DESIGN AND OPTIMIZATION OF A FEEDER DEMAND RESPONSIVE TRANSIT SYSTEM IN EL CENIZO, TX

A Thesis

by

SHAILESH CHANDRA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2009

Major Subject: Civil Engineering

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Approved by:

Chair of Committee,	Luca Quadrifoglio
Committee Members,	Francisco Olivera
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ABSTRACT

Design and Optimization of a Feeder Demand Responsive Transit System

in El Cenizo,TX. (August 2009)

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Chair of Advisory Committee: Dr. Luca Quadrifoglio

The colonias along the Texas-Mexico border are one of the most rapidly growing areas in Texas. Because of the relatively low income of the residents and an inadequate availability of transportation services, the need for basic social activities for the colonias cannot be properly met. The objectives of this study are to have a better comprehension of the status quo of these communities by examining the potential demand for an improved transportation service and evaluate the capacity and optimum service time interval of a new demand responsive transit “feeder” service within one representative colonia, El Cenizo. A comprehensive analysis of the results of a survey conducted through a questionnaire is presented to explain the existing travel patterns and potential demand for a feeder service.

The results of this thesis and work from the subsequent simulation analysis showed that a single shuttle would be able to comfortably serve 150 passengers/day. It further showed that the optimal cycle length between consecutive departures from the terminal should be between 11-13 minutes for best service quality. This exploratory study should serve as a first step towards improving transportation services within these growing

underprivileged communities especially those with demographics and geography similar to the target area of El Cenizo.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Quadrifoglio (CVEN), and my committee members, Dr. Olivera (CVEN), Dr. Zechman (CVEN), and Dr. Kianfar (ISEN), for their guidance and support throughout the course of this research.

Thanks also go to my friends, especially Chung- Wei Shen and colleagues, and the department faculty and staff, for making my time at Texas A&M University a great experience. I also want to extend my gratitude to the University Transportation Center for Mobility (UTCM) and the Southwest Region University Transportation Center (SWUTC) for supporting this research.

I would like to thank the representatives of the Center for Housing and Urban Development (CHUD) for their guidance, help and support. I am particularly grateful to: Dr. Jorge Vanegas (Director), Mr. Oscar Munoz (Deputy Director), Mr. Pete Lara (Associate Director for the Central Rio Grande Region), and Mrs. Sara Buentello (Program Coordinator for the Colonias Program). I would also like to express our gratitude to the Promotoras in Laredo, TX, who work very hard and unbelievably efficiently in getting the survey questionnaires completed by the residents of El Cenizo, TX. I would have not been able to accomplish this research study without their help. Finally, thanks to my mother and father for their encouragement, for their patience, and love.

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CHAPTER I

INTRODUCTION

Colonias (a Spanish word for ‘colonies’) are unincorporated settlements outside city boundaries along the US – Mexico border. Thousands of residents live in these relatively underdeveloped areas, which can be found in New Mexico, Arizona, California and Texas, but the latter state not only has the largest number of colonias, but also the highest colonia population; in fact, more than 400,000 people live in the colonias in Texas. El Cenizo, adjacent to the Rio Grande River, is a colonia located in Webb County, TX, about 15 miles south of Laredo (Figure 1).

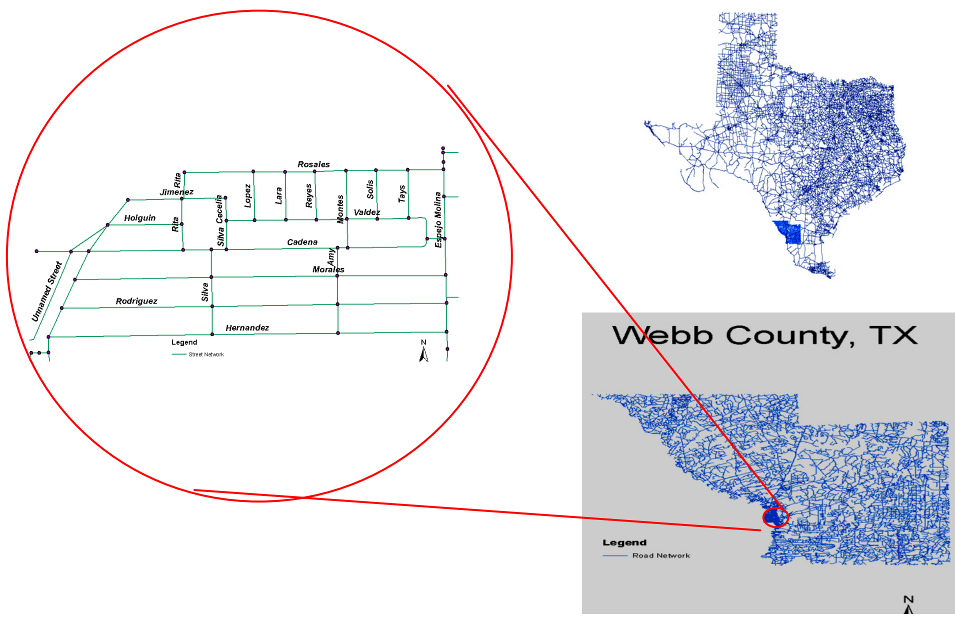


Figure 1: Map of El Cenizo, Webb County, Texas.

This thesis follows the style of *Transportation Research Record.*

According to the U.S. Census 2000, the total population of El Cenizo is 3,545 and the population for June 1st, 2007 was 3,823. The total area is nearly 0.5 square miles with the number of households being 730. Approximately 98.9% of the population is Hispanic or Latino and 82.7% of them are of Mexican origin. The age distribution of El Cenizo comprises 52.9% of the population under 19 year old, 41.9% between 20 and 60, and only 5.1% of them are over 60.

Although the economic situation of El Cenizo has improved and is still developing, about 66.3% of families and 68.1% of the population are below the poverty line in these colonias (1). Due to a relatively low income, families living in these areas cannot afford the high housing costs in Laredo. They only have the option of living in the colonias surrounding the city, such as El Cenizo, which has relatively lower housing prices. Many problems exist in the colonias. The most important one concerning the residents is the lack of potable water that is needed on a daily basis. Residents have to buy and transport water from water stations (2). Most residents use barrels, 500 gallon bladders and drums to store the water that have minimal protection from contamination (3). Then, there is the problem of substandard housing in which the residents live. Most of the houses are not built according to the code standards and lack indoor bathrooms or plumbing. As shown by past studies conducted by the University of Texas System Texas-Mexico Border Health Coordination Office, the general lack of hygiene causes residents of these colonias to be almost twice more prone to communicable diseases such as tuberculosis and hepatitis A than in any part of Texas. In addition, there is a lack of proper health care services such as access to hospitals and clinics which have further aggravated these problems.

The employment situation is also not good. While the overall unemployment rate in Texas is about 7%, in the colonias it ranges from 20% to 60% (2). Most of the employment for the colonias' residents are related to agricultural service providers and construction. These jobs form the basis of employment for the young and unskilled workforce. However, many of these jobs are low paying and seasonal which adds to the unemployment for the majority of the residents. Another major issue among the colonias is the level of education, since the dropout rate from schools is excessively high.

All the above problems are severely worsened, if not partially caused, by a general lack of acceptable transportation services and facilities. The existing unpaved roads are difficult for any vehicle to traverse on. This problem becomes aggravated at times of heavy rainfall, since roads become muddy and it makes it very difficult to walk as well. Thus, school-bus operations, medical vans, transit vehicle and private cars/trucks cannot be used as desired. The large distance and limited means of private transportation between the colonias and the closest city denies the colonia residents easy access to jobs, health care facilities and grocery stores for meeting their basic needs. Below we present a brief summary of the existing transportation services currently provided to El Cenizo residents.

a.) Rural Transportation: El Aguilar, operated by the Laredo Webb County Community Action Agency, provides fixed routes and demand responsive rural public transportation to unincorporated areas within Webb County. It is a small transit operation with a limited number of vehicles and seating capacity. El Aguilar currently operates a total of five fixed routes. These five routes provide service to the colonia communities of Mirando City, Oilton, Bruni and the colonias of Larga Vista, Tanquecitos, D-5 Acres, San Carlos, Ranchitos, Laredo Ranchettes, and Pueblo Nuevo located east of Laredo along Highway 359. Also served are the City of Encinal, located off IH 35 just north of the Webb County line in LaSalle County, and the colonias towns of El Cenizo and Rio Bravo, located along Highway 83 in southeastern Webb County. In general, each of these routes is designed to transport passengers only to Jarvis Plaza, the central transfer point for El Metro, the municipal bus service of Laredo. The cost for a one-way trip on El Aguilar is 75 cents. Tickets must be purchased in advance because cash is not accepted on board the bus (4).

b.) Medical transportation: Medical transportation is provided by LeFleur Transportation and managed by TxDOT-MTP (Medical Transportation Program). MTP usually needs two working days for most routine trips and five working days for others. When next day service is needed, MTP makes every effort to arrange transportation, but may not always be able to schedule it with contractors responsible for that area. This service can be requested online or over the telephone.

c.) In 1996, the Texas A&M University Center for Housing and Urban Development (CHUD), working with the Texas Transportation Institute, began a demonstration project designed to improve the lives of impoverished people living in colonias along the Texas border. After evaluating the needs of the colonias, Southwest University Transportation Center (SWUTC) developed a demonstration project to supply a 15-passenger van for transportation service for the colonias along a ten-mile stretch of Highway 359 east of the City of Laredo. The initial feedback of the demonstration project was very positive. The local partners, including county governments and hospital districts, provided support for operating and conducting maintenance. El Cenizo has the specific locations where the CHUD-operated community centers also serve as headquarters for the home station and dispatching of the vans, which serve the needs of the residents (4).

d.) Transportation for school children living in the El Cenizo is provided by the United Independent School District, a school district headquartered in Laredo. El Cenizo is zoned into Kennedy-Zapata Elementary School (Unincorporated Webb County), Salvador Garcia Middle School (Rio Bravo), and Lyndon B. Johnson

> High School (Laredo). Because most school buses are restricted to traveling only on paved roads due to safety issues, the students were forced to walk to the paved road bus stop in inclement weather. In 2001, the 77th Legislature passed Senate Bill 1296, which provided $175 million in bond revenues to provide financial assistance to counties for roadway projects serving border colonias. Unpaved and deteriorated roads in many of the Texas' border colonia communities cause transportation and drainage problems.

The above transportation services can only pick up and drop off riders at designated bus stops outside or just at the entrance of El Cenizo (except for those meant for extreme medical emergencies). In addition, the schedule of fixed route bus service is limited to the morning and afternoon peaks. Furthermore, residents have little resources and most of them cannot afford to buy and maintain private vehicles. As a consequence, most of them basically have no means of acceptable transportation.

