors intercepts transit users at transfer centers) are basically self-administered surveys (including interviews) conducted on board of buses, trains and at stations. These types of surveys involve in-person interaction between the surveyor and the transit users. The TCRP Synthesis 63 reports that during 2002 to 2004, 96% of transit agencies in the U.S. conducted onboard surveys (Schaller, 2005). Large agencies tend to conduct more than five onboard/intercept surveys per year, while small agencies typically conduct surveys every one to three years.

Onboard and intercept transit surveys may be the only effective way to gather riders' trip information since they provide higher response rates than other methodologies (Schaller, 2005). Although onboard-intercept surveys are widely used by transit agencies, they are laborious and time consuming. A systemwide O-D survey is perhaps the longest-duration survey with a median of ten months from start to finish. Even the smallest surveys done by some U.S. transit agencies took a median duration of three months (Schaller, 2005). Moreover, as reported in the TCRP Synthesis 63, survey planning, data collection/data processing, and analysis each generally take about the same amount of time than the survey itself. Therefore, this chapter proposed an easy-to-implement and quick O-D survey technique that can be completed in few weeks for a corridor.

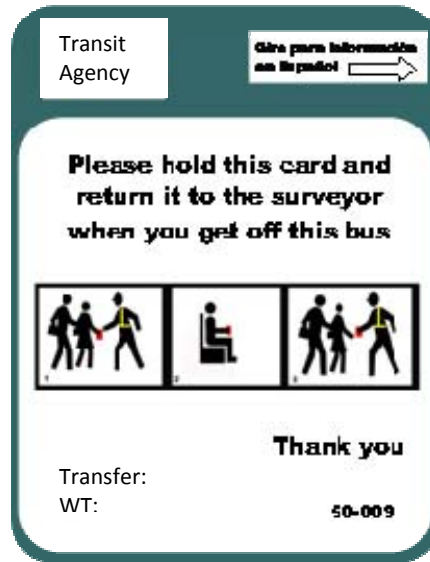
## **6.2 Proposed Onboard Origin-Destination Survey**

After analyzing onboard survey methods, a floating card linking O-D with transfers was selected as the most convenient and simplest technique for determining the potential ridership coming from outside the area of study. This technique was partially based on a pilot report that describes non-standard survey methods for a system-wide onboard O-D study conducted by NuStats for the Los Angeles County Metropolitan Transportation Authority (NuStats, 2009). Although alike, the survey technique presented in this dissertation represents a simplified version that was adapted in order to save time and effort. The main advantage of the method is its ability to significantly reduce the amount of labor force needed compared to other conventional onboard O-D surveys: only two surveyors per bus trip are necessary. For validation purposes, the method was tested in a potential BRT corridor (Mesa St.) in the City of El Paso Texas. Results of this test are presented in Section 6.4 of this chapter.

### **6.2.1 Methodology of Onboard Origin-Destination Technique**

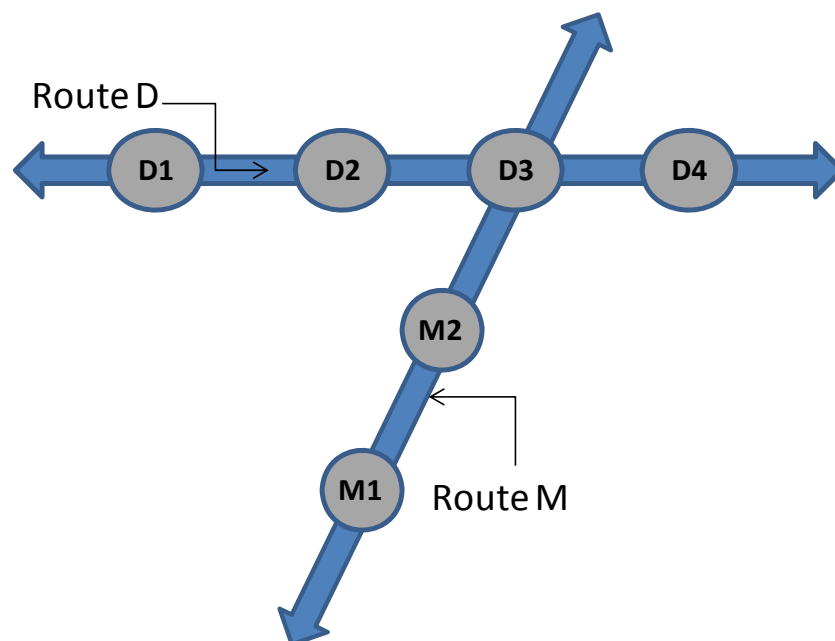
One surveyor at front door for boarding and other surveyor in the rear door for alighting are capable of survey a bus unit roundtrip. The surveyors distribute the cards to each one of the passengers boarding the bus. After that, one of the surveyors' documents all serial numbers of cards distributed at individual stops. This surveyor asked each boarding passenger to hold and return the card when alighting. Additionally, the surveyor records the individual serial number or the set of serial numbers depending on the passenger load at boarding stops. The second surveyor collected the cards at the rear door when passengers alight and records the serial number of each card on a separate paper. In some occasions, passengers alight using the front door, this issue can be solved with some help from the front-door surveyor by making the card collection and pass it to the rear-door surveyor. The survey card includes two questions regarding the user's transfer patterns and the walking time to the bus stop. When a passenger is alighting the second surveyor asks the passengers if he or she is transferring to another route and writes the transferring route on the card as well as the approximate amount of time they took from their origin to the bus stop. With this valuable information the number of transfers and walking distance can be estimated. The following Figure (Figure 6.1) shows a sample of the card design that users handle during the survey.





**Figure 6.1** Survey Card Sample

The following figure (Figure 6.2) and table (Table 6.1) illustrate an example of a two-route configuration and survey records respectively. The figure shows route “D” and its corresponding stops (D1 to D4) and route “M” with stops M1, M2 sharing the transfer stop D3.



**Figure 6.2** Example of a Two-route Configuration

**Table 6.1** Example of Card Serial Number Recording

Stop ID	Serial Number of Cards Distributed at the Stop	Serial Number of Cards Collected at the Stop	Cards With Transfer Information
D1	1-10	-	-
D2	11-16	2-9	-
D3 (Transfer Stop)	17-22	1, 11-14	1, 11-13
D4	-	10, 15-16,17-22	-
Total Riders on Route D = 22, Total Transfers to Route M = 4			

The representation of all unlinked trips (trips that start and end at the same route) will be as shown in Table 6.2.

**Table 6.2** Unlinked Trips Representation

Origin	Destination	Riders
D1	D2	8
	D3	1
	D4	1
D2	D3	4
	D4	2
D3	D4	6
Total Riders = 22		

Consequently, all the linked trips (trips transferring from Route “D” to Route “M” are shown in Table 6.3 below.

**Table 6.3** Linked Trips Representation

Origin	Destination	Riders
D1	M2	1
D2	M2	3
Total Transfers = 4		

### **6.2.2 The Iterative Proportional Fitting Process**

The Iterative proportional Fitting (IPF) is a method for adjusting an O-D matrix cells to add up the selected totals for both columns and rows of that O-D table ([Hunsinger, 2008](#)).

The objective of the IPF process is to create seed trip tables representing realistic O-D patterns of existing transit riders including those transferred from other routes. These matrices are obtained from the O-D surveys on bus routes described in the previous section. The matrices are then used as seed values to estimate total riders between various origins and destinations within the same bus route (unlinked trips) and between routes (linked bus routes) ([Cui, 2006](#)). Both bus routes operate as local bus routes with large number of bus stops in both inbound and outbound directions. The O-D survey previously described produces O-D matrices consisting of all stops along the bus routes.

At a corridor level, it is recommended that separate seed matrices are produced for outbound/inbound and peak/off peak periods to fulfill FTA's requirements. The seed matrices can be created using field survey of only single trip for each peak/off peak period and outbound/inbound directions.

### **6.2.3 Procedure for Determining Transferring Users**

The step-by-step procedure to develop seed matrices and apply IPF method to determine station-level O-D matrices are:

- Step 1: From surveys of individual bus trips without transfer, create stop-level O-D matrices. For each bus route, output four O-D trip tables for outbound+peak, outbound+off-peak, inbound+peak, and inbound+off-peak periods. Stop level O-D matrices (seed matrices) can be aggregated to BRT station-level O-D matrices using 1/2-mile buffer around the planned stations.
- Step 2: Stop level trip-by-trip boarding and alighting patterns are aggregated to determine BRT station level boarding and alighting patterns. Boarding and alighting of individual bus trips surveyed within the peak or off-peak hours are summed to obtain total boarding and alighting for peak and off-peak periods.
- Step 3: Combine seed matrices to form total boarding and alighting.
- Step 4: Using station-level O-D matrices as seed matrices, the IPF method is used to determine total O-D trips for peak and off-peak periods.

### **6.3 Application of the Proposed Onboard O-D Survey Method in a BRT Corridor**

To test the efficiency of the proposed O-D survey technique presented in this chapter, a survey was performed along a potential BRT corridor in the City of El Paso, Texas. Details of this BRT Corridor will be explained in Chapter 9.

The survey technique was developed in which each transit rider's boarding and alighting stop location (for the bus route being surveyed) was obtained by the survey team by noting where the survey card was handed out and where it was returned. The survey was performed for at least two consecutive bus trips during peak (6:00-9:00 am) and off peak (9:00 am-12:00 pm) periods. The onboard survey was conducted during the week of January 25-27, 2010.

#### **6.4 Survey Results**

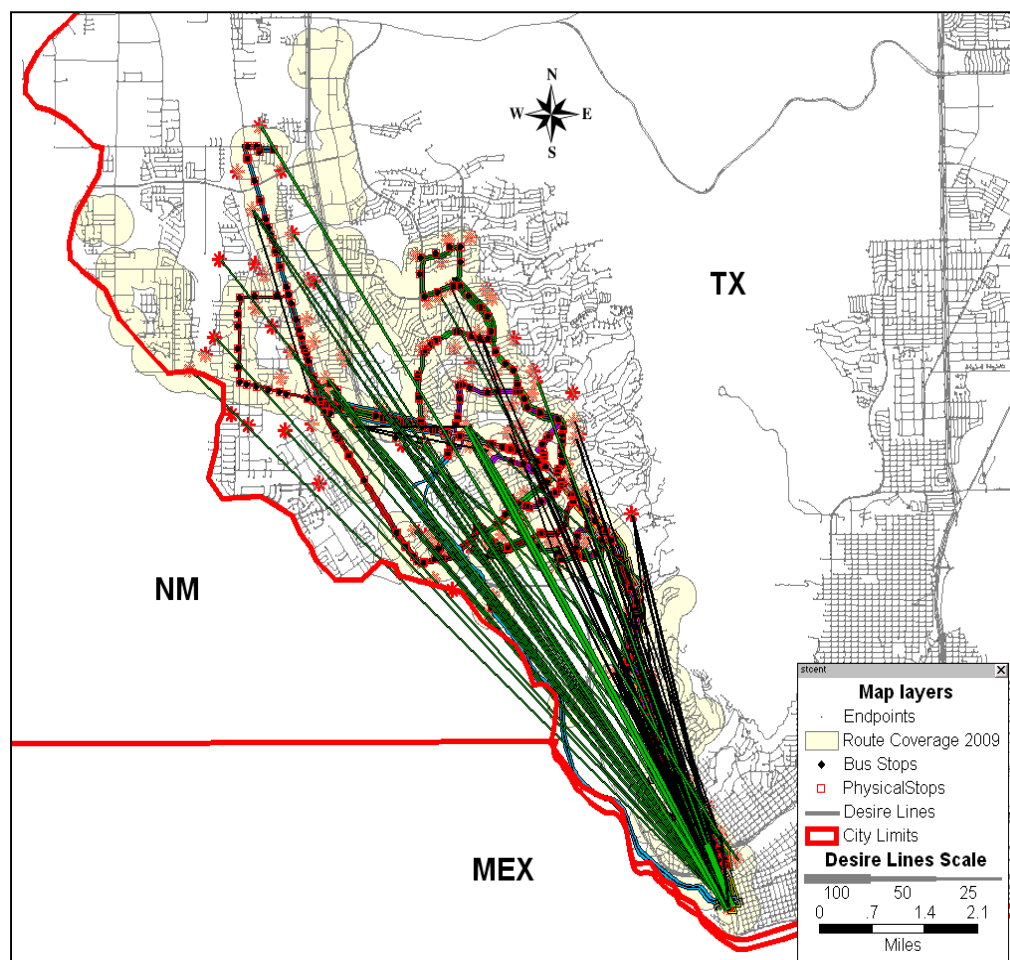
Results from the survey were used to construct O-D trip tables for morning peak and off-peak periods for inbound and outbound trips along Mesa St. Corridor in El Paso, Texas. The O-D trip tables were then used as seed matrices to apply the IPF method to create trip tables for each bus route surveyed.

The seed matrices determined from a single trip survey resulted in several null cell values. The IPF was performed using seed trip table for peak and off-peak and outbound and inbound trips. A constant number of IPF iterations equal to 100 were used to determine individual cell values. Due to the fact that typical boarding on a trip on these routes is small (<100 riders), a significant number of O-D stops have zero values in the O-D matrix. Final O-D matrices (seed matrices) were then created by aggregating bus stops based on proximity to planned bus rapid transit locations (1/2-mile).

Data regarding the transfer patterns from the onboard O-D survey provided O-D information for linked trips between the bus routes. Due to the fact that the total number of

transfer between the routes were extremely low, applying IPF to determine transfer O-D matrix using seed matrices for linked trips among the routes was probably unnecessary.

The following Figure (Figure 6.3) shows a sample result of both the O-D and the IPF process for Mesa Street BRT Corridor. The O-D tables (trip tables) were input in TransCAD (Caliper, 2005) software for a better representation of O-D pairs.



**Figure 6.3** Origin-Destination Representation for Mesa Street, El Paso, TX

## **6.5 Summary**

This chapter describes a process to estimate the O-D trip table patterns as well as the transfer movements along a BRT corridor. The simplicity of this process saves time and requires a minimum labor (surveyors) and data analysis. The process described in this chapter is also useful for stop/station distribution when a BRT is in the planning stage. It helps identify the most frequent O-D pairs which may lead to a better design of shelters, vehicle capacity, forecast operating time, dwelling time, waiting time, in vehicle travel time, among others BRT parameters.

## **CHAPTER 7 : FORECASTING BUS RAPID TRANSIT RIDERSHIP USING THE SYSTEM DYNAMICS THEORY**

Ridership estimation for BRT is crucial for planning and designing important elements at any system's deployment phase. This chapter states the BRT ridership estimation problem and describes the proposed method for BRT demand estimation using the SD model fed by a GIS model. This chapter also includes an introduction to the SD theory followed by its application to BRT demand forecast including the analysis of some BRT element and its dynamic influence in the entire transit system.

### **7.1 The BRT Ridership Estimation Problem**

Most of the existing methodologies for estimating bus ridership are based on TDMs. However, in the case of BRT services, this estimation becomes difficult when the planned BRT corridor has only regular bus services.

Several research projects have documented guidelines for planning and implementing BRT in urban travel corridors ([Kittelson & Associates, et al., 2007](#)) ([Wright, et al, 2007](#)) ([Wright, Bus Rapid Transit: Planning Guide, 2004](#)) ([Levinson H. , et al., 2003](#)) ([Levinson H. S., et al., 2003](#)) ([California Department of Transportation \(Caltrans\), 2007](#)) ([Diaz, et al., 2004](#)). These guidelines are used to identify main BRT elements, corridor location and characteristics, operation and construction costs, financial and marketing opportunities, transit oriented development (TOD) potential along the corridor, and other operational issues. Rarely in these guides, a detailed BRT ridership estimation is presented and if so, the recommended



methodologies include analogies between cities that share similar demographic, economic, geographic conditions, or even with cities that already have a BRT service in operation. For that reason, a systematic methodology for the estimation of BRT travel demand over time using SD approach is developed in this chapter.

The use of methods that employ “borrowed” factors or analogies from other cities ‘cases to forecast ridership could result in erroneous demand estimations that may put both, the overall BRT system performance and the entire local transportation network, at a risk.

## **7.2 Using System Dynamics to Develop a Tool Capable of Estimate Bus Rapid Transit Ridership**

As mentioned in Chapter 4, BRT systems rarely include the whole set of possible attributes in the first stage. Rather, they are gradually developed. During the planning process of a BRT system, one of the most important decision is to determine which BRT features will be included in the BRT system as well as when they will be deployed (deployment phases) (Golub & Miller, 2007).

All BRT features behave as variables interacting with each other over a given time frame. Additionally, changes in initial conditions and variables interactions result in different output values that affect the system as a feedback sequence or loop. The SD theory is useful for the complex analysis of variable interactions as occur in BRT systems. This methodology has been used to address practically every sort of feedback system (System Dynamics Society, 2008). This

chapter presents a detailed sequence for the construction of an interactive model capable of forecast BRT potential ridership. The model offers an innovative technique that can help decision makers and city planners to redefine or restate important BRT planning decisions that are not possible to be analyzed by existing methodologies.

### **7.3 Fundamentals of Systems Dynamics**

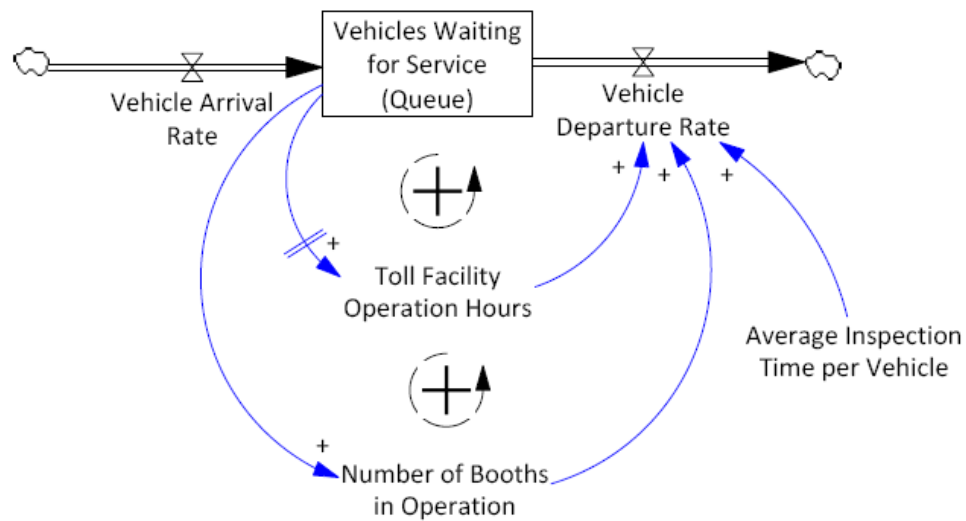
System dynamics is a modeling approach that allows users to perform simulation of dynamic systems that involve many variables with feedback loops, some of which the relationship may not be well defined ([Sterman, 2000](#)). The System Dynamics Society describes SD as a “methodology for studying and managing complex feedback systems, such as one finds in business and other social systems” ([System Dynamics Society, 2008](#)). The field of SD was introduced by Forrester in 1956 and since it has been applied to corporate planning and policy design, public management and policy, biological and medical modeling, energy and the environment modeling, system modeling in natural and social sciences, and etc ([Forrester, 2009](#)).

System dynamics is an approach well suited for the modeling of complex dynamical systems. A complex dynamical system consists of many variables interlocked by feedback loops, with the states of the system and its components change with time. A change in value of one of the variables affects its related variables. Such changes propagate to other variables in the system and feedback to some of the variables. A feedback is a situation in which one variable affects the other and vice versa. If there are two variables X and Y, feedback refers to the situation when X affects Y (may be with a time delay) and in return Y affects X (may be with a time delay).

Therefore, the link of X and Y and the link between Y and X should be analyzed as a feedback system in order to more accurately predict the final outcome.

Because a complex dynamically system consists of a web of interlocking variables with feedbacks, linear and nonlinear relationships and time delays, the system cannot be easily represented by a set of equations (as in control theory) and solved analytically. It is, at the current state of practice, modeled and solved by the time-stepping simulation approach. In SD models, variables and their relationships are represented by the so-called casual loop diagrams. [Figure 7.1](#) shows an example of a simple SD model. In [Figure 7.1](#), the variables are classified into level, rate or auxiliary variables. A level variable (a rectangle) accumulates or integrates a value over consecutive time periods. A rate variable (next to two triangles that represent a valve), as its name suggest, controls the rate of change of a level variable. The auxiliary variables are used as intermediate, input or output variables. The relationships between the variables are represented by arrows. The direction of an arrow symbolizes the influence one variable has towards the other. A positive sign (+) indicates a positive relationship while a negative sign (-) indicates a negative relationship. A “=” symbol denotes a time delay switch. It means that the positive or negative effect of one variable towards another will only take place with a specified time delay. Each variable has a constant value or equation attached to it. The level variable has all its associated rate variables as its dependent variables in the equation. The equations for the rate and auxiliary variables can only consist of variables that are pointing to it by the arrows. A feedback loop occurs when two or more variables are linked by a series of arrows in the clockwise or anti-clockwise direction. Depending on number of positive and negative

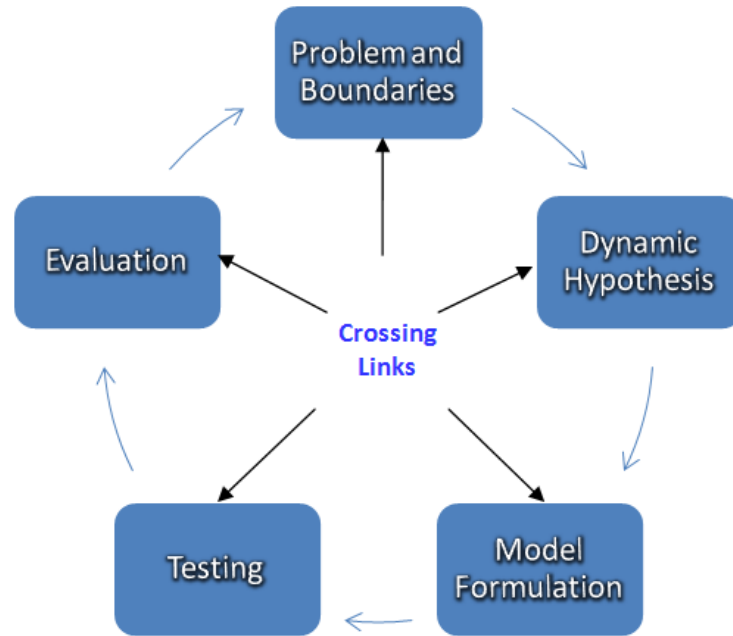
relationships in a loop, the feedback loop can be either “positive” (self-reinforcing) or “negative” (equilibrating or self-correcting).



**Figure 7.1** Structure of a SD model  
Adapted from Sterman, 2000 (Sterman, 2000)

#### 7.4 Systems Dynamics Model for Total Daily Bus Rapid Transit Ridership

This section describes the development of the SD model simply referred to an SD-BRT model to forecast total daily BRT corridor ridership. The SD-BRT model described in this section has been developed in Vensim and each variable’s name has been written starting with an upper case alphabet for an easier identification along the text. In order to structure the SD-BRT model, a series of modeling steps were followed. [Figure 7.2](#) shows the interactive process to build the BRT SD model following the method suggested by Sterman ([Sterman, 2000](#)).



**Figure 7.2** Interactive process for SD modeling

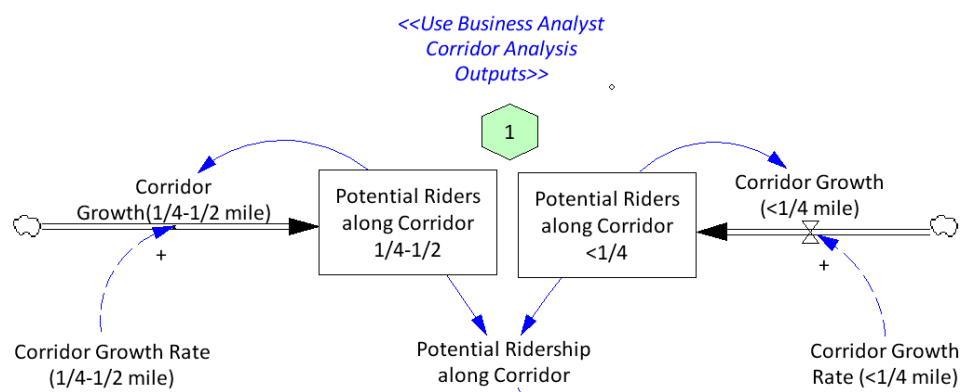
#### 7.4.1 Potential Ridership along the Corridor

To facilitate the explanation of the BRT SD model, its structure was separated in seven different modules. Each module represents a set of mathematical relations with output feeds into a different module. As a final output, the model estimates the Total Daily Ridership. This output was compared to official ridership data from Los Angeles Orange BRT line and Las Vegas MAX for model validation and calibration purposes.

As documented in the Transportation Planning Handbook (Dunphy, 1999) and other transit planning documents (Kittelson&Associates, et al., 2003) (Wright, et al., 2007) (Wright, Bus Rapid Transit: Planning Guide, 2004), transit ridership in corridors is highly correlated to activity centers or Central Business Districts. There are three main drivers or parameters that can

be identified as the most sensitive factors in ridership estimation: Real estate market trends, Employment trends, and Population trends (Dunphy, 1999). The population trend basically directs the market for retail, services and household sectors; therefore, population could be considered as the most sensitive parameter for in ridership forecast modeling. The SD model implementation covers these main three parameters in separate modules that will be explained in detail in the following sections.

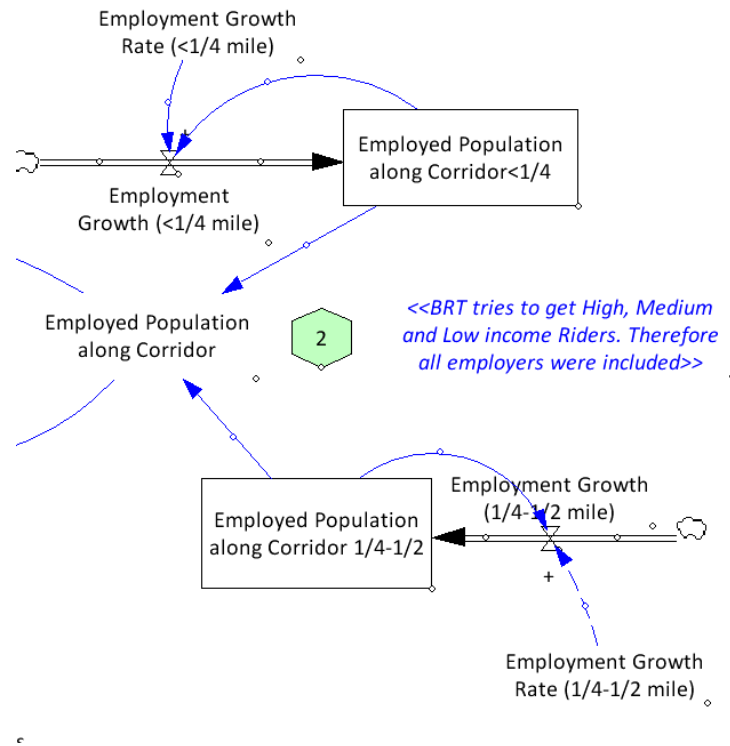
The first module of the SD model deals with the identification of “Potential Ridership”. This concept includes some of the data obtained in Chapter 5. For this module the input variables are the population growth rate along the corridor and the initial population. Due to the different profile in population for a  $\frac{1}{4}$  -mile and a  $\frac{1}{2}$  -mile radii, a separate feedback structure was developed for each case. Figure 7.3 illustrates this part of the model. The two level variables (“Potential Riders along Corridor  $<1/4$ ” and “Potential Riders along Corridor  $1/4-1/2$ ”) feed the potential ridership along the corridor.



**Figure 7.3** Level Structure for the Potential Ridership along the Corridor

#### 7.4.2 Employment Population along the Corridor

Employment has always been a key variable for transit demand estimation purposes (Florida Department of Transportation, 2009) (Vuchic, 2005) (Wright, Bus Rapid Transit: Planning Guide, 2004) (Kittelson&Associates, et al., 2003). Employment generation is fundamental for work purpose trips. In order to estimate the employed population along a given BRT corridor, the SD-BRT model simulates the employment growing base on a similar level structure as the one shown for potential riders along the corridor. BA reports were input separately in a ¼ -mile and a ½ -mile ratio buffers to represent the total employment growth along the corridor. In this module, all types of employment classification were taken into account since BRT systems has the purpose of attracting high, medium and low income riders (Wright, et al., 2007) (Wright, Bus Rapid Transit: Planning Guide, 2004). Figure 7.4 illustrates the structure of this loop.



**Figure 7.4** Employed Population along Corridor

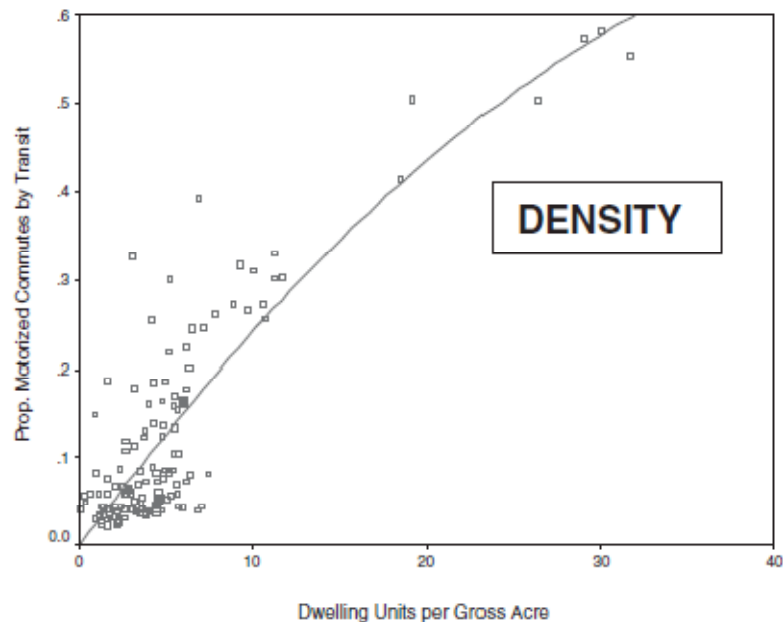
### 7.4.3 Household Level Population along the Corridor

According to the TCRP Report 102 (Cervero, et al., 2004) the number of dwelling units can be directly related to the transit commute modal split behavior. A study made in 2000 in southern California revealed that household density along the corridor can be an explanatory variable for estimating the transit share along a transit corridor. The proportion of commutes by transit is given by the following expression:

$$Prop. Commutes by Transit = 0.0015 + 0.266(Housing Density) - 0.00025 (Housing Density)^2$$



The following figure (Figure 7.5) shows the data representation of the household level-transit share relationship directly from the survey.