CHAPTER II

OBJECTIVES AND METHODOLOGY

The objective of this research is to conduct a pilot study for the colonias around the area of Laredo and McAllen in TX. The aim is to collect data and assess the appropriateness and the feasibility of a potential future implementation of flexible transit solutions in these Colonias. El Cenizo, south west of Laredo, has been selected as a representative colonia for this study. The purpose is to understand the current basic travel needs and to conduct a simulation study for the design and possible implementation of a "feeder" demand responsive transit service within the colonia. The study has the ultimate goal to improve the quality of life of Colonias' residents by enhancing their mobility and efficiently responding to their essential transportation needs. The result could be eventually used to incorporate an efficient transit system also in another area having similar geometry and demographics.

The primary data source used for this analysis is a travel survey conducted in the colonia of El Cenizo from April 1 to April 22, 2008 (see Appendix). Homes were randomly selected. Surveys were conducted by teams of TAMU Promotoras (outreach workers) who knocked on doors during various times of the day and conducted in person interviews. The next step was to determine the number of surveys needed. According to the US Census Bureau, Census 2000 data there are 740 occupied housing units. Under the condition of 5% margin of error and for 95% confidence level, the minimum sample size was found to be approximately 250. We thus collected 250 surveys for our analyses.

The goal was to determine the travel demand distributions, location wise, time wise and also with respect to the demographics.

The derived distributions were then used to generate random demand for the simulation of the operations of a hypothetical feeder transit service. Simulated demand was in this way a very good representation of the real travel pattern in El Cenizo. Demand points (either pick ups or drop offs) were assigned to the closest point in the road network, as it would likely be in reality. An ad hoc assignment algorithm was used for this purpose. Shortest path distances between all pairs of points in the network were calculated with the Dijkstra's algorithm. Passengers were then assigned to be served by the vehicle by means of a scheduling algorithm, attempting to minimize the total distance traveled by the bus. Scheduling problems, such as the one we face in this research, are known combinatorial problems, which cannot be solved to optimality in a reasonable time when the number of demand points is large enough, because of the exponential explosion of the solution space including all feasible scheduling solutions. To solve these problems various approximation algorithms exist. We used one of the most popular ones: the insertion heuristic.

MATLAB which is a numerical computing environment and programming language created by The MathWorks is used for all our computational needs. There are various built in features that allow "easy matrix manipulation, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs in other languages" (5). The Bioinformatics toolbox is used extensively in carrying out the simulation required in this project. The output of the simulation and analysis is represented through graphs and charts later in this report.

CHAPTER III

LITERATURE REVIEW

Several studies have focused on the transportation service in the colonias. The Burke et al. (3) analysis of the Texas Colonias Van Project concluded that unscheduled, non-routine trips are a persistent and enduring need of families and individuals in the isolated colonias. Although the van program increases the access of colonia residents to many kinds of services available at community resource centers established within colonias by the TAMU Colonias Program, there are obvious needs in some colonias that can be better served than by using only the 15-passenger van. Jasek and Kuhn (2) attempt to assess and document innovative, affordable, and cost-effective methods for meeting some of the unique transportation challenges facing residents of the colonias. Van service is a more effective form of transportation services than rural transit services because the former has the ability to provide a cost effective means of transporting people on either a scheduled or on demand basis. However, van services still have only reached a limited number of people because it can only pick riders up at some fixed locations.

Barr et al. (1995) (6) has provided reporting guidelines for computational experiments to test heuristic methods. Yepes et al. (2006) (7) used three step local search algorithm for the vehicle routing problem with a heterogeneous fleet of vehicles and soft time windows.

Quadrifoglio et. al. (8) developed an insertion heuristic for scheduling Mobility Allowance Shuttle Transit (MAST) services. In their work a MAST system is characterized by the flexibility to allow vehicles to deviate from the fixed path in order to serve customers within a service area. A set of simulations are performed. The results show that the insertion heuristic approach developed could be used as an effective method to automate scheduling of MTA Line 646 in Los Angeles County and other services which have a similar demand need.

Quadrifoglio et al. developed an analytical model which aids in decision-makers in designing a hybrid grid network integrating a flexible demand responsive service with a fixed route service (9). Two cases one with a small service area and the other with a large metropolitan area are analyzed. For both cases the minimum of the Total Cost function with respect number of zones and number of buses per fixed route are found. It is concluded in the study that the total cost function is monotonically increasing with number of buses per fixed route.

Campbell et al. (10) studied the impact of complicating constraints on the efficiency of insertion heuristics for the standard vehicle routing problem. The time complexity of O(n3) is maintained compared to O(n4) by involving a careful implementation of the insertion heuristic. The complicating constraints identified were significant as they affect the feasibility and the efficiency of the schedule. Thus, the constraints considered were the time windows, shift time limits, variable delivery quantities, fixed and variable delivery times, and multiple routes per vehicle.

Jaw et al. (11) described a heuristic algorithm for a time constrained version of the many-to-many Dial-A-Ride Problem (DART). The algorithm described as the Advanced Dial-a-Ride Problem with Time Windows (ADARTW) with service quality constraints, identifies feasible insertions of customers into vehicle work-schedules. An incremental cost of each insertion is evaluated through an objective function. The cost is the weighted sum of disutility to the customers and of the operating costs. The solutions provided by the ADARTW did not have any ‘optimal” solutions to compare with and no exact algorithms existed to solve problems of similar size.

Software packages such as the Network Analyst extension of ArcGIS 9.3 handles vehicle routing problems uses a tabu search-based algorithm to find the best sequence of visiting the stops. Tabu search is a metaheuristic algorithm for solving combinatorial problems. It falls in the realm of local search algorithms (12).

The Users' Manual for Assessing Service-Delivery Systems for Rural Passenger Transportation (13) provides case studies which represent a real attempt to tailor the service specifications to local conditions. The El Aguila is one of the cases to be mentioned, because of its efficiency due to concentrated housing.

Concerning the characteristics of work schedules, Sinha et al. (14) concluded that the ability to select certain occupations in specific industries is relative to the ability to select work schedules. Some jobs that need to start during off-peak hours might indirectly prevent employment of those who cannot reach the employment locations at that time. In order to facilitate access to jobs that do not coordinate with the existing transit service times, the Federal Transit Administration (FTA) initiated the Job Access and Reverse Commute (JARC) program especially to develop transportation service to connect welfare recipients and other low-income residents to jobs and other support programs around the country. Thakuriah et al. (15) have found that the overwhelming majority of riders in smaller metropolitan areas and rural areas indicate that JARC services were important to them. The following study explored the determinants of the importance of transit services funded by the JARC program (16). It was shown that demand-responsive services are most likely to receive the highest ranking among all services. The commuting patterns of newly built towns are discussed intensively. Research has found that the proportion of people working or studying in urban area is proportional to the age of the new town (17). Moreover, cross-district commuting to work is more prevalent than to school. Lockwood et al. (18) compared the weekend and weekday activity patterns in the San Francisco Bay Area, California. This research found that the weekend travel patterns are quite different from weekday travel patterns in many aspects such as time of day, mode, and the total volume. McLeod (2006) used the concept of estimating bus passenger waiting times from incomplete bus arrivals data (19). Mishalani et al. (2006) (20) evaluated the impact of real-time bus arrival information using the passenger wait time perceptions at bus stops. Chien et al. (2000) (21) developed a CORSIM-based microscopic simulation model which could simulate bus operations on transit routes.

Lipmann et al. (2002) (22) and Hauptmeier et al. (2000) (23) evaluated the performance of DRT systems taking traffic conditions into account. Feuerstein and Stougie, 2001 (24) and Bailey and Clark, 1987 (25) have investigated changes of performance using different number of vehicles for the dial-a-ride system. Simulation was used to compare different heuristics in assessing the effect of the service area and quality along with the demand density for a different fleet size in the work by Wilson et al. (1970) (26). Haghani and Banihashemi (2002) (27) studied the relationship between efficiency of vehicles and town size.

There have been various studies regarding the comfort and the convenience of the passengers using a transit service. Researchers such as Todd Litman, Victoria Transport Policy Institute have studied the impact of the inconvenience and discomfort (28). Quiroga et al. (1998) performed the travel time studies by using global positioning system (GPS) and geographic information system (GIS) technologies (29).

The travel demand analysis of this project will focus on both weekday and weekend activity travel patterns, while studying the effects of travel on peak period traffic for work and school trips. However, the frequency of health related and grocery supply activities are analyzed over a longer period because of the trip characteristics. Some of the factors affecting the travel time costs have been listed in Table 1 (28). The elements considered in this analysis are the waiting time (*) arising due to time taken by the bus in reaching the request point and the riding time (*) spent before being dropped off at the destination.

Table 1: Factors affecting travel time costs

Factor	Description	Transit Evaluation Implications
Waiting*	Waiting time is usually valued higher than in-vehicle travel time	Transit travel usually requires more waiting, often along busy roads, with little protection.
Walking links	Time spent walking to vehicles is usually valued higher than in-vehicle travel time.	Transit travel usually requires more walking for access.
Transfers	Transfers impose a time cost penalty.	Transit travel often requires transfers.
Trip duration/Riding time*	Unit costs tend to increase for trips that exceed about 40 minutes.	Transit travel tends to require more time than automobile travel for a given distance.
Unreliability (travel time variance)	Unreliability, particularly unexpected delays, increase travel time costs.	Varies. Transit is often less reliable, except where given priority in traffic.
Waiting and vehicle environments	Uncomfortable conditions (crowded, dirty, insecure, cold, etc.) increase costs.	Transit travel is often perceived as providing little user control.
Cognitive effort (need to pay attention)	More cognitive effort increases travel time costs.	Varies. Driving generally requires more effort, particularly in congestion.
Variability	Transit travel conditions are extremely variable, depending on the quality of walking, waiting, and vehicle conditions.	Transit benefit analysis is very sensitive to qualitative factors that currently tend to be overlooked and undervalued.
Captive vs. discretionary travelers	Some transit users are captive and so relatively insensitive to convenience and comfort, but discretionary travelers tend to be very sensitive to these factors.	Achieving automobile-to-transit mode shifts requires comprehensive analysis to identify service quality factors that attract discretionary travelers.