**Figure 7.5** Influence of Density in Transit Commute

*Source: TCRP Report 102 (Cervero, et al., 2004)*

The final representation of household level structure is illustrated in the following figure (Figure 7.6)

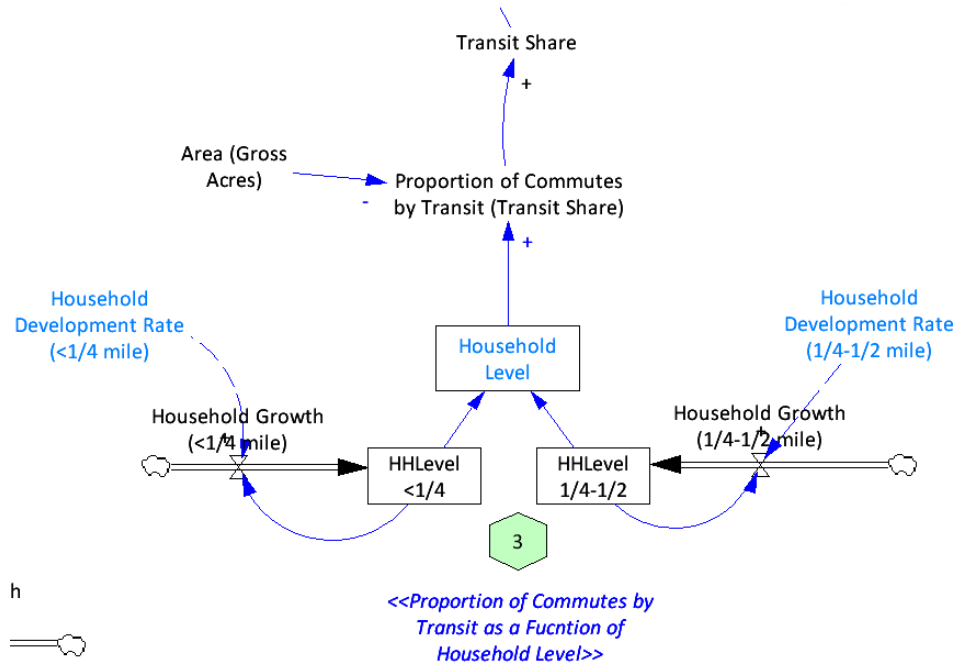
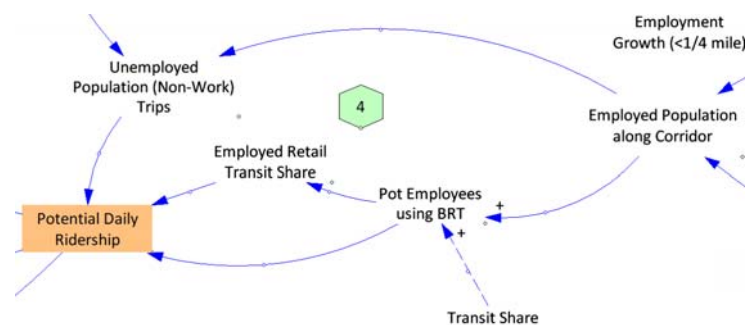


Figure 7.6 Transit Share as a Function of Household Density (Module 3)

#### 7.4.4 Employed and Unemployed Population Transit Share

In order to extract the Unemployed Population Along the Corridor, a loop involving the Employed Population along the corridor (1/4-mile and 1/2 -mile buffers) and the Potential Ridership along the corridor was created. This loop estimates the potential employees that may use the BRT based on the Transit Share calculated in the household module (Module 3). Since the Transit Share variable is dynamically changing the Potential Employees using BRT, as well as Unemployed Population Trips will be also changing over time. According to a national survey on 15,000 households from the American Housing Survey (Cervero, et al., 2004) the probability of work-base trips making a shopping trip is on average 3%. This percentage was used to estimate the Employed Retail transit Share variable. Finally in this module, the Unemployed Population Trips was estimated based on a research study that estimates the unemployed

population trip generation for mass transit mode (Cohen, 2004). In this research the author estimates an average “mass transit share” for unemployed population of around 60% of the total number of trips in mass transit system. This research includes the New York, Los Angeles, Chicago, Washington D.C., San Francisco, Philadelphia and Boston metropolitan areas. The output of this module is the Potential Daily Ridership, a variable that feeds both Module 6 and Module 7.



**Figure 7.7** Transit Share for Unemployed and Employed Population

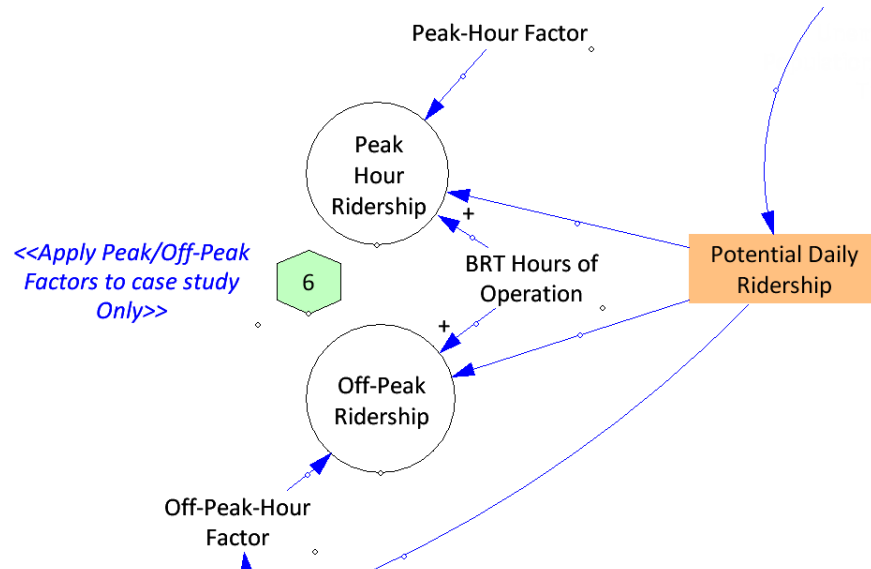
#### 7.4.5 Business Growth Impact

This module was built based on a comprehensive research report done by Bazeley (Bazeley, 2007). This document was useful to identify the relationship between business expansion along a transit corridor and the off-peak ridership generated by retail activity. The module takes as input the BA sales volume reports from the two different ring areas.



### 7.4.6 Peak and Off-Peak Ridership

Module 6 represents the Peak and Off-Peak BRT ridership. This is to comply with FTA requirements and have an estimated BRT demand during these two periods. Figure 7.9 illustrates all variables that structure this module.



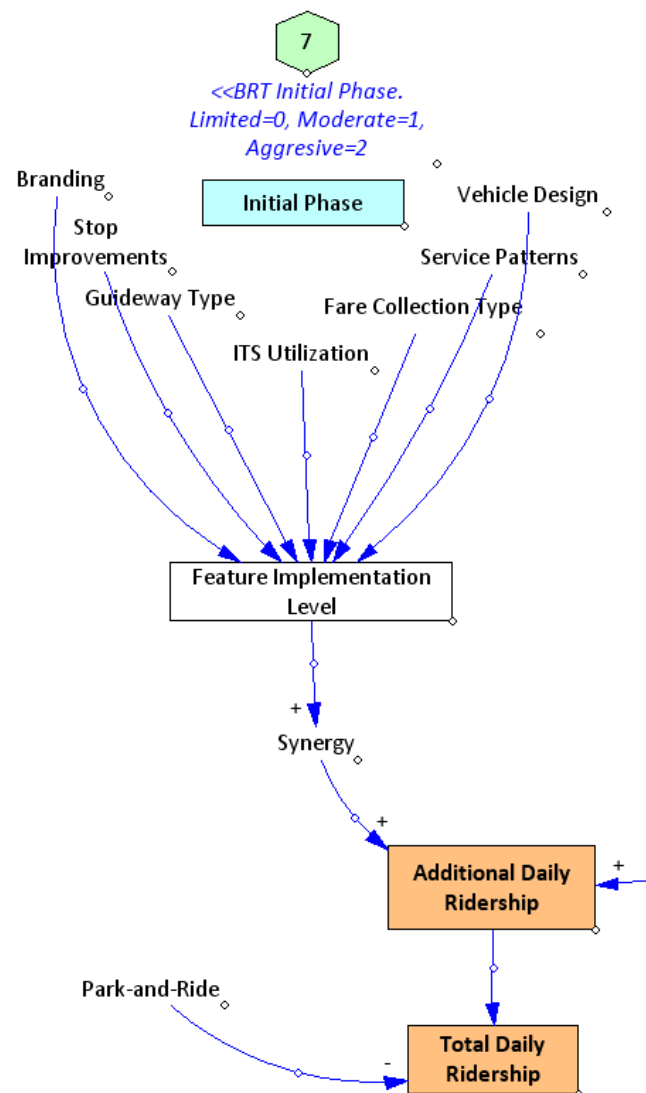
**Figure 7.10** Peak and Off-Peak Ridership Module

### 7.4.7 Additional Ridership due to Bus Rapid Transit Feature Implementation

The last module of the SD-BRT model corresponds to the BRT feature implementation. This SD level structure depends on a group of BRT features deployed at every stage of system development. For this purposes a set of three different deployment stages was created (following Chapter 4). The first, referred as “limited”, included basic elements that were identified as part of the primary phase of construction in a BRT project. The second, cited as “moderate”, consisted of a more complete group of characteristics that has specifically demonstrated an improvement in the system level of service (capacity and travel speed). The third phase called “aggressive”

included those key characteristics that provided high quality service or excellent performance in terms of operation and comfort of the entire system. The detailed selection of BRT elements included in each phase was determined in Chapter 4 of this research.

The Additional Ridership depends on seven features and their synergistic combination as modeled in Figure 7.10.



**Figure 7.11** Additional Ridership Module Structure

The seven features are Branding, Stop Improvements, Guideway Type, ITS Utilization, Fare Collection Type, Service Patterns and Vehicle Design. Branding accounts for the uniqueness of the stations and vehicles. Stop Improvements account for the physical design of boarding and alighting places. Guideway Type considers the bus guideway. ITS Utilization deals with any type of transit technology. Service Patterns takes into account the line coverage, frequency and hours of service. Vehicle Design refers to the design of the BRT vehicle and all the commodities it may include. The Fare Collection Method was based on experience and lessons learned from the review of different systems nationwide included in Chapter 4. These features were taken from TCRP Report 118 ([Kittelsohn & Associates, 2007](#)) because this report lists the percentage increases in ridership attraction due to each of these features (see [Table 7.1](#) and [Table 7.2](#)) for “minimal” and “high level” of BRT implementations.

**Table 7.1 Additional Ridership Impacts**

	COMPONENT	PERCENTAGE
1.	Running Ways (not additive)	20
	Grade-separated busways (special right-of-way)	(20)
	At-grade busways (special)	(15)
	Median arterial busways	(10)
	All-day bus lanes (specially delineated)	(5)
	Peak-hour bus lanes	--
	Mixed traffic	--
2.	Stations (additive)	15
	Conventional shelter	--
	Unique/attractively designed shelter	2
	Illumination	2
	Telephones/security phones	3
	Climate-controlled waiting area	3
	Passenger amenities	3
	Passenger services	2
3.	Vehicles (additive)	15
	Conventional vehicles	--
	Uniquely designed vehicles (external)	5
	Air conditioning	--
	Wide multi-door configuration	5
	Level boarding (low-floor or high platform)	5
4.	Service Patterns (additive)	15
	All-day service span	4
	High-frequency service (10 min or less)	4
	Clear, simple, service pattern	4
	Off-vehicle fare collection	3
5.	ITS Applications (selective additive)	10
	Passenger information at stops	7
	Passenger information on vehicles	3
6.	BRT Branding (additive)	10
	Vehicles & stations	7
	Brochures/schedules	3
	Subtotal (Maximum of 85)	85
7.	Synergy (applies only to at least 60 points)	15
	<b>Total</b>	<b>100</b>

NOTE 1: Applies to a maximum of 10-min travel time bias constant (e.g., percentage of 10 min)

NOTE 2: Applies to a 25% gain in ridership beyond that obtained by travel time and service frequency elasticities

SOURCE: Estimated by research team of Report 118

**Table 7.2 Estimated Additional Ridership Impacts of Selected BRT Components**

Component	Maximum %
Running ways	20%
Stations	15%
Vehicles	15%
Service patterns	15%
ITS applications	10%
Branding	10%
<i>Subtotal</i>	<i>85%</i>
BRT component synergy (when subtotal is 60 or more)	15%
<b>Total</b>	<b>100%</b>

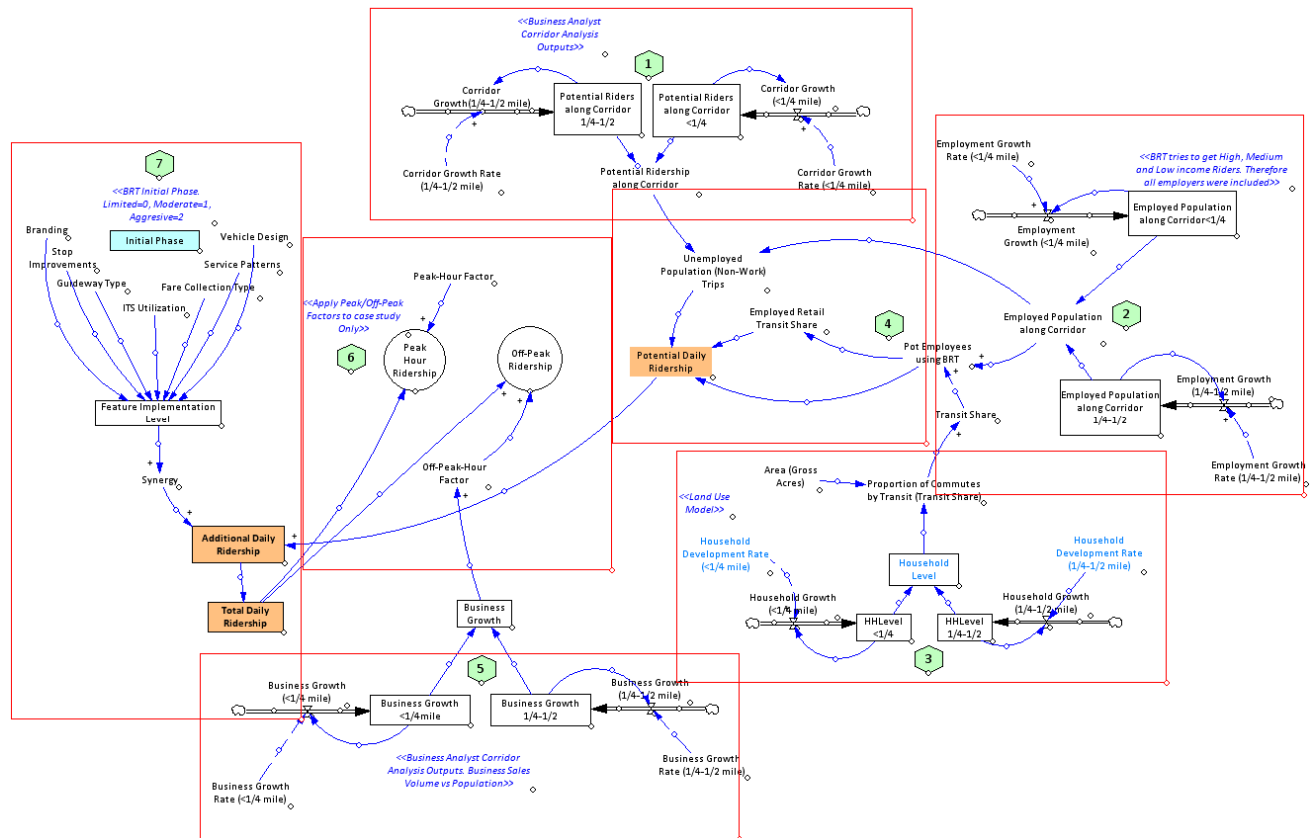


Each of the features contributes a certain percent of additional ridership depending on the phase of implementation (limited, moderate or aggressive phase) of the BRT system. For example, Stop Improvements contributes 2, 9 and 15 points in the limited, moderate and aggressive phases, respectively. The points programmed into the SD-BRT model were adapted from Report 118 (Kittelson & Associates, et al., 2007) and factored by the features listed in Table 4.1 and Table 4.2 in shown Chapter 4. The limited, moderate or aggressive phase of implementation is entered via a variable named Initial Phase. The Initial Phase helps to select the points contributed by each of the seven features. The summation of the points from the seven features forms the Feature Implementation.

According to (Kittelson & Associates, et al., 2007), if the sum exceeds 60 points, an additional bonus points should be added to reflect the synergy of combining the different features. Hence a variable named Synergy was added to increase the ridership forecast. The maximum output of Synergy is 100 points, which correspond to 25% of the Potential Daily Ridership. Thus, the maximum Additional Daily Ridership is 25% of the Potential Daily Ridership.