CHAPTER IV

TRAVEL DEMAND PATTERN CHARACTERISTICS

To capture a more precise travel demand pattern for the residents of El Cenizo a questionnaire was designed. The questionnaire, distributed to the residents through a survey, has three major parts. The first part is basic demographic data of each household. The second part is the evaluation of travel demand patterns. The third part sought to understand the community members' likelihood of transfer from the existing transport mode to the new shuttle transit service and the characteristics that community member would value in the new shuttle service. This new system can pick them up at home and take them to any location in the surrounding area. Thus, the survey has primarily three components:

1. Questionnaire design/development and administration of the survey,
2. Compare travel demand and trip mode against different travel purposes, and
3. Analyze the likelihood and characteristics of the new shuttle service.

The survey data results were compiled and reported. The average household size in El Cenizo is 4.25 persons; figure 2 shows the percentage of each household size. Nearly 60% of the respondents' household size is between 3 to 5 people as compared to the average household size of only 2.5 for all the United States. This implies that the travel demand volume in El Cenizo would be larger than the national average.

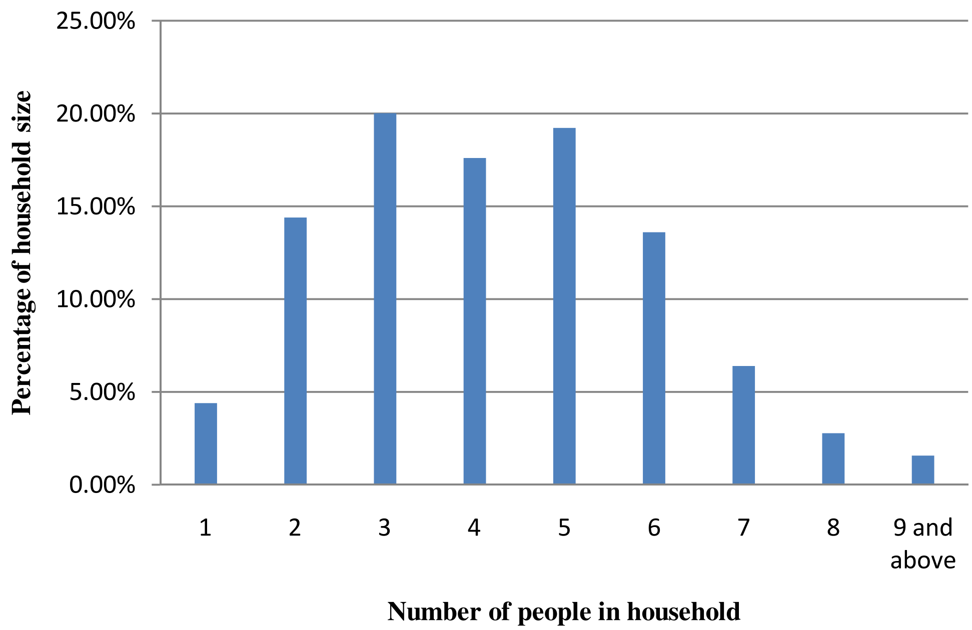


Figure 2: Distribution of household size.

The chart in figure 3 shows that 25% of the households do not own any private vehicles and nearly half (47%) of the households have only one private vehicle. On an average, there are 1.13 private vehicles per household. Here the private vehicles include cars, vans or trucks. Compared to the average size of each household, data show that there are a large number of households that do not have a vehicle available for daily use other than work.

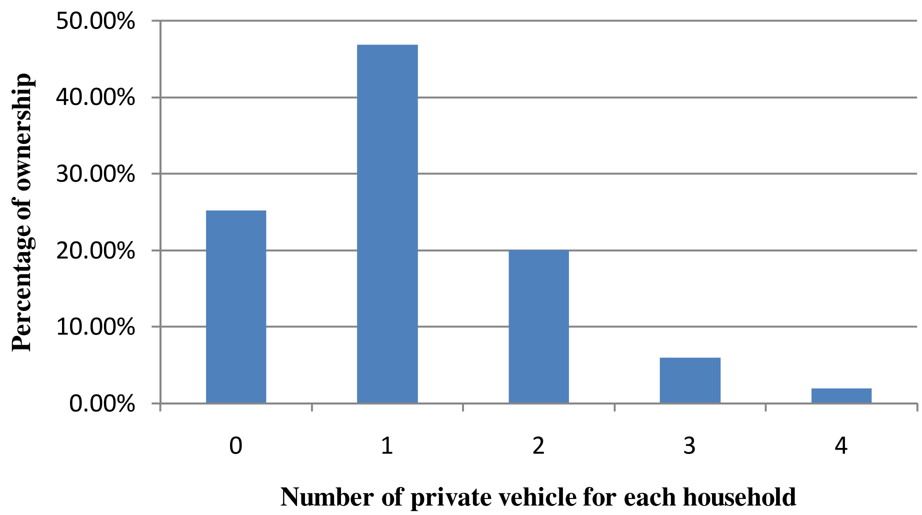


Figure 3: Distribution of private vehicle ownership.

Existing Travel Characteristics

This section of the report compares weekday travel characteristics for different purposes. First, the time-wise distribution of work, school, health, and groceries trips are studied. In addition, the mode of travel for different trip purposes and the destination of travel are also analyzed. These analyses contribute to the development of the travel demand pattern of the residents in El Cenizo.

Travel Time Distribution

For the work related trips, the majority of the householders left home during morning peak hours. Around 74% of the work trips originated between 6 and 8 AM. On the other hand, around 67% of the trips coming back from work are between 5 and 8 PM. The time distribution of work trips are shown in figure 4.

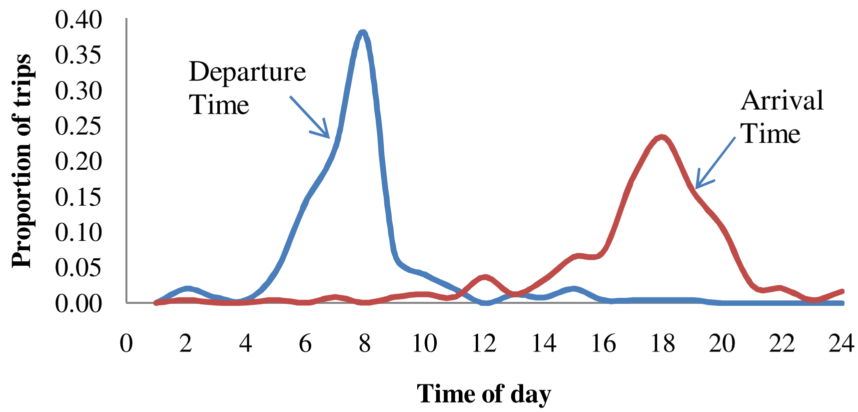


Figure 4: Time distribution of work trip for departure and arrival times.

Concerning school trips, almost all school age children (99%) leave between 6 and 9 AM. On the other hand, around 92% return between 3 and 5 PM. In comparison to the work trips, both the departure and the arrival times are more in line with the morning and afternoon peaks. This is because school time is more uniform and consistent than the work time. The time distribution of the school trips is shown in figure 5.

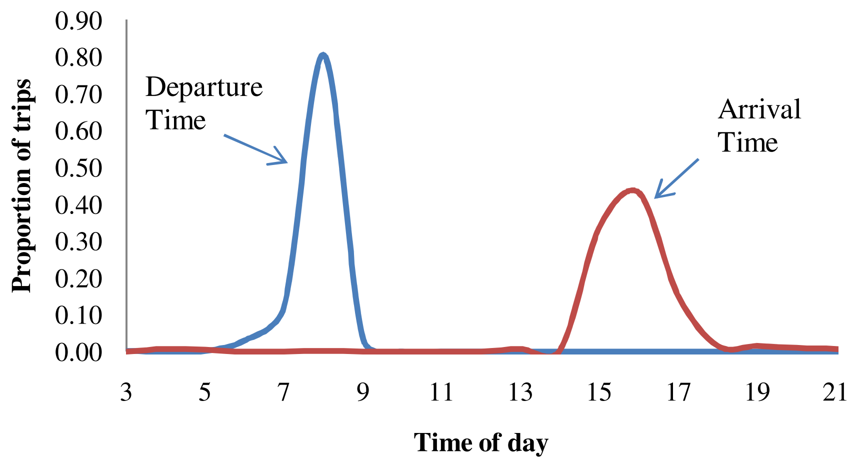


Figure 5: Time distribution of school trip for departure and arrival times.

Besides work and school trips, health and grocery related trips are also evaluated. For the health related trip (Figure 6), around 9% of respondents have less than 1 trip per month and almost 67% of respondents expressed that they travel 1 to 3 times per month for health related reasons.

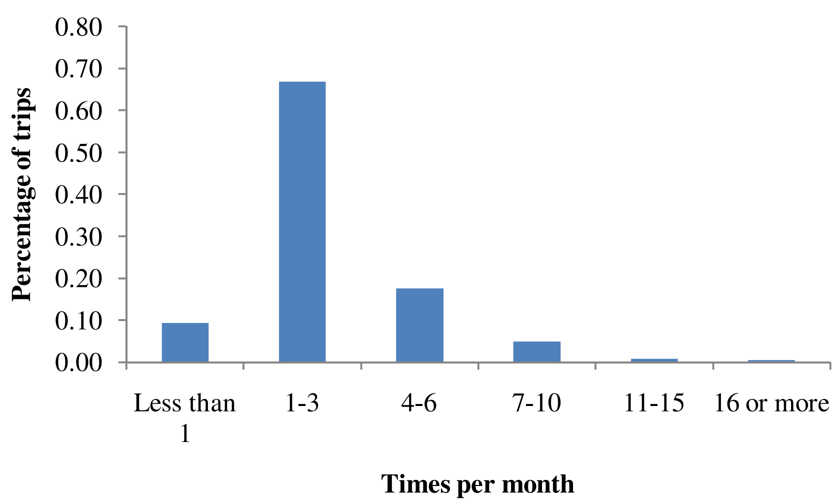


Figure 6: Time distribution of health trip for departure and arrival times.

For grocery trips (Figure 7), nearly half of the respondents (45%) reported that they go once a week. Another 33% of the respondents indicated that they make grocery trips twice a week. About 16% of the respondents indicated that they perform at least 3 groceries trips per week.

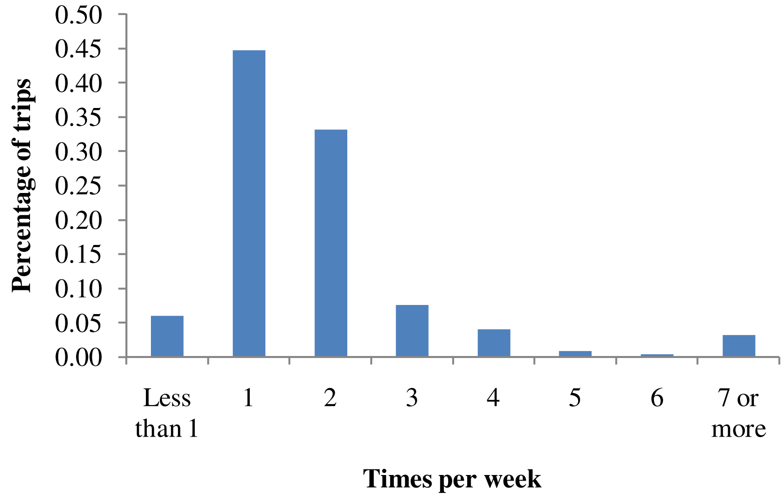


Figure 7: Time distribution of groceries trip for departure and arrival times.

Mode of Travel by Trip Purpose

The charts in figure 8 present the percentage of trips undertaken by each of the travel modes. The results are presented for each trip purpose. A look into the percentage of private vehicle by trip purpose reveals that trips to work, school, health, and groceries are most likely done by using a car. For the health related and grocery trips, some respondents (7.35% and 7.49%, respectively) indicated that they carpooled.

Next, the proportion of the transit mode is evaluated. Overall, not including school trips, the proportion of transit is highest for the health related issues, whereas it is lowest for the work trip purpose. For school trips, nearly half of them (46%) use the school buses. This should be attributed to the provision of school bus systems, which is provided by the UISC, as mentioned before. Finally, the proportion of the non-motorized modes (like bicycles, walking etc.) is examined. The shares of these two modes are only shown for work and school trips. There are a higher proportion of respondents walking to school than to work. Moreover, the proportion of bicycle trips is more than one-fifth (21.3%) of all school trips.

The travel destinations are mainly dependent on the place where people can fulfill their needs. For work trips, the majority of them (74%) head towards Laredo City. This is also the case for health related and groceries trips. The reason is likely that there are few work opportunities in El Cenizo and hospital or groceries stores are also located far outside of El Cenizo. If there is a grocery store located in town, it is insufficient.

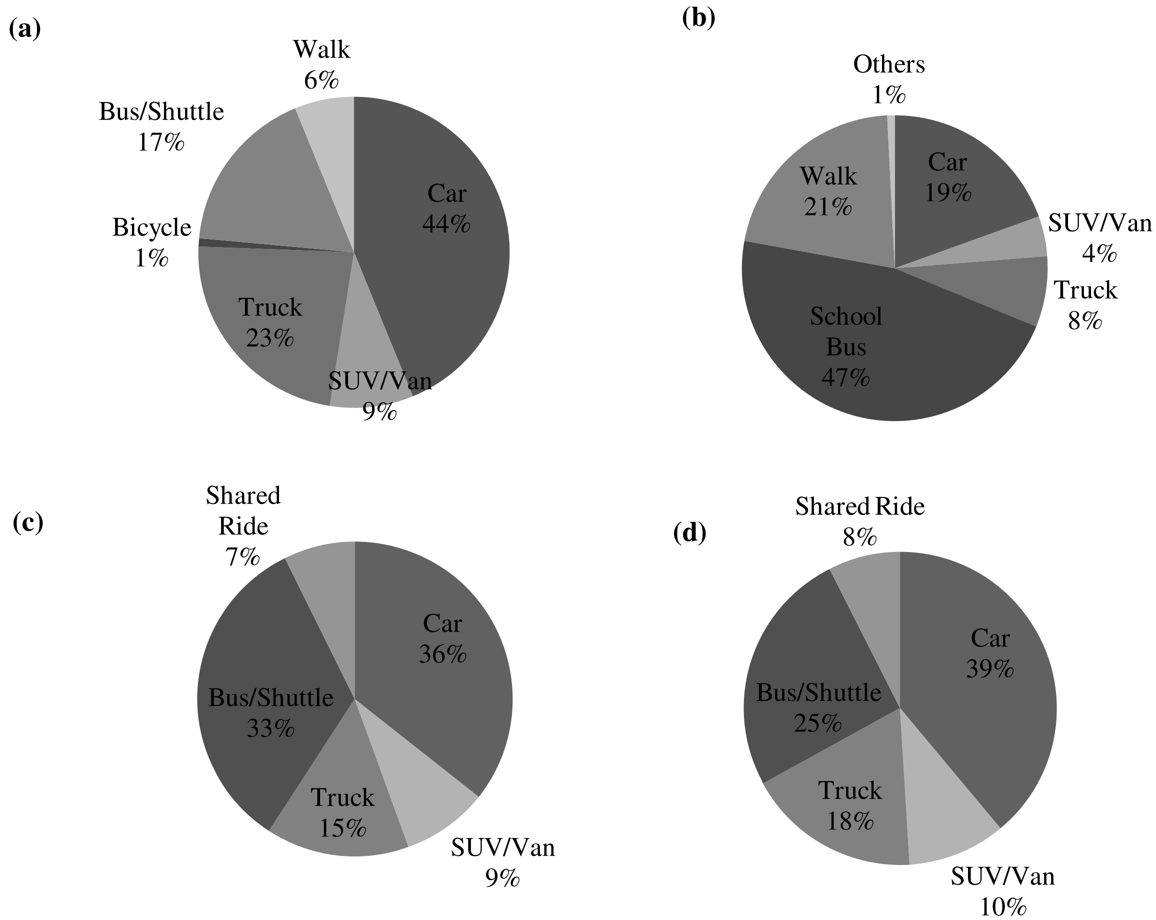


Figure 8: Mode for different trips: a) Work trip, b) School trip, c) Health trip, and d) Groceries trip.

The Gateway Community Health Center near Laredo is one of the most visited places for health issues. For groceries, HEB and Wal-Mart are major destinations. The only exception is school; the elementary and middle schools are located in the adjacent colonia, Rio Bravo. The walking distance ranges from 2 to 3.5 miles. For higher education institutes other than elementary and middle schools, almost all of them are located in Laredo City.

CHAPTER V

SIMULATION AND ANALYSIS

Proposed Demand Responsive Transit Service

Demand-Response Transit (DRT) Service could be defined as being comprised of vehicles operating in response to calls from passengers to the transit operator for requesting a ride. The transit operators then dispatch a vehicle to pick up the passengers and transport them to their destinations. A demand response operation primarily consists of two elements. Vehicles do not operate on a fixed route or on a fixed schedule and they are dispatched to pick up and drop off several passengers at different locations. It is a shared ride door-to-door (or door-to-terminal) service. It must be noted that DRT is particularly suitable for low-density population areas or low travel demand periods. The proposed DRT in this report is a response to assess the level of willingness and the rank of service characteristics for using a new DRT kind of shuttle service by the community. For this purpose, two questions were asked in the last part of the questionnaire related to the likelihood of using the new service and the importance of some characteristics of the new service. The questionnaire assumed that the new shuttle service would pick up and drop off customers door to door without using other modes of transportation. The overall likelihood of switching from the current mode of transport to the new shuttle service is on an ordinal scale from “Definitely” to “Definitely Not.” A comparison by trip purposes is given in figure 9. It shows that more than 75% of these respondents are willing, at least likely, to use the new shuttle service for all trip purposes. It can be seen that respondents would use the new shuttle service mostly for health related and grocery activities.

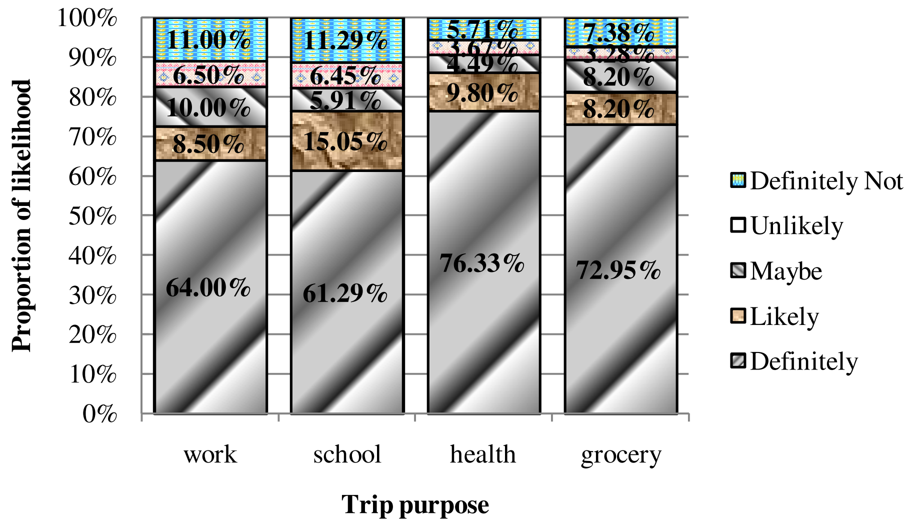


Figure 9: Likelihood to use the new shuttle service.

The chart in figure 10 shows the mean ranking of six characteristics of the new shuttle service. The chart includes the mean ranking on a scale from 1 to 6, where 1 means most important and 6 means least important. The numbers in parenthesis indicate the higher ranks, considering only from rank 1 to rank 3, for each characteristic. It can be seen that safety is the most important characteristic desired. Next, punctuality and fare are also more important to respondents than are waiting time, comfort, and ride time.

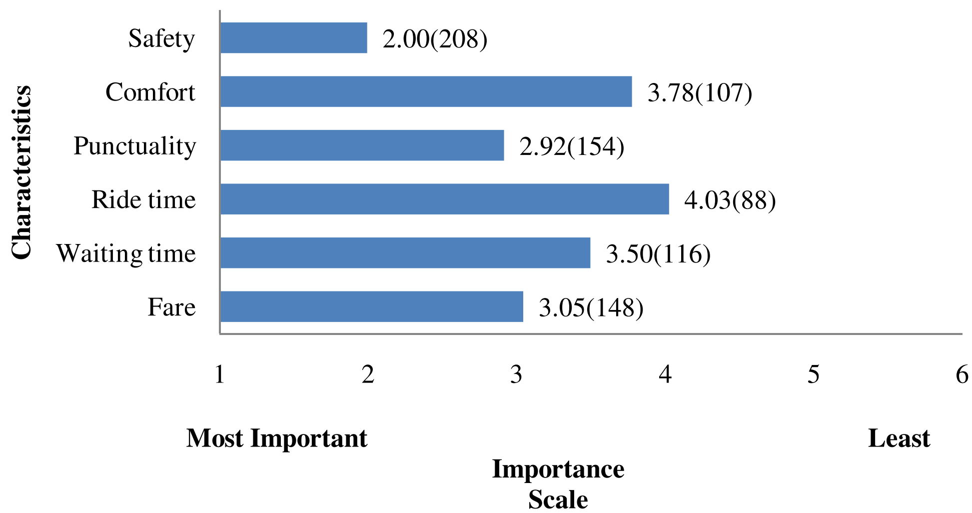


Figure 10: Mean ranking for characteristics of new shuttle service.