For the cases of Las Vegas MAX and Los Angeles Orange Line, the model was simulated setting the initial phase as “aggressive” since both lines were built as full BRT lines. For the case study presented in Chapter 9, the initial phase was set to “limited”.

After adding all modules and setting all the variables connection, the entire SD-BRT model structure can be observed in Figure 7.11.



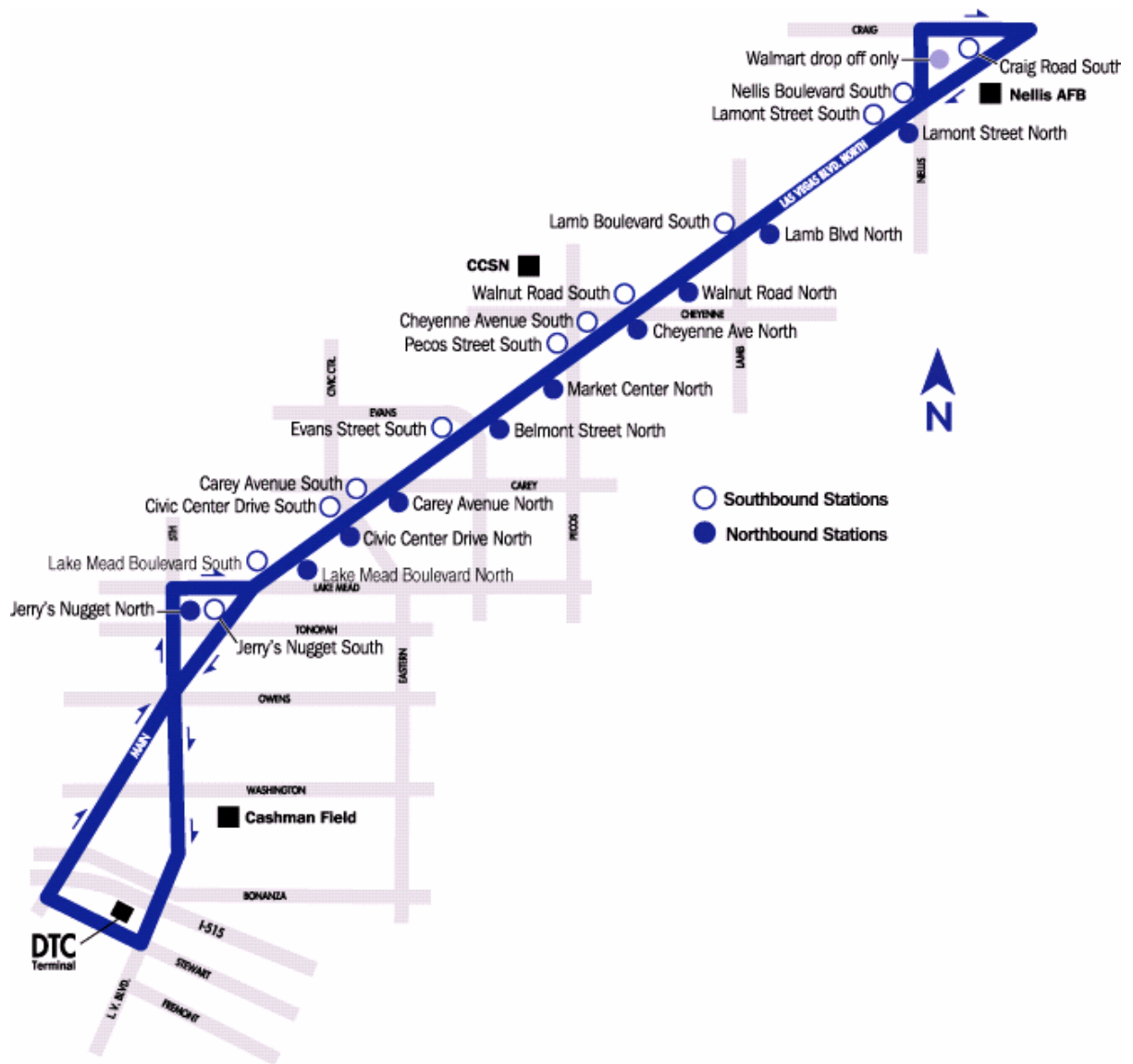
**Figure 7.12** System Dynamic BRT Model Structure (All Modules)

## CHAPTER 8 : MODELING RESULTS

This Chapter shows the modeling results for the Las Vegas MAX and Los Angeles Orange line BRT corridors. The model was validated using official monthly ridership data from the Regional Transportation Commission of Southern Nevada ([Regional Transportation Commission of Southern Nevada, 2010](#)), and the Los Angeles County Metropolitan Transportation Authority ([Los Angeles County Metropolitan Transportation Authority \(Metro\), 2010](#)) respectively.

### 8.1 Las Vegas MAX Brief Description

During the summer of 2004, the Regional Transportation Commission (RTC) of Southern Nevada introduced Metropolitan Area Express (MAX), a 7.5-mile limited stop BRT line serving Las Vegas Boulevard North between the Downtown Transportation Center (DTC) in downtown Las Vegas and Nellis Air Force Base at Craig Road ([Booz Allen Hamilton, Inc., 2005](#)). Las Vegas Boulevard North, with 48 stations stop locations throughout the corridor. Figure 8.1 shows the MAX line configuration and stop locations.

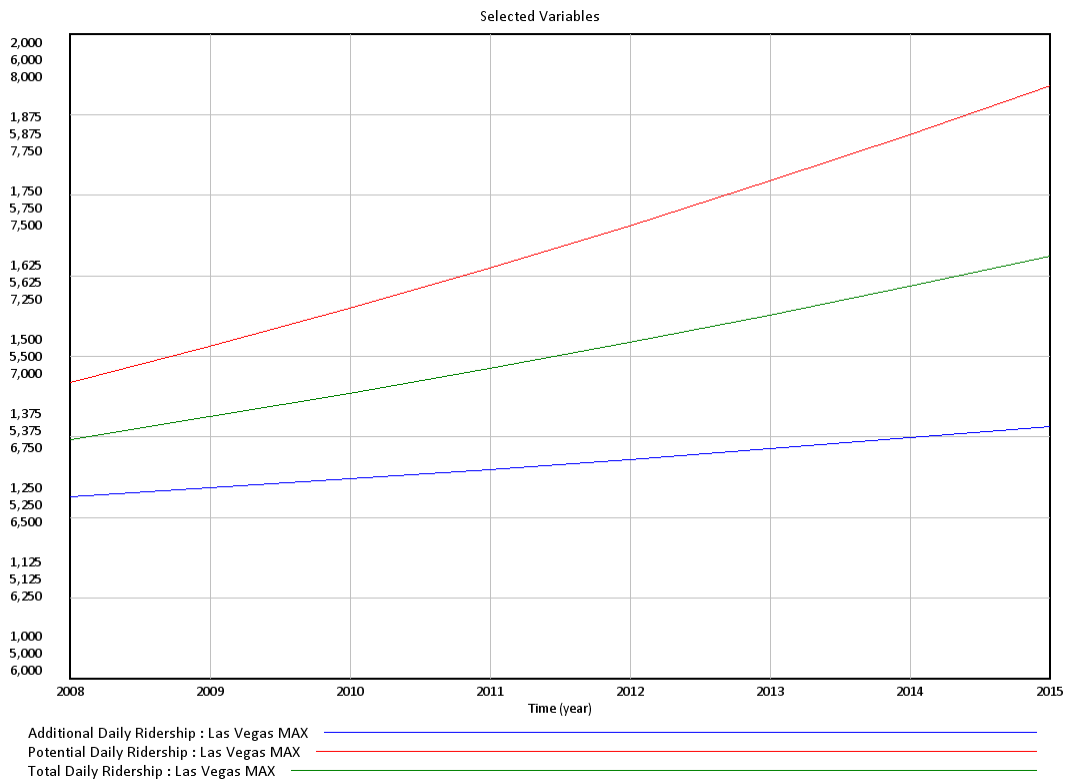


**Figure 8.1** Las Vegas MAX Configuration

With all GIS-BA input obtained in Chapter 5 the SD model was fed and run to estimate ridership results. These results are shown in the following sections.

## 8.2 Modeling Results for Las Vegas MAX

Details on the mathematical relations among modeled variables can be found in Appendix B. Figure 8.1 and Table 8.1 show the results for the Additional Daily Ridership, Potential Daily Ridership and Total Daily Ridership for Las Vegas MAX BRT line.

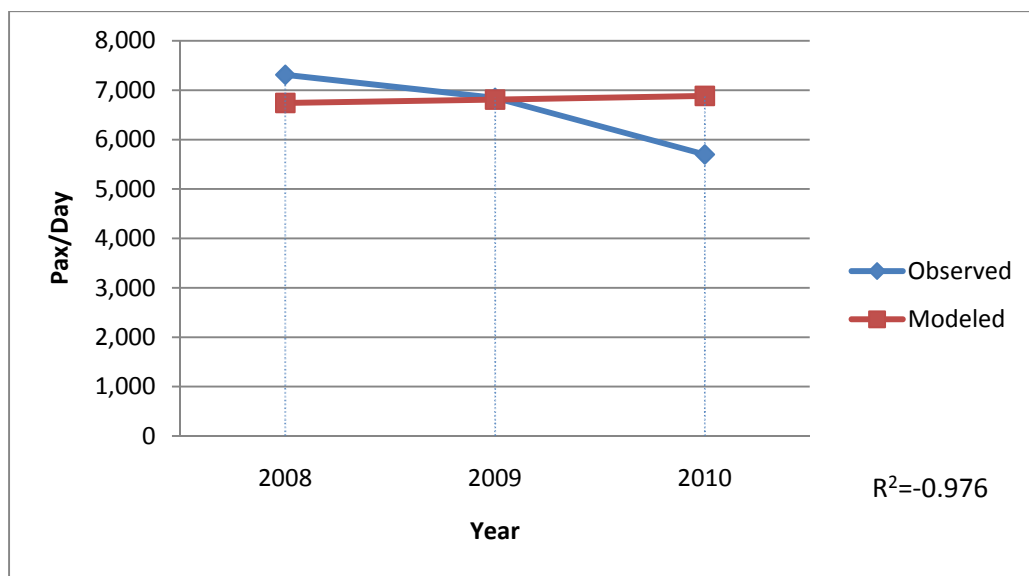


**Figure 8.2** Additional, Potential, and Total Daily BRT Ridership (MAX)

**Table 8.1** BRT Ridership Results for Las Vegas MAX

Time (year)	2008	2009	2010	2011	2012	2013	2014	2015
Selected Variables Runs:	Las Vegas MAX							
Additional Daily Ridership	1,282	1,296	1,310	1,324	1,340	1,356	1,373	1,391
Potential Daily Ridership	5,459	5,515	5,575	5,637	5,702	5,771	5,843	5,919
Total Daily Ridership	6,742	6,811	6,885	6,962	7,042	7,127	7,216	7,310

The modeled results for Las Vegas MAX were compared with official data from the Regional Transportation Commission of Southern Nevada (RTC-SN) for validation and calibration purposes. The modeling process for Las Vegas MAX included an aggressive initial phase since MAX construction included all features implemented at once. The following figure (Figure 8.2) shows the correlation between the observed data and the modeled data of  $R^2=0.97622$ .



**Figure 8.3** Model Calibration-Las Vegas MAX

Table 8.2 shows the observed versus the modeled values for Las Vegas MAX. The model calibration can be considered as acceptable.

**Table 8.2** Model Calibration-Las Vegas MAX

	Time (Year)		
	2008	2009	2010
Observed (Pax/Day)	7,313	6,846	5,699
Modeled (Pax/Day)	6,742	6,811	6,885

### 8.3 Los Angeles Orange Line Brief Description

Opened in October 2005, the Metro Orange Line (“Orange Line”) is one of the first true BRT lines in the United States. It is operated by the Los Angeles County Metropolitan Transportation Authority (Metro) and connects the Red Line subway with the San Fernando Valley to the west (Vincent & Callaghan, 2007). This paper reviews the development of the Orange Line and provides a preliminary evaluation based on its first year of operation, focusing upon system performance, cost effectiveness, and operational issues. Figure 8.4 shows the Los Angeles Orange Line configuration along the Corridor. Figure 8.5 recalls the GIS BA data collected for LA Orange Line (Buffering data previously summarized in Chapter 5)

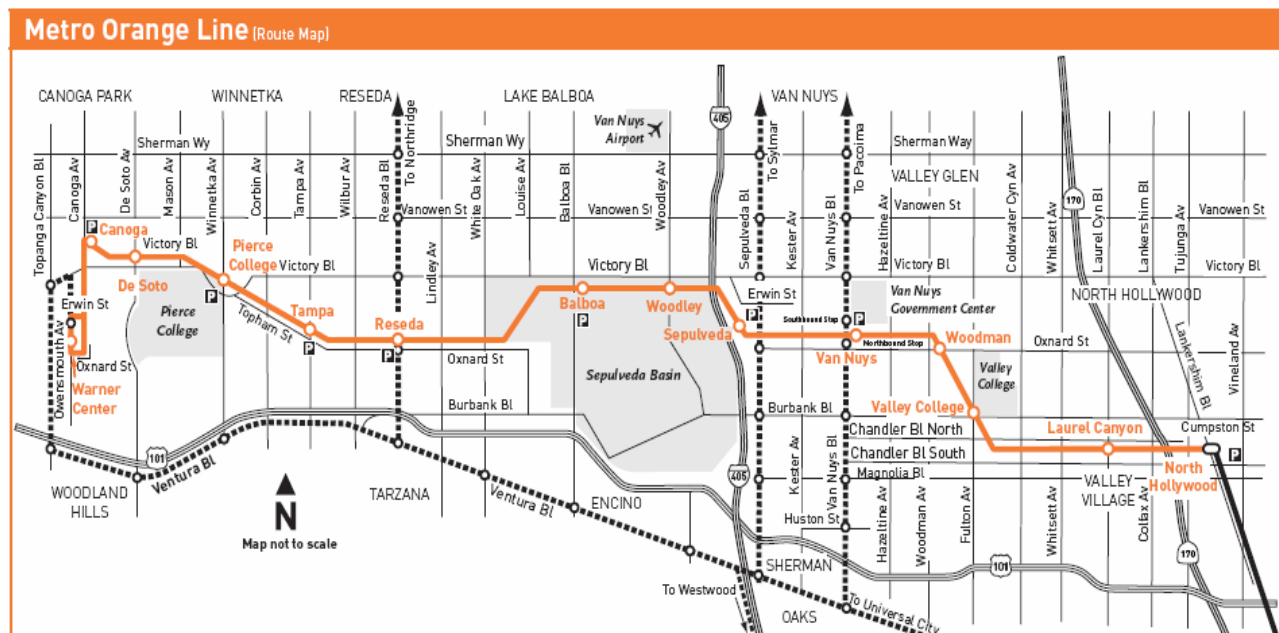
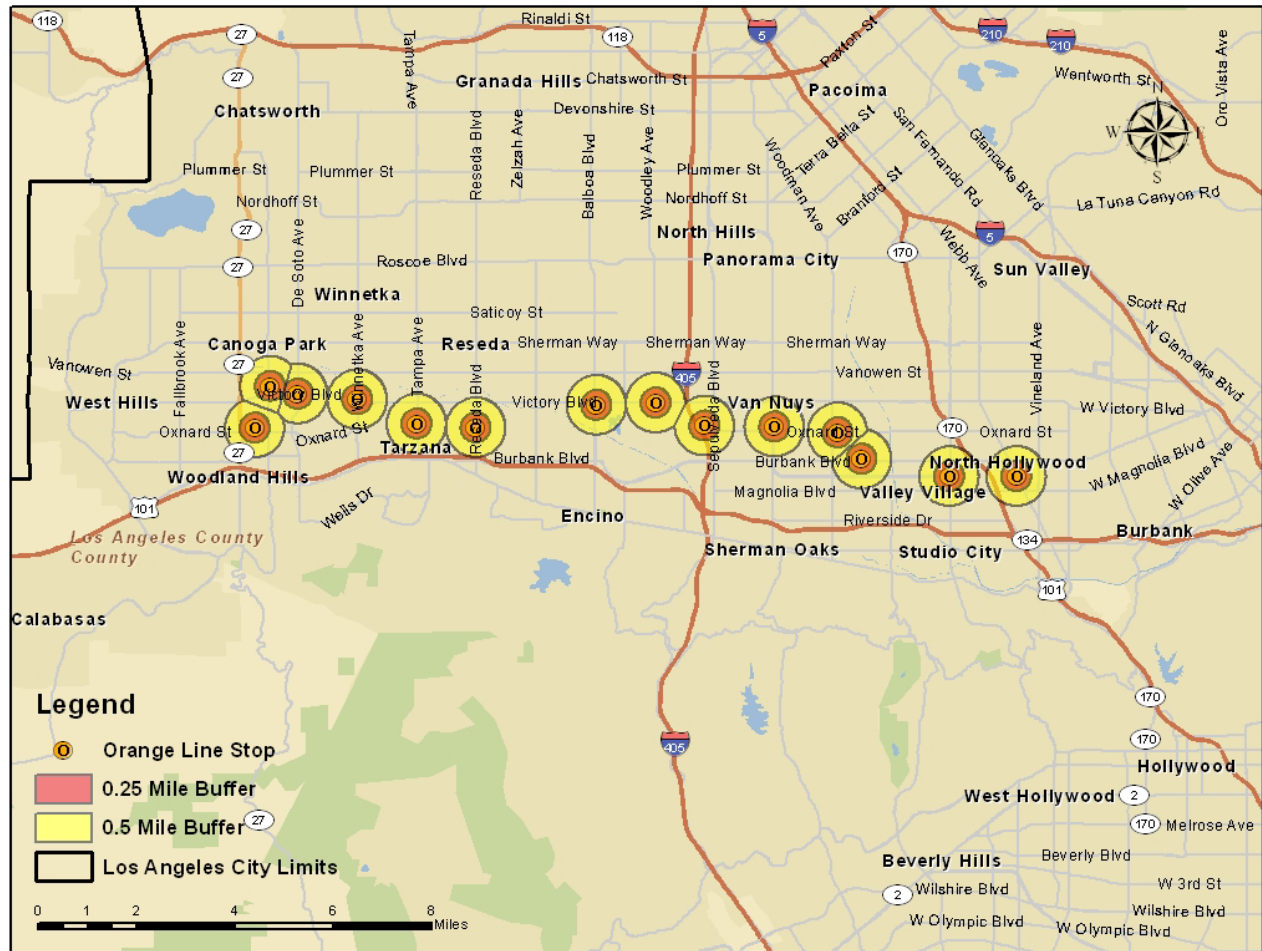