Of all the factors the respondents considered important, the waiting time and the riding time have been selected for simulation and analysis in this research report. These two factors are easy to model and reasonably accurate results could be obtained which could improve the popularity of the DRT. The data pertaining to the geographic information such as the length of the streets are obtained from the shapefile of the transportation data from the Texas Natural Resources Information System (TNRIS) database (33). Though the shapefile obtained consists of the entire Webb County the area of interest in this case El Cenizo streets are selected and exported as separate data using ArcGIS. The coordinate system used is GCS North American 1983. The attribute table for the shapefile is studied using ArcGIS 9.3. The segment length of the individual streets is thus obtained from the attribute table of the shapefile. The segments are straight lines and their lengths are important in creating coordinates of the nodes of the street network.

The entire street network can be broken down into individual rectangles, square or trapeziums. Once the lengths of the sides of these quadrilaterals are obtained, the node coordinates are generated manually with the origin (0,0) fixed at the intersection of the two Jimenez streets shown in figure 11 below. Further, using the Network Analyst extension of the ArcCatalog the nodes of the streets are created as represented by dots shown below. Thus the nodes are easily identifiable at the first glance.

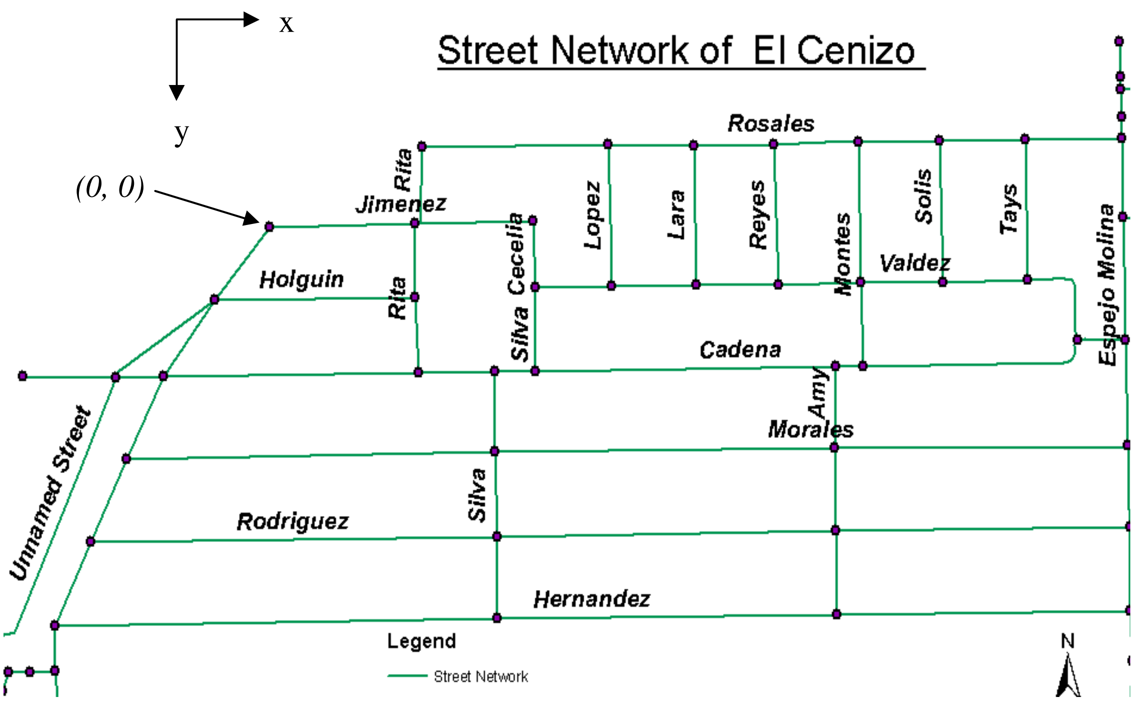


Figure 11: Map showing El Cenizo street networks with dots as junctions.

Demand Modeling and Sampling

The probability density function (pdf) for the arrival and departure times is plotted for each of the data sets obtained from the survey. According to the probability theory, a distribution is built to either identify the probability of each value of a random variable (when the variable is discrete) or to identify the probability of the random variable falling within a particular interval (when the variable is continuous). The time of departure or arrival can be considered as a continuous event as the request for using a transit service could be made at any point of time. The probability function is used to describe the range of possible values that a random variable can have. The survey data was used to plot the probability distribution function as shown in figure 12 and figure 13. Figure 12 shows the pdf of the school goers and figure 13 shows the pdf for the residents going to work.

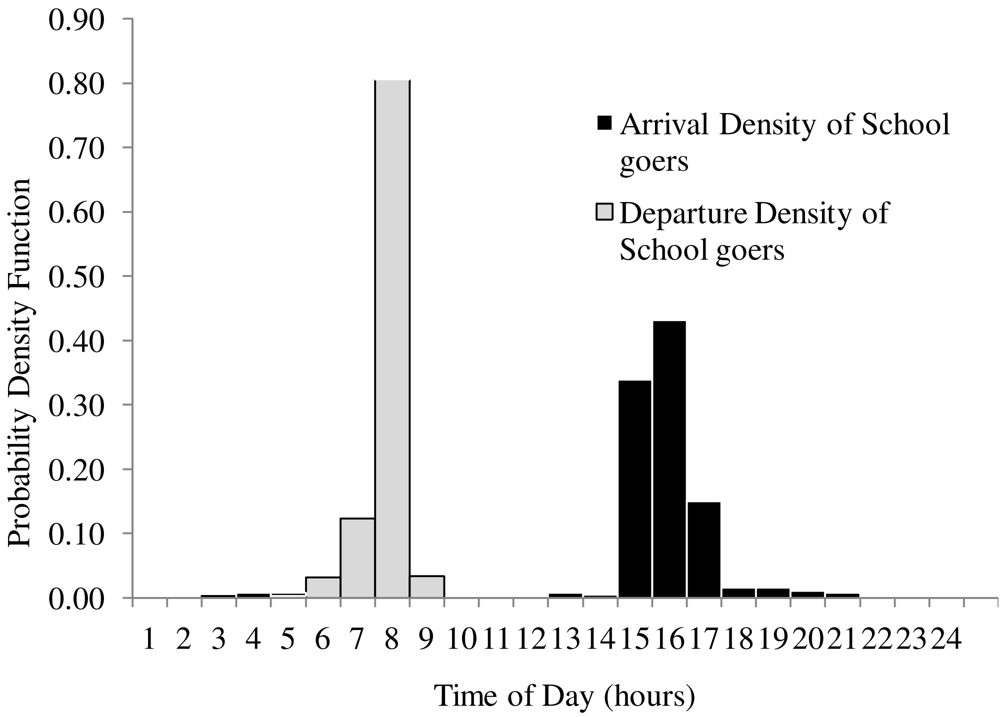


Figure 12: Probability density function (pdf) for the school goers for arrival as well as for departure.

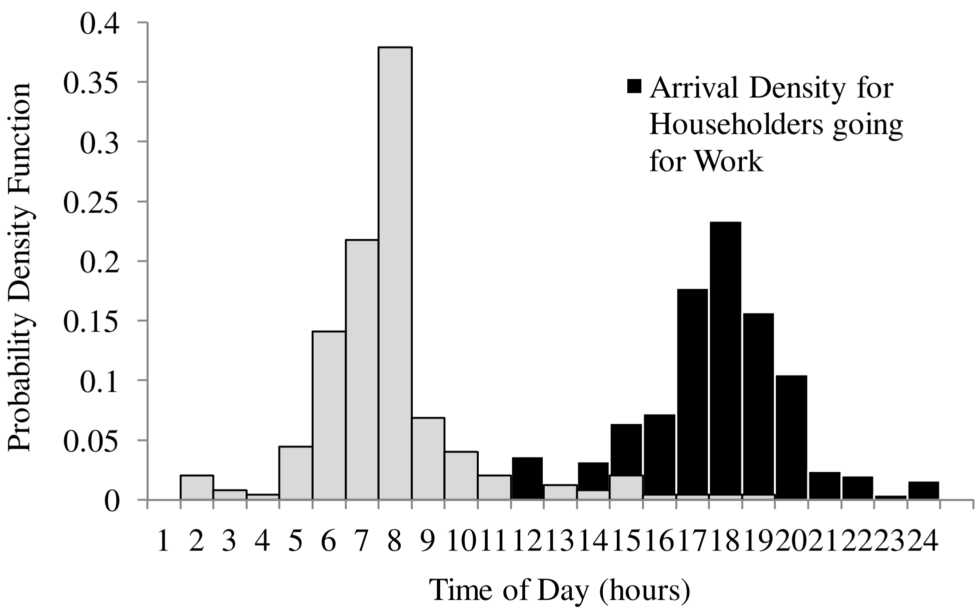


Figure 13: Probability density function (pdf) for the residents going to work for arrival as well as for departure.

The cumulative density function (cdf) is the integral of its respective probability density function (pdf). The cdfs are usually well behaved functions with values in the range [0, 1] and are important in computing critical values, P-values and power of statistical tests. The cdfs for the householders going to work and the school goers are plotted in figure 14 and figure 15 respectively. The plots in figure 14 and figure 15 represent the cdfs corresponding to departure as well as the arrival time and are basically cdfs for the pdfs as illustrated in figure 11 and figure 12 before for the collected data.

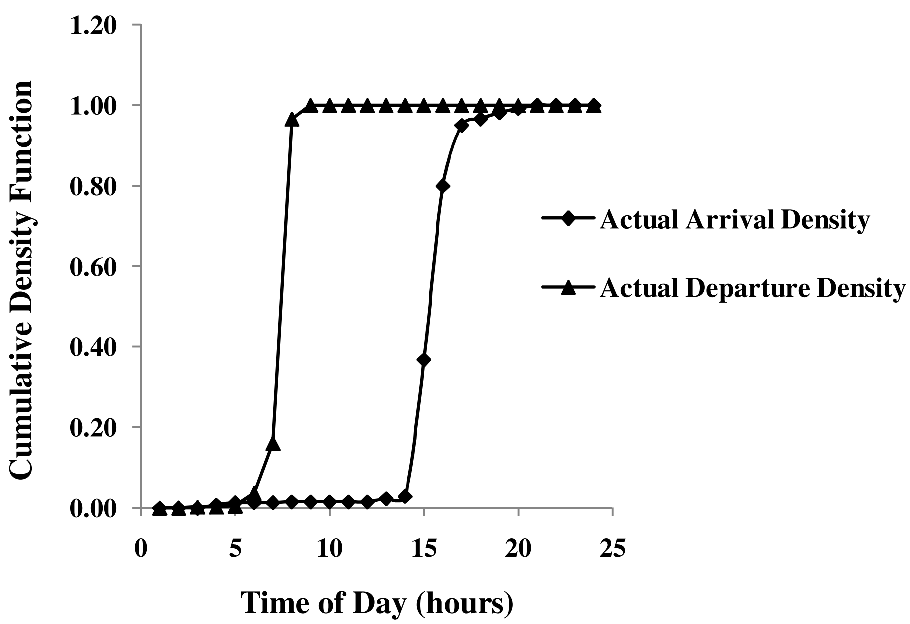


Figure 14: Actual cumulative density function (cdf) for the school goers for arrival as well as for departure.