Figure 8.4 Las Vegas MAX Configuration



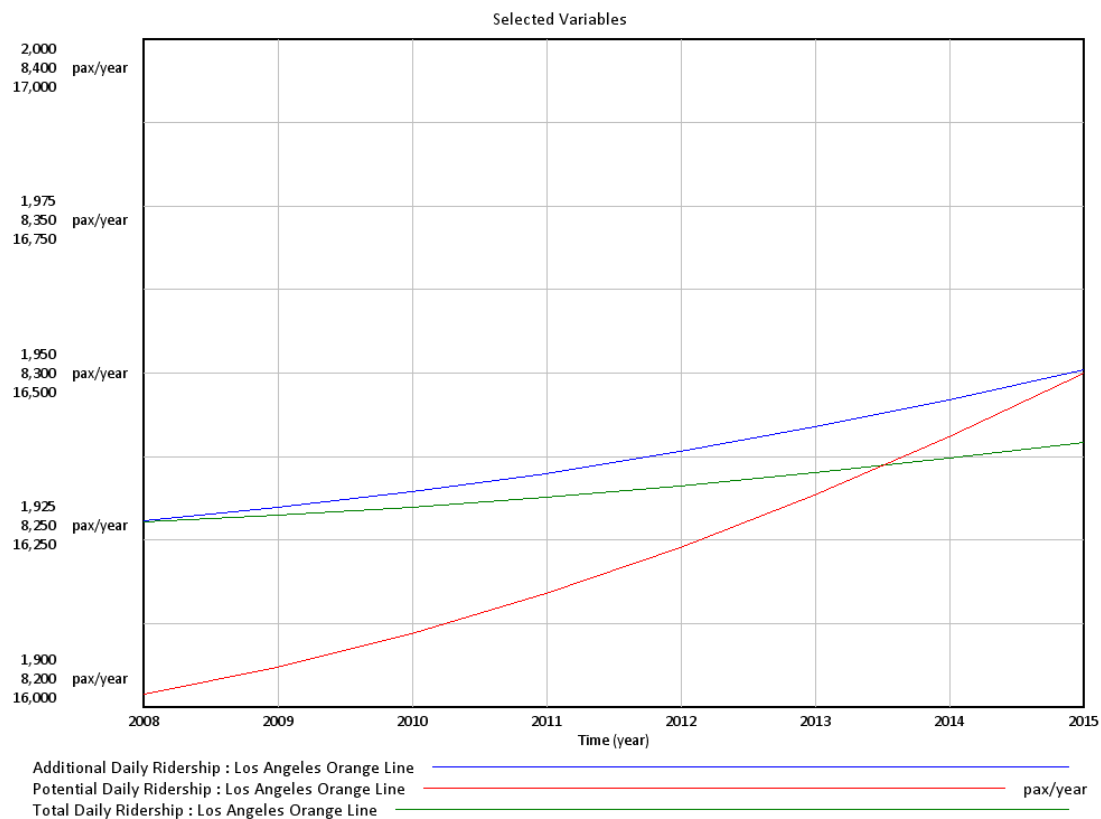
**Figure 8.5** Los Angeles Orange Line Buffering Areas

## 8.4 Modeling Results for Los Angeles Orange Line

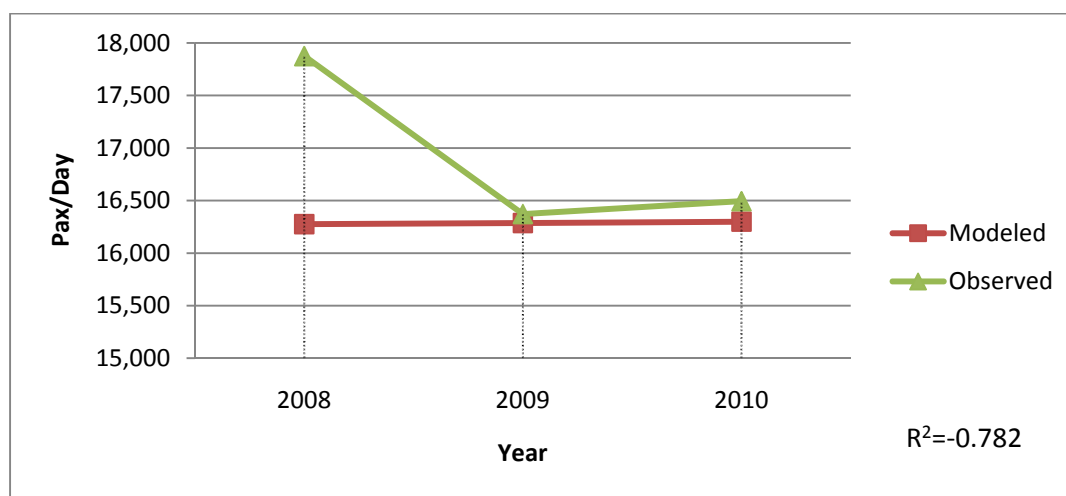
The modeled results for Los Angeles Orange Line were compared with official data from the Los Angeles County Metropolitan Transportation Authority (Metro) for validation and calibration purposes. The following figure (Figure 8.3) shows a correlation between the observed data and the modeled data of  $R^2 = -0.782$



Time (year)	2008	2009	2010	2011	2012	2013	2014	2015
Selected Variables Runs:	Los Angeles Orange Line							
Additional Daily Ridership	1,927	1,929	1,932	1,934	1,938	1,941	1,946	1,950
Potential Daily Ridership	8,203	8,211	8,222	8,234	8,247	8,263	8,280	8,300
Total Daily Ridership	16,276	16,286	16,299	16,313	16,331	16,350	16,371	16,395



**Figure 8.6** Additional, Potential, and Total Daily BRT Ridership (Orange Line)



**Figure 8.7** Model Calibration-Los Angeles Orange Line

Table 8.2 shows the observed versus the modeled values for Los Angeles Orange Line. The model calibration can be considered as acceptable.

**Table 8.3** Model Calibration-Los Angeles

	Time (Year)		
	2008	2009	2010
Observed (Pax/Day)	17,875	16,372	16,494
Modeled (Pax/Day)	16,276	16,286	16,299

Additionally to the SD model structure, the Los Angeles SD model was influenced by transfer passengers. In order to correctly identify these amount of commuters or linked-trip passengers the survey technique described in Chapter 6. Due to the time and resources limitation, an alternative analysis was performed using official information from the Los Angeles Metro regarding the park-and-drive activity ([Los Angeles County Metropolitan Transportation Authority \(Metro\), 2010](#)). [Table 8.4](#) shows the capacity of each of the park-and-ride lots at orange line stops and terminals. The assumption that the system reaches its maximum capacity at least once per day was useful to approximate the transfer users in a day.

**Table 8.4** Capacity of Orange Line Park-and-ride Lots

	Park-and-Ride Lot	Capacity
1	North Hollywood	1,904
2	Reseda Orange Line Station	522
3	Van Nuys/Sepulveda	1,205
4	Van Nuys	1,259
5	Woodlands	373
6	Canoga Park	612
7	Encino	270
Total Capacity		6,145

## CHAPTER 9 : CASE STUDY

This chapter describes the application of all the planning tools described in this document. The region selected for this case study is the city of El Paso, Texas. With a population of nearly 720,000 inhabitants, this city is planning to incorporate BRT systems on at least four corridors in the near future. Although the region is unique in a geographic sense (US-Mexico Boundary), the concepts included in this dissertation can be used to produce reliable estimations for BRT demand.

### 9.1 Background and Case Study Justification

El Paso, like some other cities in the United States, is currently experiencing an increase in traffic volume. Simultaneously, the city has recorded low growth rates in terms of centerline miles (i.e. roadway infrastructure) in the past few years which generate a higher congestion index year after year ([Texas Transportation Institute, 1983-2007](#)). Although the level of congestion for El Paso is not as high as some other major cities in the U.S. (Chicago, Los Angeles, San Diego or Dallas), its congestion index has worsened in the short term getting the 6th worst among the Nation in 2005, ([Table 9.1](#)) according to the Urban Mobility Report published by the Texas Transportation Institute (TTI).

From the planning perspective, higher traffic congestion means also higher travel times and more delays on the entire transportation network. As it can be assumed, inefficient transportation networks triggers a deceleration in the local economy producing a slow development for the region ([Dipasquale & Whaton, 1996](#)).

**Table 9.1** Annual Roadway Congestion Index for El Paso, TX

<b>Annual Roadway Congestion Index</b>			
<b>Population group</b>		<b>Medium</b>	
<b>Urban area</b>		<b>El Paso, TX</b>	
<b>Year</b>		<b>Congestion Index</b>	
1982		0.6	
1985		0.66	
1990		0.71	
1991		0.76	
1992		0.8	
1993		0.81	
1994		0.83	
1995		0.83	
1996		0.83	
1997		0.84	
1998		0.87	
1999		0.91	
2000		0.94	
2001		0.97	
2002		0.99	
2003		1.01	
2004		1.05	
2005		1.07	
<b>Points change</b>	<b>Short-term 2000-2005</b>	<b>Points</b>	13
		<b>Rank<sup>a</sup></b>	6
	<b>Long-term 1982-2005</b>	<b>Points</b>	47
		<b>Rank<sup>a</sup></b>	12

Many variables can be attached to the congestion problem; however one of the greatest causes could be the historical dependence that American society has toward the use of private vehicle (Greene & Pick, 2006). The city of El Paso is not the exception for this private-vehicle dependency. Comfort and easy access to this particular transportation mode, has caused its usage to increased considerable in the last decades. Although the total number of vehicles in a network is not totally represented by private vehicles, trends for the U.S. confirm the population's preference for driving passenger cars (Vincent, 2006). For the city of El Paso, reports indicate that the number of vehicles registered has continuously increased (Fullerton, 2008), while the

centerline miles grow at a lower rate as reported by the Texas Department of Transportation (Texas Department Of Transportation, 2006).

It is evident that, if these trends continue, in the near future the road capacity (supply) will be surpassed by the number of vehicles traveling through those roads (demand). Different actions could be taken in order to avoid the transportation system to reach capacity constraints. Historically, the most frequently and erroneously used solution by planners has been the construction of new roads or simply adding lane capacity to the existing network. However, as the number of vehicles increase, road users experience higher congestion, longer travel times and rush hour expansions which create drivers' frustration increasing the political pressure to city representatives to build more roads or somehow add capacity to the existing road configuration. If added, road capacity will work temporarily until population and economical factors increase the congestion levels again (Stermann, 2000).

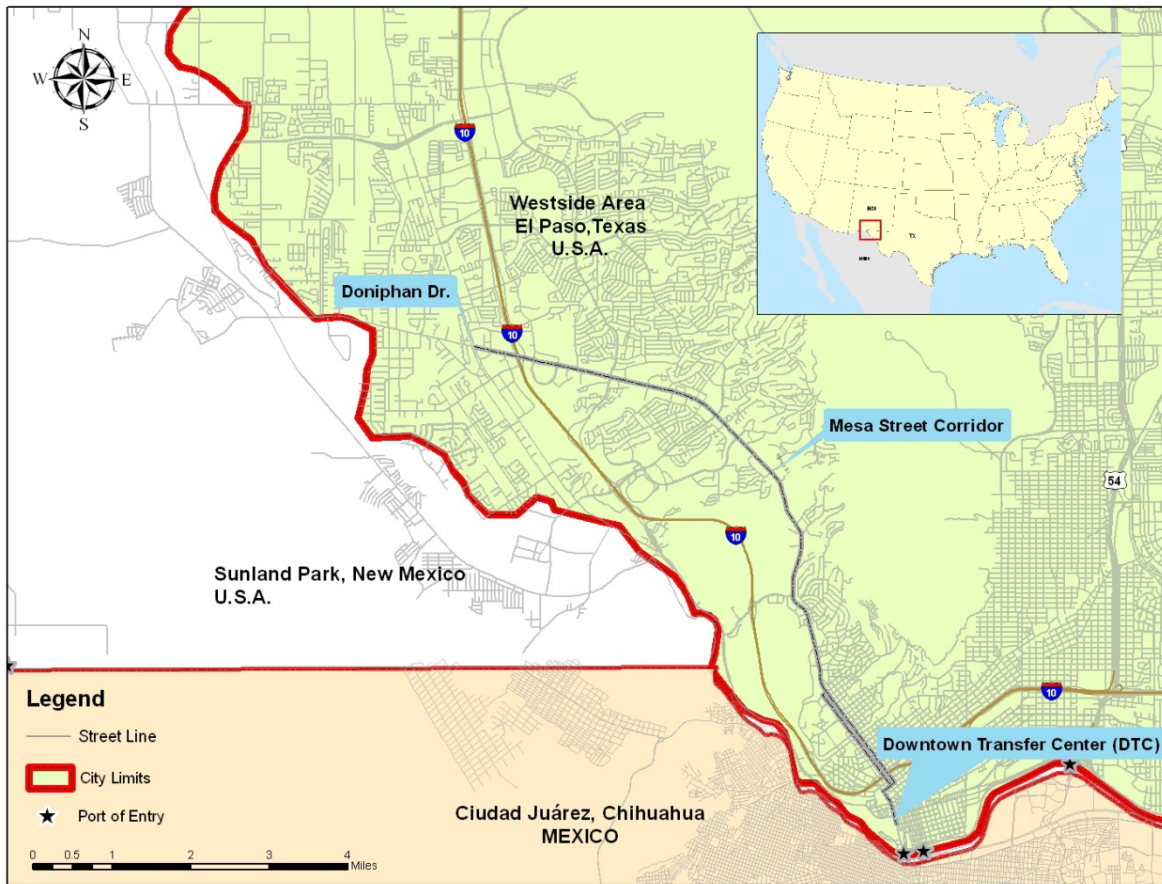
A different approach to diminish the congestion problem lies on the modal choice. User's selection of the mode to travel directly influences the capacity of the transportation network. As previously explained in Chapter 4, experience has shown that transit mode has a vast significance for reducing traffic congestion (Vuchic, 2005) (Kittelson & Associates, 2007) (Galicia et al., 2009). The main characteristic of transit systems is that they serve a greater number of people and offer capacities that roads cannot indeed provide. It is therefore urgent that alternative travel modes, such as public transit, be developed as part of the regional transportation improvements.