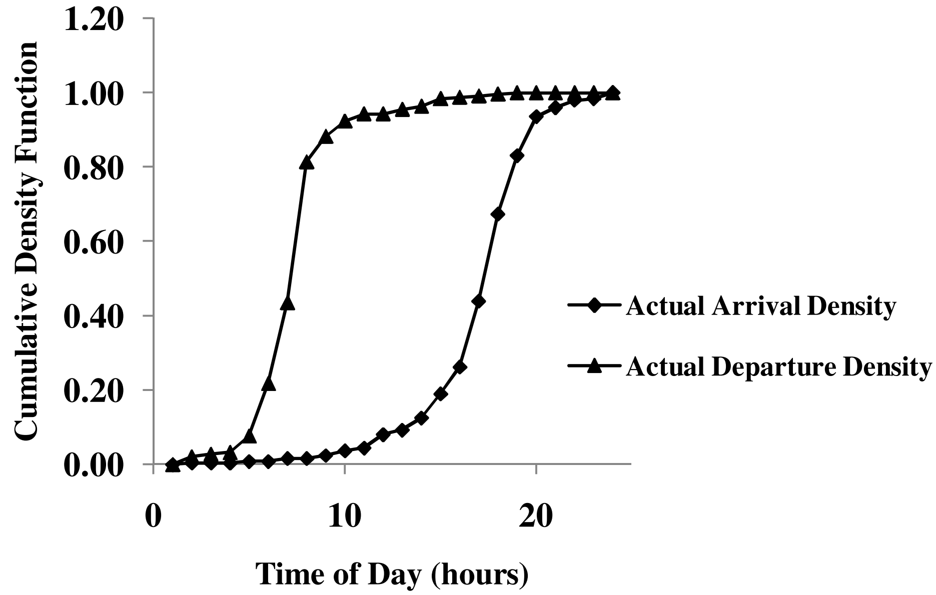


Figure 15: Actual cumulative density function (cdf) for the householders going to work for arrival as well as for departure.

In the real world, choosing a model often means choosing a parametric family of probability density functions and then adjusting the parameters to fit the data. The choice of an appropriate distribution family is usually based on a priori knowledge, such as matching the mechanism of a data-producing process to the theoretical assumptions underlying a particular family, or it could be a posteriori knowledge, such as information provided by probability plots and distribution tests. Parameters can then be found that achieve the maximum likelihood of producing the data. Several known probability distribution functions (pdf) were tested to fit the obtained demand data from the survey for the school goers and the residents going to work. The fit with a particular probability distribution function was compared to the data of the residents going to work. The distribution functions used for checking were Log-Logistic, Rician, Weibull, Lognormal, Extreme Value, Nakagami, and Logistic. These are some of the widely used probability distribution functions used for a given set of data and they also closely appeared to be overlapping with the observed probability distributions. Figure 16 shows some of the theoretical existing probability distribution for departure data compared to the actual obtained data for departure. Similarly figure 17 represents the theoretical probability distribution for arrival data compared to the actual obtained data.

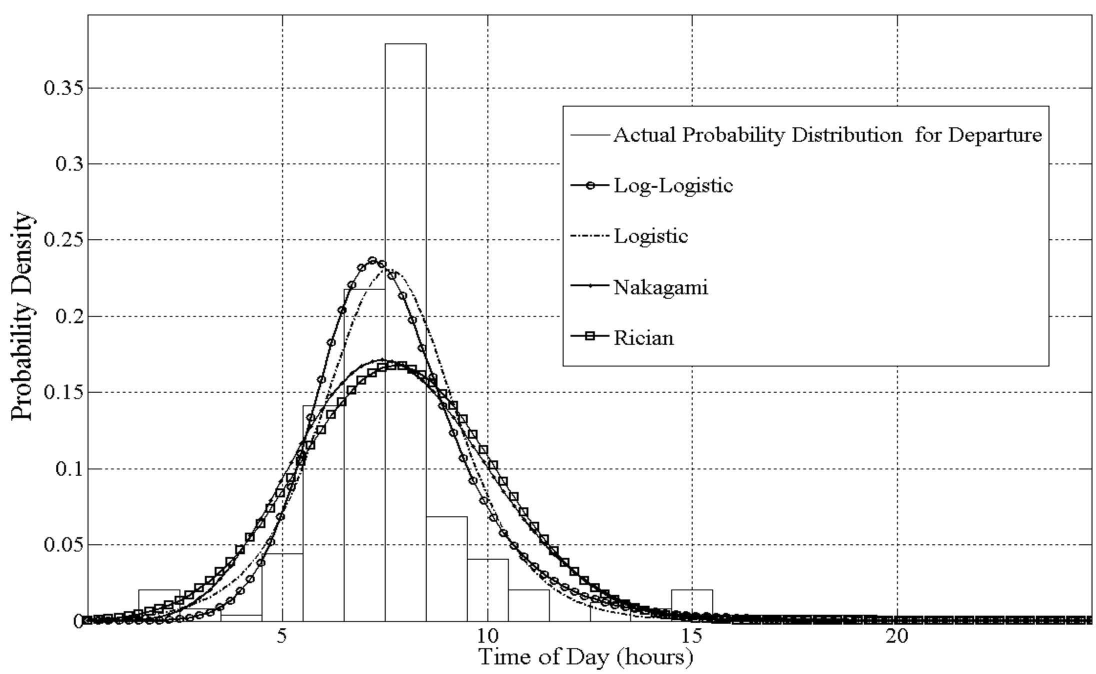


Figure 16: Plot of theoretical existing probability distributions with the given data for departure for householders going to work.

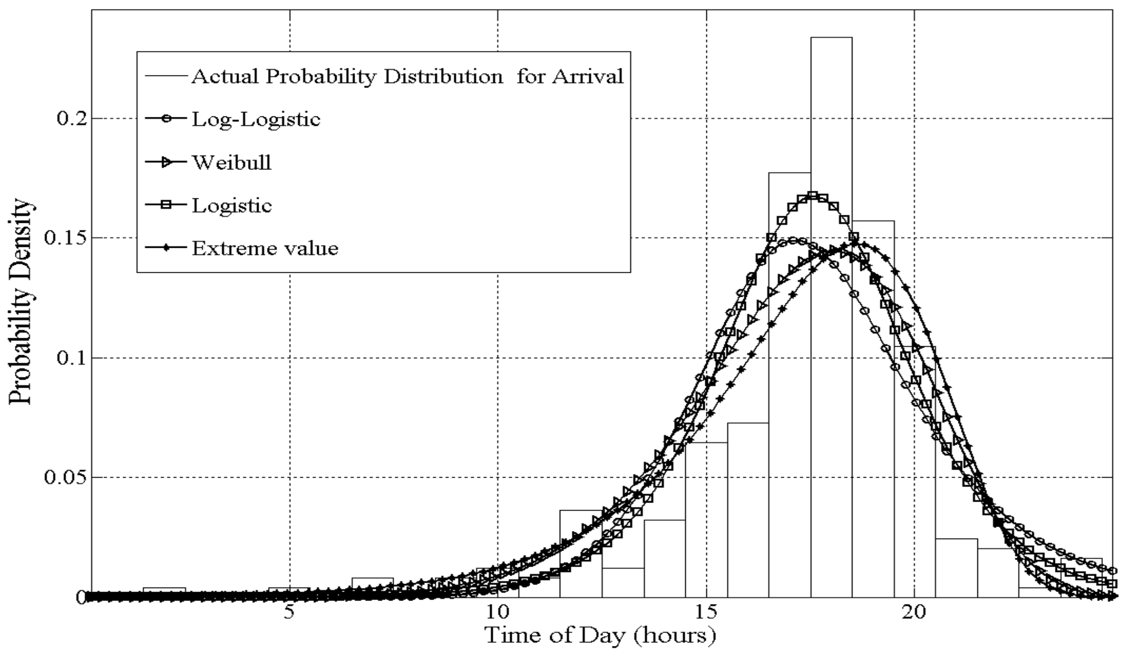


Figure 17: Plot of theoretical existing probability distributions with the given data for arrival for householders coming back from work.

The visual test for the available data with these distributions gave a negative result and no distribution was observed to fit the survey data with the theoretical ones. Furthermore, a statistical test was performed which showed that the selected distributions did not fit the available survey data. For this a hypothesis was assumed that the obtained survey data fit the chosen theoretical probability distributions mentioned earlier. The distribution data for work was selected first for the hypothesis. This was performed for each of the theoretical probability distributions, departure as well as the arrival.

The outcome of the Chi-Square test for a 95% confidence level resulted in the rejection of the hypothesis for each of the theoretical probability distributions selected for testing. For the arrival data, the one chosen for the Chi-Square tests were the Weibull, Logistic, Log-Logistic and the Extreme value probability distributions. The Chi-Square calculated using each of the selected distributions for a 95% confidence level was found to be 42.1, 46.1, 75.1 and 65.8 respectively. These values were much larger than the Chi-Square value obtained from the tables which was 12.6. For the departure data, the one chosen for the Chi-Square tests are Log-Logistic and Logistic as only two of these resemble closely the departure probability distributions. The Chi-Square values calculated were 72.4 and 59.4 respectively for each of the distributions and it was found that these values were much larger than the Chi-Square value obtained from the tables which was 12.6. Thus, the failure of the available survey data to fit any theoretical distribution encouraged us to use a manual approach to obtain a suitable distribution for the survey data.

The manual approach simplified the analysis as in it did not require any parameters to be estimated. The manual sketch for defining a distribution was performed on the cumulative density functions shown previously in figure 14 and figure 15. A new set of assumed cumulative density curves are marked for the school goers and the residents going to work. The assumed cumulative density function thus obtained through piecewise linearization is shown in figure 18 and figure 19 along with the actual existing cumulative density functions.