Particularly the city of El Paso, Texas is planning the implementation of a Bus Rapid Transit system along one of the most important corridors: Mesa Street. The local transit agency: Sunmetro operates all transit routes within El Paso District ([The City of El Paso, 2010](#)). The agency has pursued a BRT system in recent years and it is currently in the planning process stage.

## **9.2 Description of Mesa Street Corridor**

Mesa Street Corridor extends north from Downtown to the west side of El Paso, Texas. It runs along North Mesa Street beginning from the Downtown Transfer Center (DTC) and ending at the Westside Transit Terminal. The street at DTC is identified as South Mesa Street. After crossing East San Antonio Avenue at downtown, the street is designated as North Mesa Street or the State Highway 20 extending northwest until crossing Doniphan Drive ([Figure 9.1](#)).

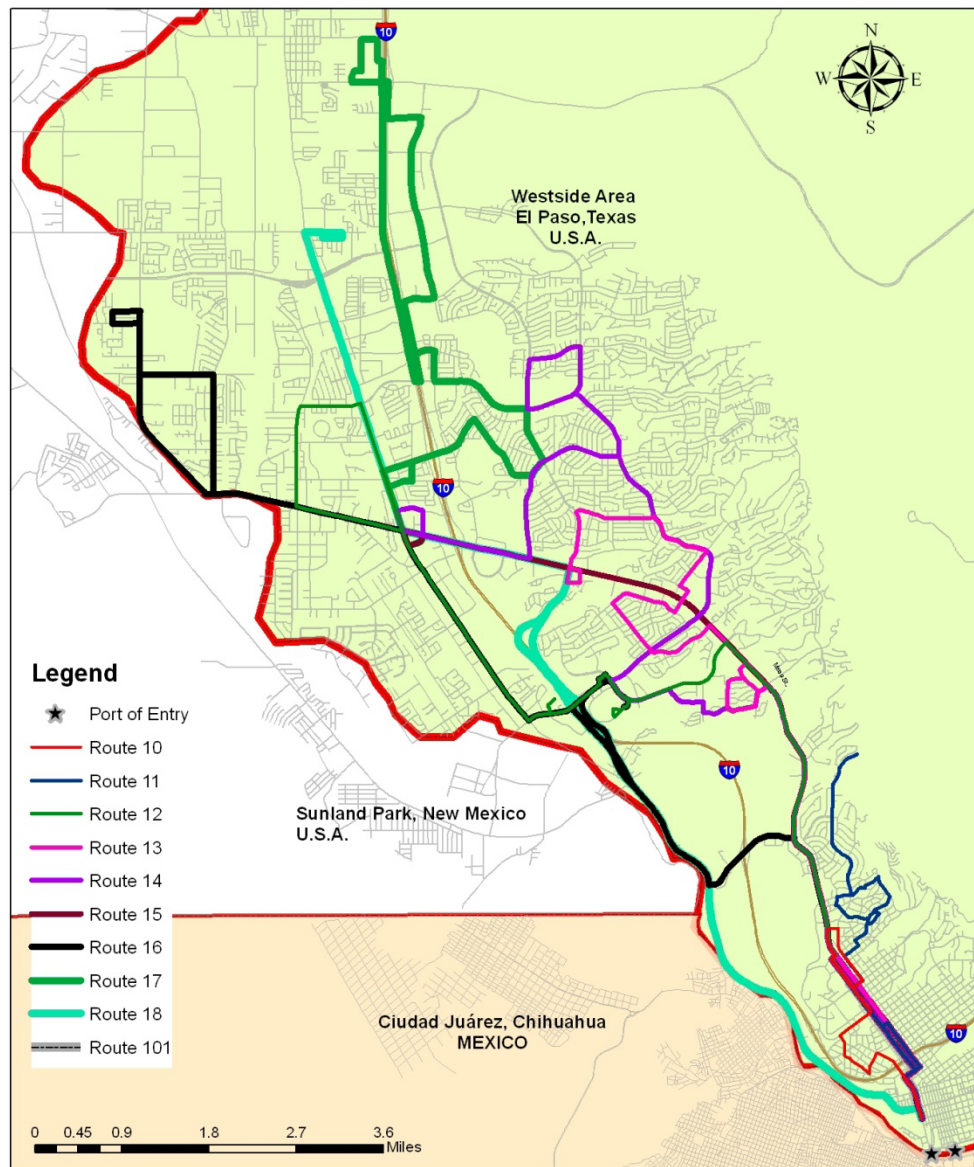
The corridor's approximated length is 10 miles, and crosses 73 traffic intersections. The intersection design along the corridor consists of 41 coordinated traffic signals and 32 intersections. Mesa St. lane configuration varies depending on the zone it is located. Segments with one (Downtown area), two (transition zone) and three circulation lanes per direction can be found along the Corridor. Speed limits also vary depending on area. The posted speed limit ranges between 30 to 50 miles per hour. The segment along South Mesa St. consists of only one lane per direction and the outer lanes in each direction are used as parking spaces. The configuration of the downtown area is mostly historic neighborhoods as well as small retail stores, restaurants and office spaces.



**Figure 9.1** Case Study Area (El Paso, Texas)

There are a total of 9 existing bus routes running along the Mesa Street from the Downtown Transfer Center and serve communities throughout the western side of the City of El Paso. Recently, El Paso Sun Metro implemented an express bus service (Smart 101) along Oregon Street between downtown and the Glory Road Transfer Center. For the purposes of this Chapter, “inbound” transit service will be that traveling from the West Side Transit Terminal in the north to the Downtown Transfer Center, while “outbound” transit service will be that traveling from the to Downtown Transfer Center to the Westside Transit Terminal. The existing network of bus routes serving the corridor is shown in [Figure 9.2](#).





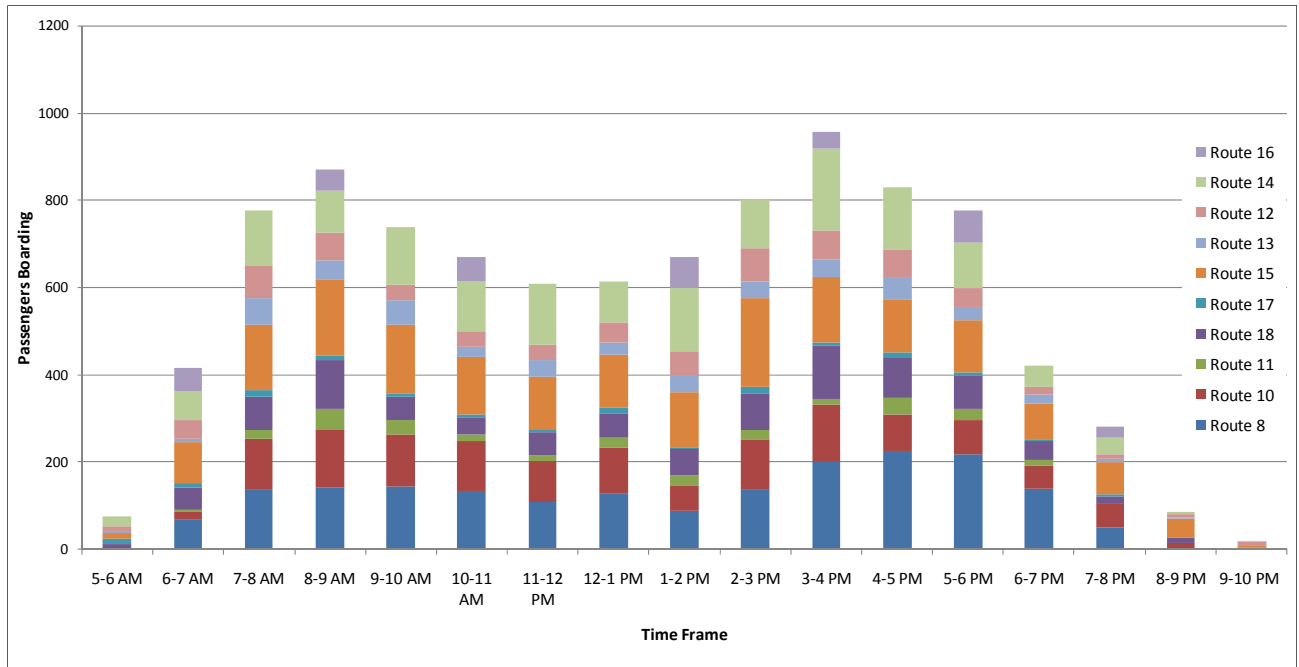
**Figure 9.2** Transit routes currently in operation along Mesa Corridor



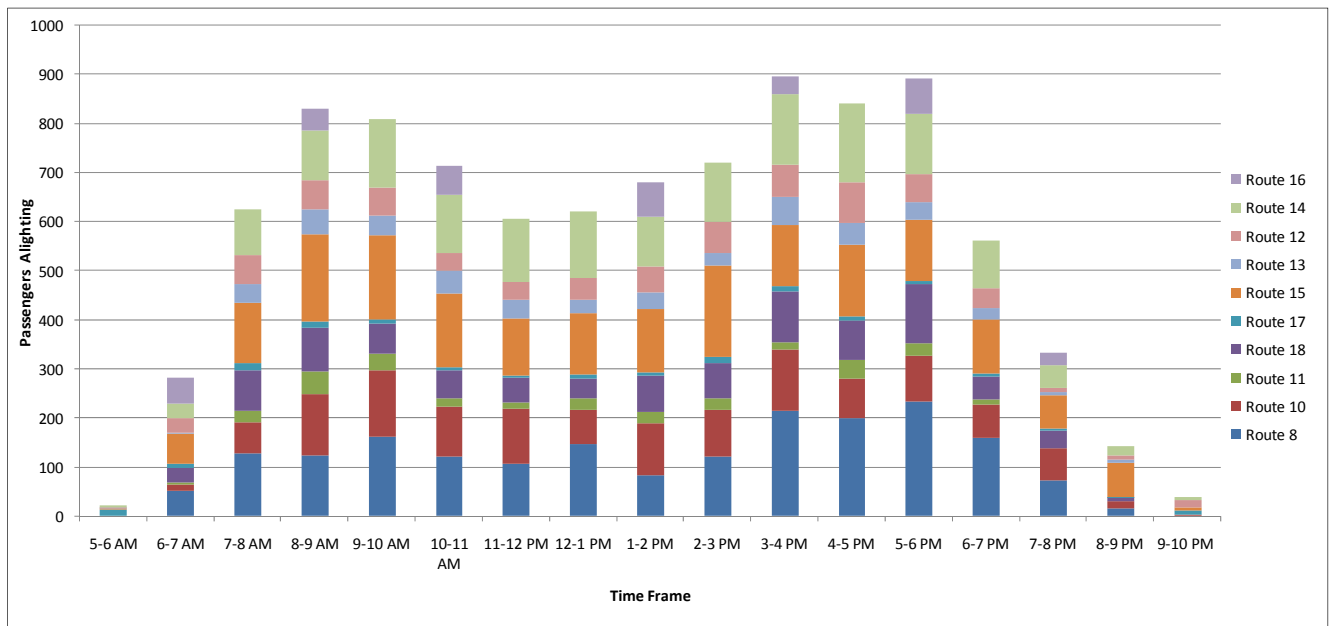
### **9.3 Current Transit Ridership on Mesa Corridor**

The most recent information regarding transit ridership in El Paso is a boarding and alighting (B/A) count of passengers on individual stops along existing routes done by Sun Metro in 2007. Sun Metro collected passenger B/A data for the entire system at all stops. This case study provides the best estimate of existing riders and the potential users who may benefit from the implementation of a BRT line.

As mentioned in Chapter 1 of this dissertation, the FTA requests ridership forecasts for the base year, opening year, “maturity” year and horizon year for all New Start transit projects. Moreover, it is necessary to provide peak and off-peak behavior by line segment and B/A patterns by stop. For this reason, a typical week-day B/A behavior was analyzed using data given by Sun Metro (Figure 9.3 and Figure 9.4). With this information, two key elements were identified in Mesa Corridor: the passenger flow during the day, and the maximum passenger volumes (morning and afternoon peak-hours).



**Figure 9.3** Passenger Boarding During Weekdays



**Figure 9.4** Passenger Alighting During Weekdays

Table 9.2 shows the results from the average daily boarding (2007) for the highest-ridership lines along Mesa and a brief description of routes. Although Sun Metro's 2007 B/A gives planners an idea of the peak (8:00-9:00 am -5:00-6:00 pm) and off-peak passenger load behavior, this information did not include origin or destination of passengers. Therefore, the innovative O-D technique proposed in Chapter 6 was put into practice.

**Table 9.2** Average Boarding along Mesa

Bus Route Number	Total Average Boarding		Description
	Outbound	Inbound	
12	363	341	This route is a circulator route connecting the Sunland Park Mall to Remcon Circle and Doniphan area. The bus route primarily runs along Doniphan Drive.
13	374	362	This route is a circulator route connecting the Sunland Park Mall to Coronado area and to the Westside Transit Terminal.
14	972	896	Connects Downtown Transfer Center to the UTEP, Sunland Park Mall and primarily serves the residential neighborhoods on Westwind Drive and Resler Drive areas. For the build alternatives, the headway would be changed from 30 minutes to 60 minutes.
15	1172	971	This bus route runs along the Mesa Street and connects downtown to origins and destinations along the Mesa Street. The bus route originates at the DTC and terminates at the Westside Transit Terminal. The build alternative would primarily follow the same alignment as this bus route. For the build alternatives, the headway would be changed from 25 minutes to 50 minutes.
18	680	445	This is an express route that runs between the DTC and the Westside Transit Terminal, but runs along Paisano Drive instead of Mesa Street.

#### 9.4 Bus Rapid Transit Stop Identification

The first step to estimate the BRT ridership along Mesa Corridor was identifying the potential BRT. This step was performed by observing the highest ridership “spots” of the current

routes running along the corridor. [Figure 9.5](#) illustrates the potential BRT stops. This information matches 99% with the formal proposal by El Paso's Sun Metro planners, indicating that a similar procedure was done by Sun Metro's planning department.

Although some selected stops do not show high passenger volume concentration, they were included because of their importance in special events (e.g. Don Haskins Center) and to avoid large gaps in between stops ([Falbel, et al., 2006](#)). Experience in the US ([Kittelsohn&Associates, et al., 2003](#)) has shown that a reduction in the number of stops improves the BRT operating speed. For instance a reduction from 6 to 2 stops per mile can save from 2.2 to 2.4 minutes per mile (excluding traffic delays).



**Figure 9.5** Potential BRT Stops for Mesa Street

## 9.5 Bus Rapid Transit Ridership Estimation on Mesa Corridor

BA data for Mesa Street was extracted to feed the SD-BRT model. These data included all demographic variables and methodology previously explained in Chapter 5. [Figure 9.6](#) illustrates the delimitation of data extraction for Mesa Street, as well as the business information.