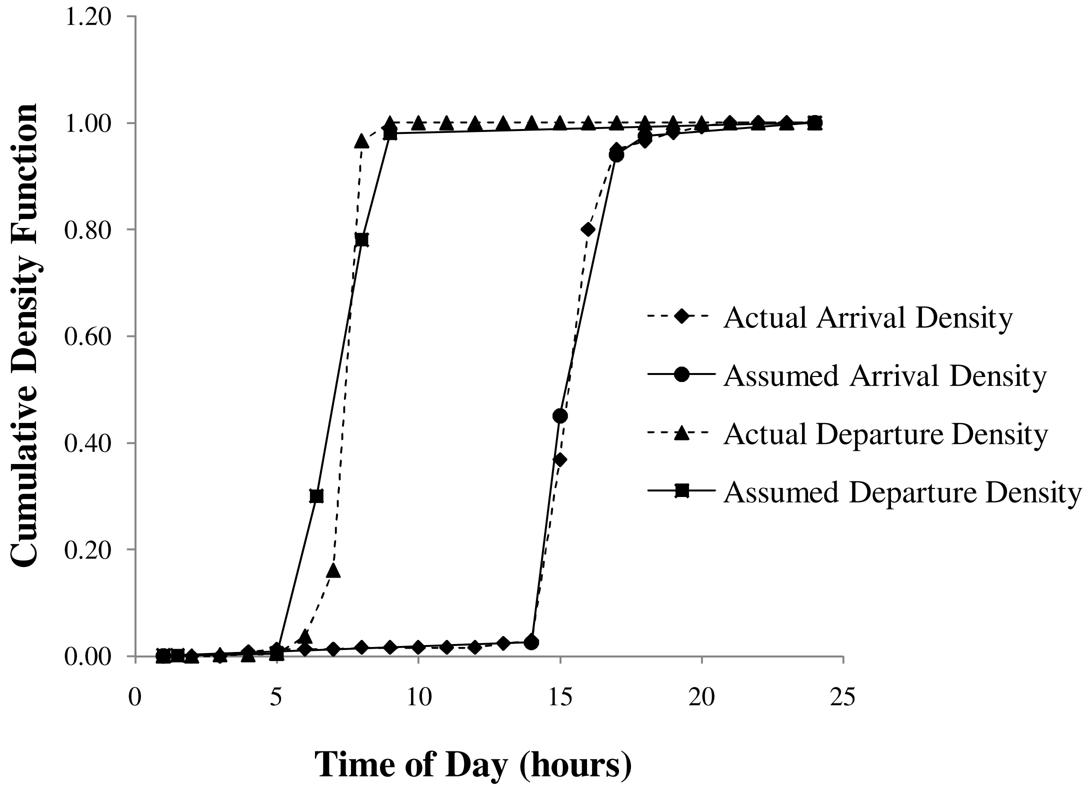


Figure 18: Actual and assumed linearly varying cumulative density function (cdf) for the school goers for arrival as well as for departure.

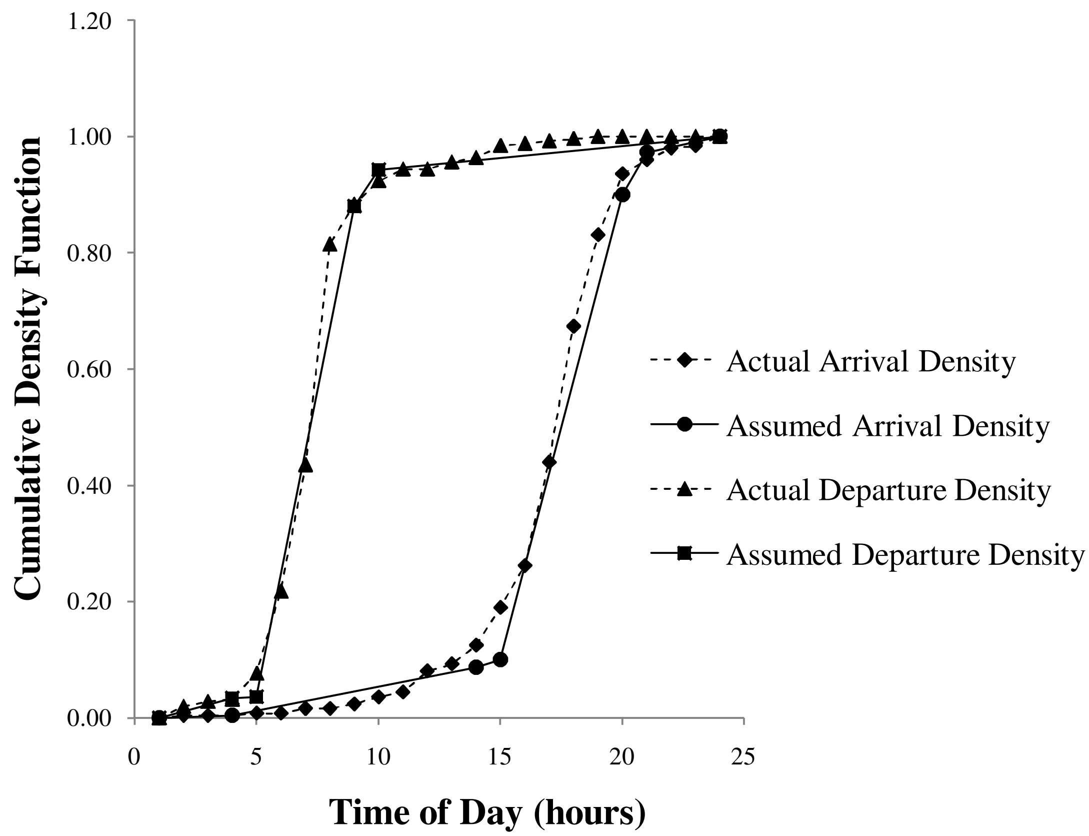


Figure 19: Actual and assumed linearly varying cumulative density function (cdf) for the householders going to work for arrival as well as for departure.

It must be noted that figure 18 and figure 19 consists of the cumulative distribution function for both the arrival as well as the departure time curves for school trips and work trips. The assumed cumulative distribution function (represented by solid lines) is linearly varying as obtained from figure 14 and figure 15. A hypothesis that there is a close resemblance of the linearly drawn sketch to the existing actual departure and arrival cdf is assumed. The Chi-Square test was performed to see if the hypothesis was correct and the results of the test indicated that the assumed hypothesis was correct. The analysis was carried further with this assumed variation of cumulative distribution function. The entire process was repeated for both the school trips as well as the work trips. The curves for assumed linearity in figure 18 and figure 19 are used to obtain the demand time distribution of the passengers by uniformly random generating numbers between 0 and 1. The generated numbers would produce time values from the *x* axis from the curves in the figures 18 and 19.

Besides school and work trips there are trips such as those for health related issues such as seeing a doctor or trips meant for groceries. These trip data for the passengers using the bus service are found out to be less in a 24- hour period time as compared to the school goers and the residents going to work. However, from the survey data it is seen that the timing of departure and arrival from their homes for these other trips closely resemble the timing of the arrival and departure for the school goers. Thus these trips are integrated with the school trips for simplicity. Or in other words the cumulative distribution function for the users for other trips such as seeing a doctor or visiting a grocery store share the same linear variation shown in assumed curves of figure 18. The locations of the demand points are also generated along with their request times. The demand points pop up assuming that the population of El Cenizo area is spread uniformly. As the departure and arrival time for transit demand is recorded, the location of the passenger where he or she needs to be picked up and dropped off is recorded as well.

Throughout the simulation it is assumed that a customer is picked up and dropped off at the same place. This gives us the idea that the children going to school and the residents going to work leave and return at the same location. This process is carried out for the entire set of customers/passengers whether school goers or working residents. Consequently, we have a departure time, an arrival time and the location of individual customers as input for our simulation study. The area of El Cenizo is contained within a given set of coordinates which cover the whole network of streets. Figure 20 shows the map of El Cenizo with the network of labeled streets.

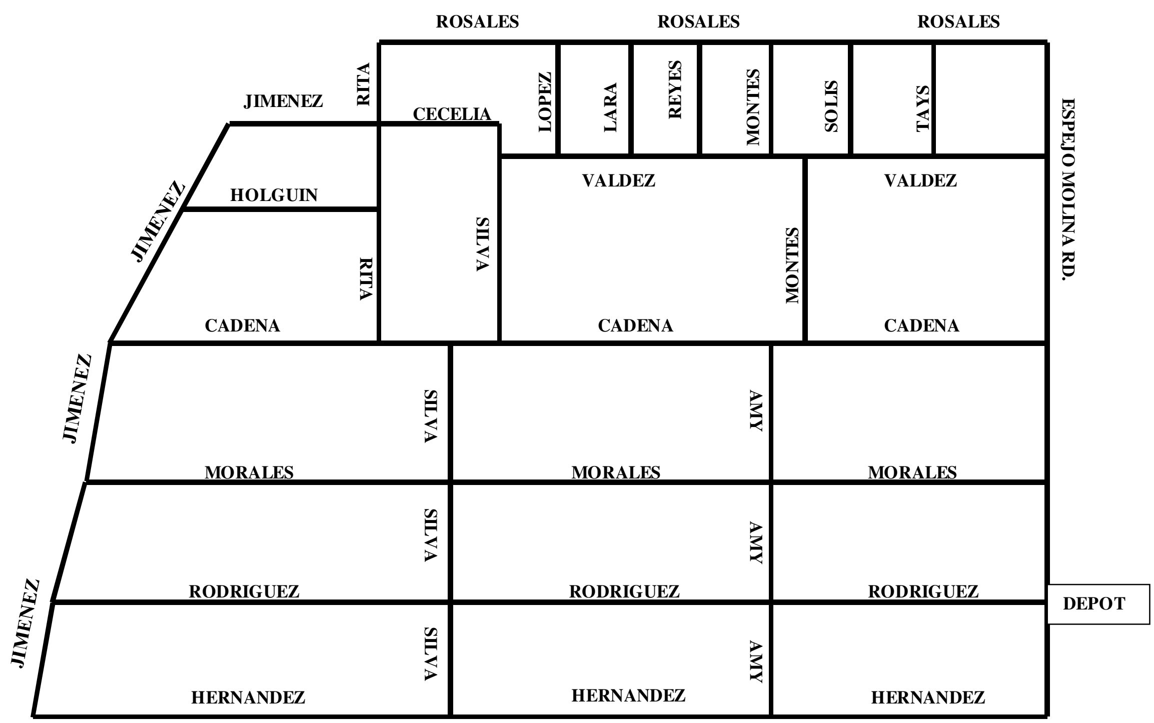


Figure 20: Straight line representations of streets of El Cenizo with a Depot.