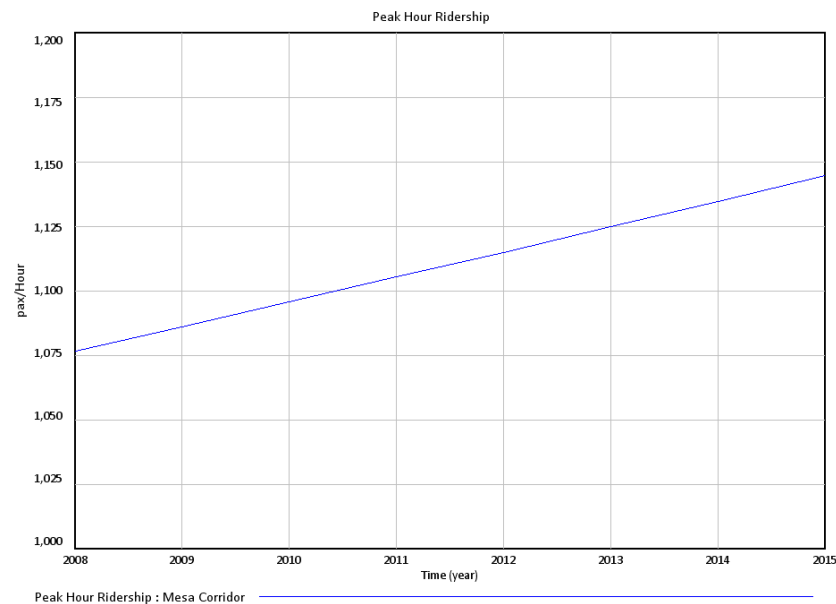


**Figure 9.6** 0.25-Mile and 0.50-Mile Buffer for Mesa Street Corridor

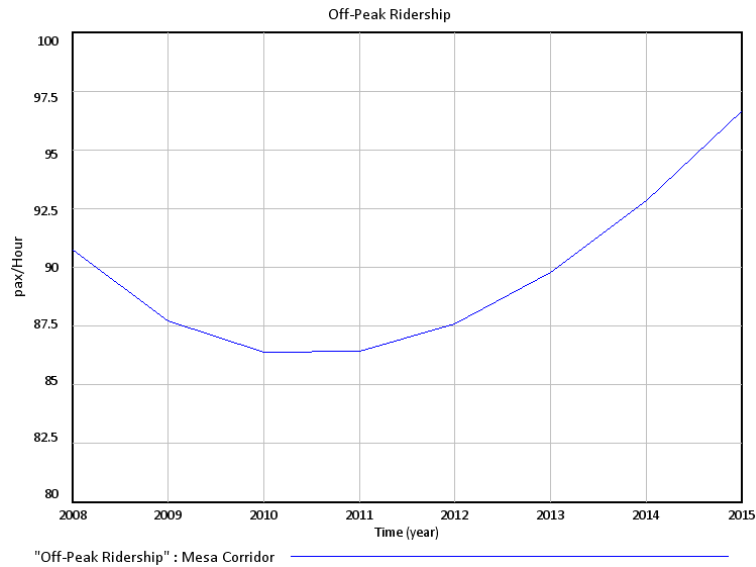
In order to estimate the BRT ridership along Mesa Corridor, the SD-BRT model described in Chapter 7 was performed. The parameters used for the case study are shown in [Table 9.3](#).

<b>Table 9.3 Modeling Parameters for Mesa Street</b>						
	<b>EMPLOYMENT</b>			<b>POPULATION</b>		
	<b>2008</b>	<b>2010</b>	<b>Growth Rate</b>	<b>2008</b>	<b>2013</b>	<b>Growth Rate</b>
<b>0 to 0.25-Mile</b>	5,216	5,171	-0.00432299	13,478	13,756	0.004092
<b>0.25 to 0.50-Mile</b>	7,643	7,732	0.00580547	21,257	21,997	0.006867
	<b>SALES VOLUME</b>			<b>HOUSEHOLD</b>		
	<b>2008</b>	<b>2010</b>	<b>Growth Rate</b>	<b>2008</b>	<b>2013</b>	<b>Growth Rate</b>
<b>0 to 0.25-Mile</b>	4,206,615	2,607,625	-0.21267111	5,834	6,024	0.006430
<b>0.25 to 0.50-Mile</b>	2,394,240	2,670,681	0.05615380	7,824	8,204	0.009530

Results of the modeling process for Peak and Off-peak hours are shown in the following figures ([Figure 9.7](#) and [Figure 9.8](#)). These results were compared with the estimations for peak hour and daily boarding done by Jacobs Engineering ([Jacobs, 2010](#)) in an alternative analysis for Mesa Street Corridor for the year 2015.



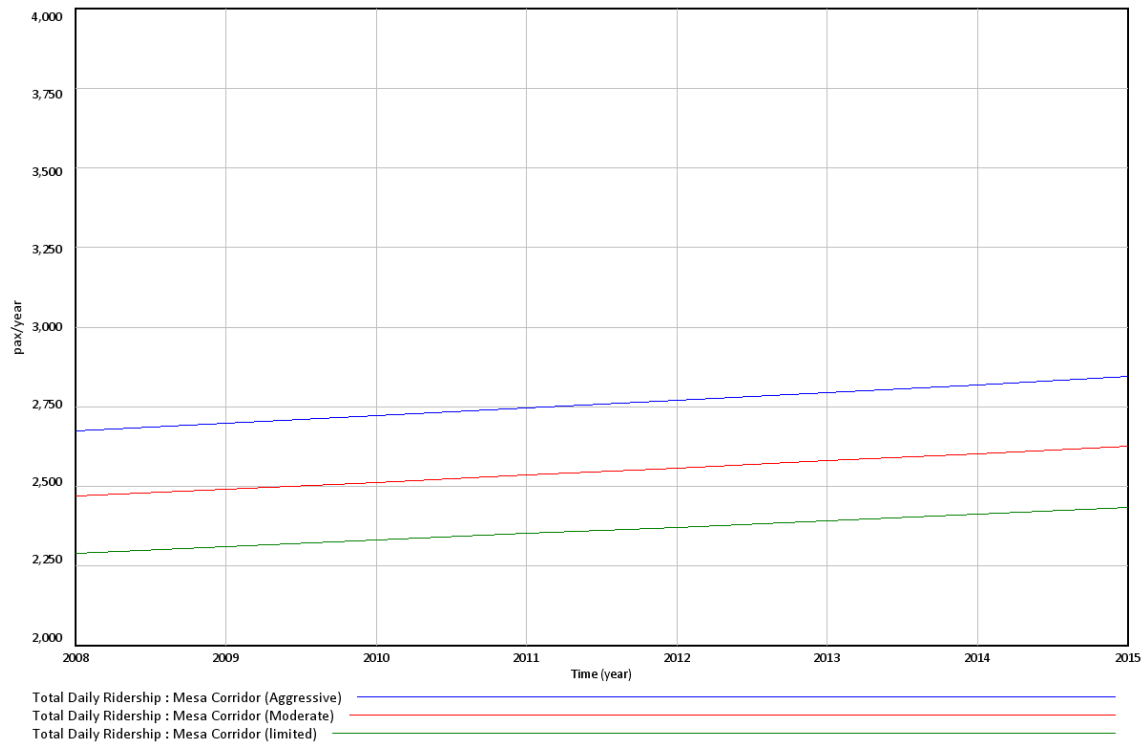
**Figure 9.7** Modeled Peak Hour BRT Ridership in Mesa Street Corridor



**Figure 9.8** Modeled Off-Peak Hour BRT Ridership in Mesa Street Corridor

Time (year)	2008	2009	2010	2011	2012	2013	2014	2015
"Total Daily Ridership" Runs:	Mesa Corridor (Aggressive)		Mesa Corridor (Moderate)		Mesa Corridor (limited)			
Total Daily Ridership	2,675	2,698	2,722	2,746	2,770	2,794	2,819	2,843
: Mesa Corridor (Moderate)	2,469	2,491	2,512	2,534	2,557	2,579	2,602	2,625
: Mesa Corridor (limited)	2,290	2,310	2,331	2,351	2,372	2,392	2,413	2,435

Total Daily Ridership



**Figure 9.9** Total Daily Ridership Forecast for Mesa Street Corridor

**Table 9.4** Mesa Corridor Projected BRT Boardings (2015) (Jacobs, 2010)

Alternative	Daily Boardings
TSM	2410
BRT Fully Dedicated BRT	2480
BRT Partially Dedicated Lanes	2410
BRT Peak Hour Dedicated Lanes	2480

Although the total BRT ridership estimated by the SD model is very similar to the one projected in the Alternative Analysis for El Paso (2,435 vs 2,410), these amount of boardings does not include the regular transit system boardings which, according to the City of El Paso authorities, is planning to directly compete with the BRT service. This issue is analyzed in the conclusions and recommendations (Chapter 10).

In addition to the Total Daily Ridership, the model is capable of monitor (show behavior and results) for every single variable included in the system. After the model runs, users can select the variable of their interest and activate the graph icon that appears at the left-hand menu in Vensim.

## **9.6 Friendly System Dynamic Model Interface**

After the model was validated, calibrated and tested in three different BRT lines (Las Vegas MAX, Los Angeles Orange Line, and Mesa Street Corridor), an easy-to-use interface was created to facilitate the data input and analysis of results. The advantage of this interface is that it can be used and dynamically modified by practically anyone with basic knowledge of transit planning skills. This interface was design to smooth the progress of inputting data without



dealing with Vensim mapping or coding techniques. Additionally, the interface tool allows visualizing the changes of any input variable in a dynamic manner.

Figure 9.10 shows the Vensim interface screenshot for the SD model. The file containing the interface platform is available in electronic form.

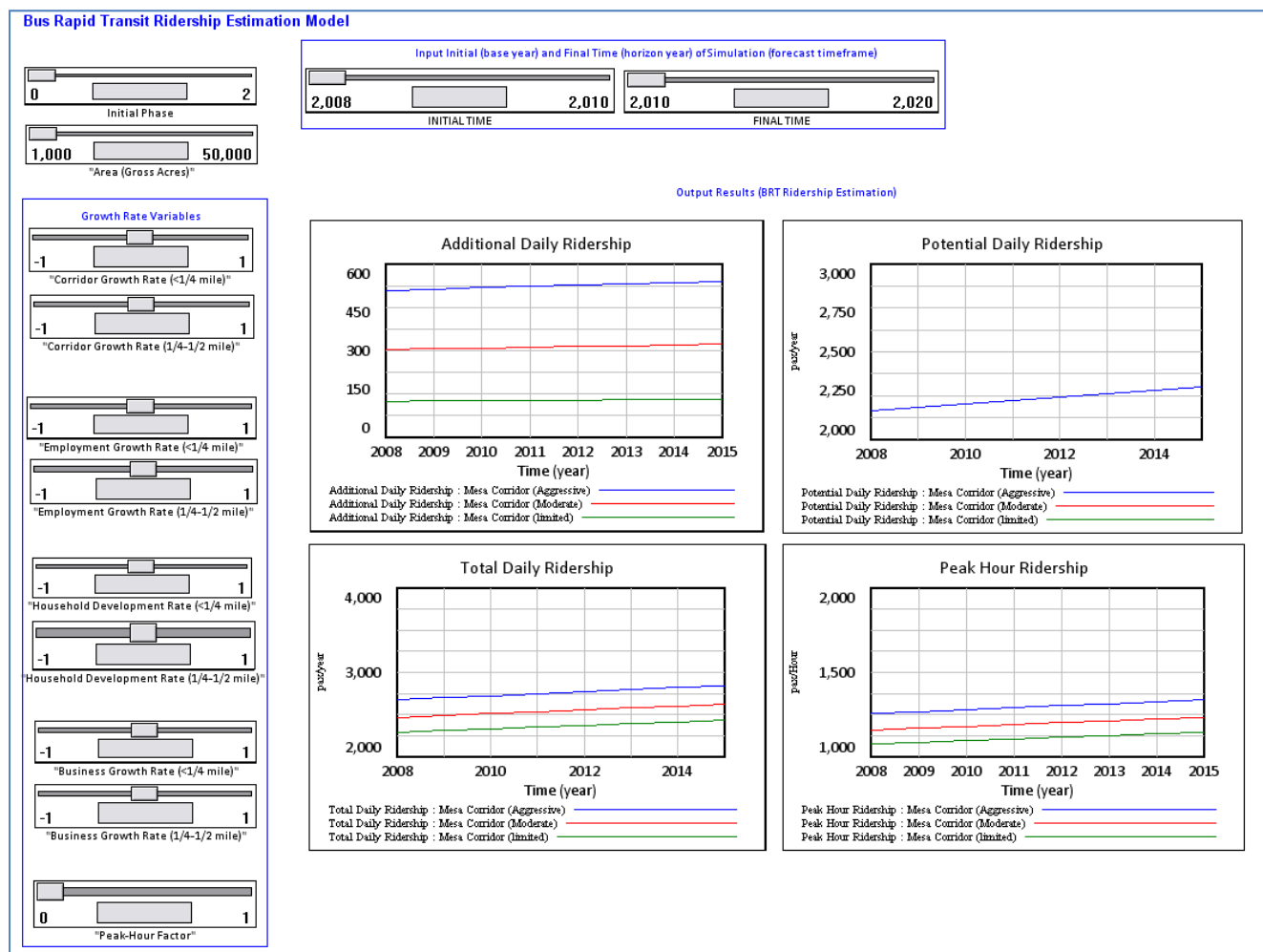


Figure 9.10 Easy-to-use Interface for Mesa Street Corridor Model

## **9.7 Cost Estimation for Different Phases of Mesa Street Bus Rapid Transit Ridership**

### **Estimation on Mesa Corridor**

One of the remarkable advantages of BRT compared to other public transportations systems is its relatively low infrastructure costs ([Kittelsohn & Associates, et al., 2007](#)) ([Wright, Bus Rapid Transit: Planning Guide, 2004](#)). Thus as a final exercise, the total cost for the BRT option along Mesa Street Corridor was estimated (Table. This information was calculated based on a spread sheet available for BRT planners ([Institute for Transportation and Development Policy, 2008](#)). The “Limited” deployment phase was used to be consistent with the initial phase the City of El Paso’s authorities are planning. In order to estimate these costs, the research team used a practical tool included as a part of a study that takes account of several cities developing-nation BRT systems and inputs from BRT experts ([Wright, et al., 2007](#)).

**Table 9.5** Estimated Cost for limited Phase

<i>Phase 1</i>				
Item	Cost per Unit	Unit	Quantity	Cost
<b><i>Busway construction / roadway reconfiguration</i></b>				
Use existing asphalt on busway / new concrete at stations	\$150,000	US\$ per kilometer	30	\$4,500,000
<b><i>Lane separators</i></b>				
10 cm separator blocks	\$5,000	US\$ per kilometer	0.1	\$500
<b><i>Station construction</i></b>				
Enhanced Stop	\$30,000	US\$ per station	20	\$600,000
<b><i>Station air conditioning / heating</i></b>				
Full air conditioning / heating	\$100,000	US\$ per station	2	\$200,000
<b><i>Station identification - sign post</i></b>				
Station identification post	\$800	US\$ per station	20	\$16,000
<b><i>Maps and information</i></b>				
Maps at stations	\$3,000	US\$ per station	24	\$72,000
<b><i>Station security</i></b>				
Emergency callbox	\$1,500	US\$ per station	2	\$3,000
Security cameras	\$8,000	US\$ per station	2	\$16,000
<b><i>Fare collection readers</i></b>				
Smart card system (4 readers per station)	\$10,000	US\$ per station	6	\$60,000
<b><i>Fare collection turnstiles</i></b>				
Rotating turnstile (4 turnstiles per station)	\$7,000	US\$ per turnstile	6	\$42,000
<b><i>Fare registering unit / vending machine</i></b>				
Smart card system	\$15,000	US\$ per machine	6	\$90,000
<b><i>Fare media</i></b>				
Smart card system with microprocessing ability	\$4	US\$ per card	10000	\$40,000
<b><i>Fare system software</i></b>				
Smart card system	\$500,000	US\$ per software	1	\$500,000
<b><i>Trunk vehicle technology</i></b>				
Stylized standard	\$330,000	US\$ per bus	10	\$3,300,000
<b><i>Feeder vehicle technology</i></b>				
Air conditioning in bus	\$2,500	*	99	\$594,000
<b><i>Terminals and depots</i></b>				
Terminal facilities	\$3,000,000	US\$ per terminal	2	\$12,000,000
Restrooms at terminals	\$15,000	US\$ per terminal	2	\$60,000
<b>Sub-total</b>				\$22,093,500
<b>Contingency</b> <i>10% contingency</i>				\$2,209,350
<b>Total</b>				\$24,302,850

\*Cost was estimated using 2008 US Dollars ([Institute for Transportation and Development Policy, 2008](#))

## 9.8 Summary

Mesa Street is a potential BRT Corridor in El Paso, Texas. City planners estimate a demand of 2,400 boardings per day. Since the transfer rate in the corridor is insignificant (see Chapter 6 section 6.4), the daily boardings can be compared to the total daily passengers

estimated with the SD model. (2,435). The cost estimated for a limited set of features (in year 2008) was also included in this chapter. The approximate amount for a limited initial phase is around 25 million dollars. This amount may be affected by the current inflation rates to update the cost for 2010.

## CHAPTER 10 : CONCLUSIONS AND RECOMMENDATIONS

The set of tools for BRT corridor planning described in this work has been analyzed and tested for two different existing BRT lines in the U.S. Additionally; these tools were applied to potential corridor currently in the planning stage: Mesa Street Corridor El Paso, Texas (case study). The research questions raised in Chapter 1 can be address in the following sections of this Chapter.

### 10.1 Research Question 1: What is a Bus Rapid Transit?

After a comprehensive review of more than 40 BRT systems (U.S. and abroad), the most common features found for such a transit mode are listed in the following table (Table 10.1). The listed set of features should be included as a “core” set of features for BRT since they, as a package, produce travel time savings and ridership attraction. Most of the BRT systems reviewed share common but not all BRT features. When designing a BRT system, the features should be selected according to project budget, local users, and traffic and corridor characteristics combined to produce maximum ridership attraction as well as a competitive operating speed.

**Table 10.1** BRT “Core” Features

Guideways (segregated or not)
Enhanced stations and shelters
Accurate travel information at boarding facilities
High capacity and comfortable vehicles
Transit oriented development efforts
High service frequency

## **10.2 Research Question 2: How Many and What Type of Bus Rapid Transit Features should be Deployed in Different Bus Rapid Transit Phases?**

As feature selection and design depend on the project budget, local users, and traffic and corridor characteristics, the deployment phases have been grouped in three different feature combinations. Infrastructure features are listed in [Table 4.1](#) and operational features are listed in [Table 4.2](#) in Chapter 4. The three phases are limited, moderate, and aggressive, in increasing order of system cost, ridership attraction, and operating speed. The recommended features in [Tables 4.1](#) and [Table 4.2](#) may be viewed as market packages in the different deployment phases. Note that not all the features listed in each of the phases in [Tables 4.1](#) and [Table 4.2](#) must be followed strictly.

The three deployment phases may be implemented progressively, starting from limited phases when funds are limited and ridership is uncertain. The limited phase represents a low-cost short-time implementation. The system may be upgraded to the moderate or aggressive phases as the BRT line reaches its “maturity” stage (i.e. attracting new riders and consequently generating more profit). However, a transportation agency may opt to implement the aggressive phase directly without having to go through the first two phases. Note that it is also possible to upgrade one feature at a time.

### **10.3 Research Question 3: How to Forecast Bus Rapid Transit Ridership?**

The use of GIS systems was crucial for addressing this research question. Business Analyst data became a substantial factor for successfully performing BRT demand forecast. Variables such as level of household, employment rates, and business activity and population growth are factors that are used for almost every transit ridership planning project (see section 2.3 in Chapter 2). The addition of a SD model which simulates the entire system gives the estimations a high correlation compared to the observed data in existing BRT lines in the U.S. The complementary O-D study proposed in this dissertation takes into account those riders coming from areas outside the corridor (linked trips). The overall performance of the BA data extraction and the SD model appeared to be a solid combination of tools for BRT ridership estimation at the corridor level.

### **10.4 Research Critique and Implications**

Even though the results of the modeled BRT ridership and the results found in the “Alternative Analysis for El Paso, Texas” (Jacobs, 2010) are exceptionally close, the fact that the BRT will be operating along with existing routes creates the need of adding this ridership to the total estimates. When the regular transit routes along Mesa Street are taken into consideration, the total daily boardings increases substantially (See Table 10.2).

**Table 10.2** Mesa Corridor Projected Boardings (2015) (Jacobs, 2010)

	No Build	TSM	BRT Fully Dedicated Lanes	BRT Partially Dedicated Lanes	BRT Peak Hr Dedicated Lanes
Projected Daily Boardings	10,450	11,850	11,920	11,850	11,920
Percent Change vs No Build	--	+13%	+14%	+13%	+14%

The disparity of the modeled results and the Alternative Analysis Report for the case study led to an additional research on the border crossing phenomena in El Paso, Texas. Additional data from an intercept O-D survey at the Mexico-U.S. port of entry revealed that more than the half of the ridership along Mesa Corridor is coming from the neighbor Mexican city (Ciudad Juarez, Chihuahua). An explanation of this issue could be that the geographic information included in BA does not take into account the everyday transit commuters attracted to relatively better employment conditions (El Paso-Ciudad Juarez case). This phenomenon goes beyond this research objectives, however a recently research by Galicia et.al; (Galicia, et al., 2010) can be consulted to find answers to this extraordinary occurrence.

From the various contributions of this research, perhaps the most important one is ridership forecast methodology. The construction of a GIS-SD interactive model capable of incorporating technical fundamentals of transit theory, economics, urban planning, traffic engineering, and infrastructure management, can help decision makers and city planners to redefine or restate important transit decisions that were originally analyzed by existing or traditional methodologies, which may not be suitable for this mode of transportation. The model can be practically used by any user via the interface presented in Chapter 9, Section 9.6. By inputting the corresponding parameters, users can see the dynamic changes their decisions make



to the overall system. These features have the peculiar advantage of “controlling” the system and forecast the stages in which a BRT line needs to be upgrade or reaches its capacity.

## **10.5 Further Research**

The performance of all tested tools presented in this dissertation may be considered as reliable due to the realistic results. However, the results of further model scenario analyses or policy experiments with a wider range of instruments and new tools could substantially improve the results and a universal applicability under variety different conditions. Stop-level ridership estimation could be the next step towards a substantial improvement of the model. A systematic way of extracting data from GIS data bases and automatically feeding such a data base to an adjusted SD model could lead to effortless updates and continuous BRT ridership estimation.

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## **APPENDIX A**

(This section is an electronic document that can be found in the CD version of this dissertation)

## APPENDIX B (Vensim Model Code)

"Off-Peak Ridership"=

Total Daily Ridership\*"Off-Peak-Hour Factor"

~ pax/Hour

~ |

Peak Hour Ridership=

"Peak-Hour Factor"\*Total Daily Ridership

~ pax/Hour

~ |

Total Daily Ridership=

Additional Daily Ridership +Potential Daily Ridership

~ pax/year

~ Additional Daily Ridership +Potential Daily Ridership

|

"Business Growth (<1/4 mile)"=

"Business Growth <1/4mile"\*"Business Growth Rate (<1/4 mile)"

~ units/year

~ |

"HHLevel 1/4-1/2"= INTEG (

"Household Growth (1/4-1/2 mile)",

7824)



~

~

|

"HHLevel <1/4"= INTEG (

"Household Growth (<1/4 mile)",

5834)

~

~

|

"Household Growth (1/4-1/2 mile)"=

"HHLevel 1/4-1/2"\*"Household Development Rate (1/4-1/2  
mile)"

~ units/year

~

|

Business Growth=

"Business Growth 1/4-1/2"+"Business Growth <1/4mile"

~

~

|

"Business Growth (1/4-1/2 mile)"=

"Business Growth 1/4-1/2"\*"Business Growth Rate (1/4-1/2  
mile)"

~ units/year

~

|

"Business Growth 1/4-1/2"= INTEG (

"Business Growth (1/4-1/2 mile)",

4.20662e+006)

~

~ |

"Business Growth <1/4mile"= INTEG (

"Business Growth (<1/4 mile)",

2.39424e+006)

~

~ |

"Household Growth (<1/4 mile)"=

"HHLevel <1/4"\*"Household Development Rate (<1/4 mile)"

~ units/year

~ |

Household Level=

"HHLevel 1/4-1/2"+"HHLevel <1/4"

~ units

~ |

Employed Population along Corridor=

"Employed Population along Corridor 1/4-1/2"+"Employed  
Population along Corridor<1/4"

~ pax/year

~ |

Employed Retail Transit Share=

Pot Employees using BRT\*0.03

~  
 ~ TOD Document TCRP page 144  
 |

"Unemployed Population (Non-Work) Trips"=  
 (Potential Ridership along Corridor-Employed Population  
 along Corridor)\*0.06  
 ~ pax/year  
 ~ look for the reference (% of unemployed using BRT)  
 |

"Employed Population along Corridor 1/4-1/2"= INTEG (  
 "Employment Growth (1/4-1/2 mile)",  
 7643)  
 ~  
 ~ |

"Employed Population along Corridor<1/4"= INTEG (  
 "Employment Growth (<1/4 mile)",  
 5216)  
 ~  
 ~ |

Pot Employees using BRT=  
 Employed Population along Corridor\*Transit Share  
 ~  
 ~ |

Potential Daily Ridership=

Pot Employees using BRT+"Unemployed Population (Non-Work)  
Trips"+Employed Retail Transit Share

~ pax/year

~ Using records for more than 11,000  
individuals....19.6% living

|

"Employment Growth (1/4-1/2 mile)"=

"Employed Population along Corridor 1/4-1/2"\*"Employment  
Growth Rate (1/4-1/2 mile)"

~ pax/year

~ |

"Employment Growth (<1/4 mile)"=

"Employed Population along Corridor<1/4"\*"Employment Growth  
Rate (<1/4 mile)"

~

~ |

"Corridor Growth(1/4-1/2 mile)"=

("Corridor Growth Rate (1/4-1/2 mile)"\*"  
Potential Riders along Corridor 1/4-1/2")

~ pax/year

~ |

Potential Ridership along Corridor=

"Potential Riders along Corridor 1/4-1/2"+"Potential Riders  
along Corridor <1/4"

~

~ 0.7\*"Corridor Growth (<1/4 mile)" + 0.3\*"Corridor  
Growth(1/4-1/2 mile)" \

Previous Equation

|

"Potential Riders along Corridor 1/4-1/2" = INTEG (

"Corridor Growth(1/4-1/2 mile)",

21257)

~ pax/year

~

|

"Potential Riders along Corridor <1/4" = INTEG (

"Corridor Growth (<1/4 mile)",

13478)

~

~

|

"Corridor Growth (<1/4 mile)" =

"Corridor Growth Rate (<1/4 mile)" \* "Potential Riders along  
Corridor <1/4"

~ pax/year

~

|

Additional Daily Ridership =

(Synergy\*0.25)\*Potential Daily Ridership

~

~

|

"Corridor Growth Rate (1/4-1/2 mile)"=

0.00696241

~

~

|

ITS Utilization=

IF THEN ELSE( Initial Phase=0 , 0.02 , IF THEN ELSE(Initial  
Phase=1, 0.1 , IF THEN ELSE\

(Initial Phase=2, 0.1 , 0 )))

~

~

|

Branding=

IF THEN ELSE( Initial Phase=0:OR:Initial Phase=1:OR:Initial  
Phase=2,0.1 , 0 )

~

~

|

Service Patterns=

IF THEN ELSE( Initial Phase=0 , 0.04 , IF THEN ELSE(Initial  
Phase=1, 0.07 , IF THEN ELSE\

(Initial Phase=2, 0.11 , 0 )))

~

~

|

Initial Phase=

2

~

~

Limited=0, Moderate=1, Aggressive=2

|

Vehicle Design=

IF THEN ELSE( Initial Phase=0, 0.05 , IF THEN ELSE(Initial  
Phase=1:OR:Initial Phase=\  
2, 0.15 , 0 ))

~

~ |

Feature Implementation Level=

Branding+Fare Collection Type+Guideway Type+ITS  
Utilization+Service Patterns+Stop Improvements\  
+Vehicle Design

~

~ |

Synergy=

IF THEN ELSE(Feature Implementation Level>=0.6, Feature  
Implementation Level+0.15 , \  
Feature Implementation Level)

~

~ |

Guideway Type=

IF THEN ELSE( Initial Phase=0 , 0 , IF THEN ELSE(Initial  
Phase=1, 0.05 , IF THEN ELSE\  
(Initial Phase=2, 0.15 , 0 )))

~

~ |

Fare Collection Type=

IF THEN ELSE( Initial Phase=0 , 0 , IF THEN ELSE(Initial  
Phase=1, 0 , IF THEN ELSE(Initial Phase\  
=2, 0.03 , 0 )))

~

~ |

Stop Improvements=

IF THEN ELSE( Initial Phase=0 , 0.02 , IF THEN ELSE(Initial  
Phase=1, 0.09 , IF THEN ELSE\  
(Initial Phase=2, 0.15 , 0 )))

~

~ |

"Corridor Growth Rate (<1/4 mile)"=

0.00412524

~

~ Growing Rate from the Buffering Analysis in Business  
Analyst

|

"Off-Peak-Hour Factor"=

6e-009\*Business Growth

~

~ BRT/Rapid Imapcts on Trasit Corridor Business

|

"Area (Gross Acres)"=



5640.87

~ gross acre

~ |

"Business Growth Rate (1/4-1/2 mile)"=

0.0561538

~

~ Sales Volume

|

"Business Growth Rate (<1/4 mile)"=

-0.212671

~

~ |

Transit Share=

"Proportion of Commutes by Transit (Transit Share)"

~

~ |

"Proportion of Commutes by Transit (Transit Share)"=

0.0015+(0.0266\*(Household Level/"Area (Gross Acres)"))-  
(0.00025\*(Household Level/"Area (Gross Acres)"\  
)^2)

~

~ |

"Peak-Hour Factor"=

0.47

~

~

|

"Household Development Rate (1/4-1/2 mile)"=

0.00953031

~ 1/year

~

|

"Employment Growth Rate (<1/4 mile)"=

-0.00432299

~

~

|

"Employment Growth Rate (1/4-1/2 mile)"=

0.00580547

~

~ BA Market Report "2008 Employed Population 16+ by  
Occupation"

|

"Household Development Rate (<1/4 mile)"=

0.00643031

~ 1/year

~

|

\*\*\*\*\*

.Control

\*\*\*\*\*~

## Simulation Control Parameters

|

FINAL TIME = 2015

~ year

~ The final time for the simulation.

|

INITIAL TIME = 2008

~ year

~ The initial time for the simulation.

## **CURRICULUM VITA**

Luis David Galicia Cabrera is the second son of Alejandro Galicia and Elizabeth Cabrera. He was born in the city of Taxco de Alarcon, Guerrero, Mexico in 1974. Luis got his primary and secondary education in the city of Tepic, Nayarit, Mexico. He moved to Mexico City to get his Bachelor's degree in Civil Engineering from the National Polytechnic Institute (Instituto Politecnico Nacional-IPN) back in 1998. Following his bachelor's graduation, he was awarded with a scholarship from the Mexican government to get a Master's degree in Civil Engineering at the University of Southern California, in the city of Los Angeles in 2003. During the following years he worked as a faculty in his Alma Mater (IPN) and as a transportation consultant back in Mexico City. In 2006 he moved to El Paso, Texas to start a doctorate program at the University of Texas at El Paso (UTEP). In the same year, he started working as a research assistant at the Laboratory of Advance Dynamic Transportation and Urban Systems under the guidance of Dr. Yi-Chang Chiu. Later on, he continued working as a research assistant but now under the supervision of Dr. Kelvin Cheu for the Border Intermodal Gateway Laboratory. He received the Texas Institute of Transportation Engineers (Tex-ITE) award for outstanding student in 2007. He also received the International Road Federation (IRF) Executive Leadership fellowship in Washington D.C back in 2009. In the fall of 2009, he was part of the UTEP team that was selected as a project finalist of the International Mondialogo Engineering Award by Daimler and UNESCO. Luis has been working as a graduate research assistant at the Texas Transportation Institute (TTI) since the summer of 2008.

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