The existing network of streets in El Cenizo is represented using straight line equations along with the location of the depot are shown in figure 20. The depot point lies on the Espejo Monila Rd that connects to US-83 leading to Rio Bravo towards Laredo City where most of the commuters go using their respective modes of transport. And it is assumed that depot would be the most convenient point to reach in case a school or the workplace lies further away from the city. The depot location is thus a strategic one for the simulation to resemble the reality. The depot in our simulation is selected to be the starting point and the ending point of the transit bus. The depot would thus also be the destination for all the school and the work trips.

Assignment of Requests

As discussed earlier, the distribution of demand points is assumed to be uniform and passengers may pop up anywhere on the map of El Cenizo. Once the time and location of each request is generated, we need to assign each request to the nearest point on the street network, where we assume the shuttle would stop for pick-up/drop-off. As the street network of El Cenizo resembles straight lines with several nodes where two or more street segments meet, a linear equation could easily describe each of them with a boundary on the starting and an ending point of the line represented by these nodes. This fact was utilized to simplify the assignment problem and perform a constrained non-linear optimization in locating the nearest point on the nearest street.

From the definitions in mathematics, a constrained optimization problem is the minimization of an objective function subject to constraints on the possible values of the independent variable. MATLAB uses Sequential Quadratic Programming (SQP) in solving the constrained non-linear optimization. SQP is one of the most popular and robust algorithms for nonlinear continuous optimization. This method is based on solving a series of sub-problems designed to minimize a quadratic model of the objective subject to a linearization of the constraints. The constraints can be either equality or inequality constraints. Thus, constrained minimization is the problem of finding a vector 'x' that is a local minimum to a scalar function h(x) subject to constraints on the allowable 'x' such that one or more of the following holds:

$C(\mathbf{a}) \leq 0,$

$Ceq(\mathbf{a}) = 0,$

$X \cdot \mathbf{a} \leq \mathbf{Y},$

$Xeq \cdot \mathbf{a} = \mathbf{Yeq},$

$\mathbf{L} \leq \mathbf{a} \leq \mathbf{U}.$

where, **a**, **Y**, **Yeq**, **L**, and **U** are vectors, X and Xeq are matrices, C(**a**) and Ceq(**a**) are functions that return vectors, and h(**a**) would be defined as a the objective function that returns a scalar. Also h(**a**), C(**a**), and Ceq(**a**) can be nonlinear functions.

For simplicity in representing ‘a’ as coordinates we replace vector ‘a’ by vector ‘x’. Thus the objective function h(x) is the Euclidean distance between the household represented as a point to a point on a street and is non linear. The bound on ‘x’ is the starting and ending x-coordinate of that street. To perform the constrained minimization problem, a built in MATLAB function ‘fmincon’ is used. The function ‘fmincon’ attempts to find a constrained minimum of a scalar function of several variables starting at an initial estimate. This is generally referred to as constrained nonlinear optimization or nonlinear programming.

For the purpose of simulating the existing problem a simple methodology is adopted to project the points onto the streets that are represented by straight lines. The streets of El Cenizo are segmented into 62 different straight lines. The problem identified is similar to a bound constrained optimization with a restriction of the x-coordinates or the y-coordinates. The formulation of the problem is shown below. The distance h(x) from a point in a plane to any given straight line in the same plane is written as,

$$h(x) = \sqrt{(X-x)^2+(Y-y)^2} \tag{1}$$

where (X,Y) is a point in a plane and the point (x,y) is on a given straight line in the same plane. The point (x,y) satisfies $y = mx + c$, where ‘m’ is the slope of the straight line and ‘c’ is its intercept with the y-axis.

Since the upper and lower bounds of all the straight lines are known parameters 'm' and 'c' could be simply written as,

$$m = \left(\frac{Uy - Ly}{Ux - Lx}\right) x \; ; \tag{2}$$

$$c = (LyUx - LxUy) \; ; \tag{3}$$

where,

Lx is the lower bound on the x coordinate of the straight line,

Ly is the lower bound on the y coordinate of the straight line,

Ux is the upper bound on the x coordinate of the straight line,

Uy is the upper bound on the y coordinate of the straight line.

The objective function is a minimization of the function h(x) in equation (1) above for the constraints given as

$$Lx \leq x \leq Ux \; ; \tag{4}$$

$$Ly \leq y \leq Uy \; ; \tag{5}$$

$$y = \left(\frac{Uy - Ly}{Ux - Lx}\right) x + (LyUx - LxUy) \; ; \tag{6}$$

where ,

$y = \left(\frac{Uy - Ly}{Ux - Lx}\right) x + (LyUx - LxUy)$ is the equation of the straight line.

It is to be noted that for simulation purposes only the streets having a designated name have been used. This also makes sense as there is no way the customer demand can be made if the street name is not known. This also means that those streets which are very narrow for bus to run comfortably are not included in the analysis or the simulation. This also requires an assigned width of the streets and for the simulation a uniform width of ten feet has been assumed. The width of the street chosen is also justified as most of the streets have a width of ten feet or close to ten feet. A width of ten feet is also considered to be suitable for the bus or any other vehicle meant for transit to run easily on the streets.

A MATLAB m-file is created to arrive at the solution of finding the minimum distance from the nearest point on a line to an individual demand point using the constraints. A series of searches are performed to arrive at the location of a line that gives the minimum Euclidean distance from the demand point to the x or the y coordinate on the line (refer figure 21). The Euclidean distance is computed by the method of constrained optimization for each of the individual lines. An arbitrary point (x,y) is assigned to define a distance from the demand point to a street selected one-at-time. For example, in figure 20 for the street of Jimenez a point (x,y) is chosen on the street. Once the x or the y coordinate is selected the respective y and the x coordinates are obtained by using the equation of the street which is represented as a straight line. There is a linear relationship between the x and y values for any particular street. The bound on the street of Jimenez is shown using the coordinates (Lx,Ly) and (Ux,Uy). Thus this is also a bound on the coordinate (x,y).

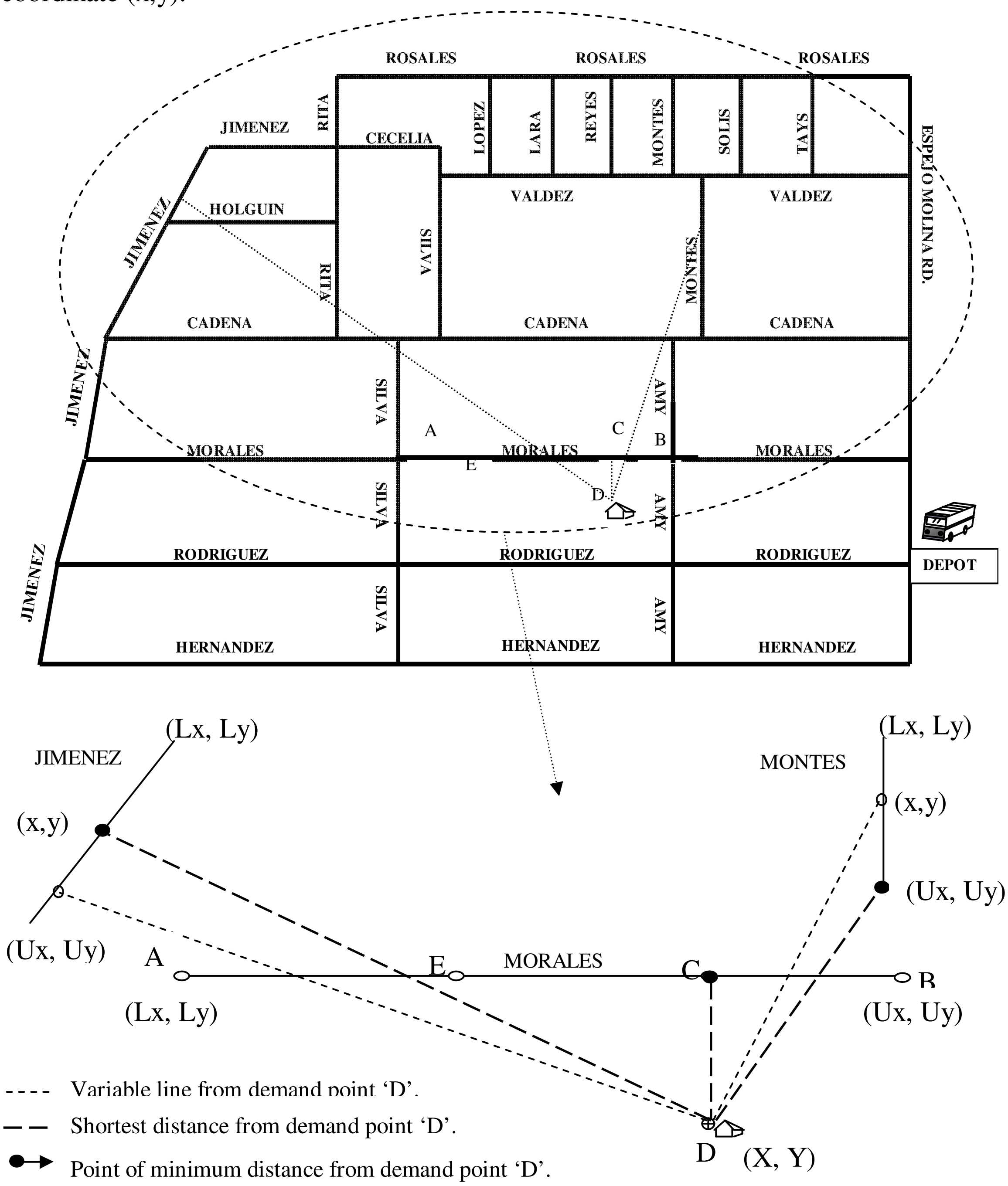


Figure 21: Point D is the location of the request for pick up or drop off on AB and points C is the projected point on the line or street of Morales with E being another projected point.

A point on the street of Jimenez (represented by a black dot) is obtained by utilizing the principles of constrained optimization, which gives the Euclidean distance from the demand point to the Jimenez Street. Similarly there are points identified on the Montes Street and Morales Street (again represented by a solid black dot) that give the minimum distance from the demand point ‘D’ to the streets. The obtained minimum distance and the coordinates on the street that give the minimum distance from the demand point are recorded and compiled in the form of an array or list. Once the entire set of minimum distances and the coordinates corresponding to these distances are included in the array, the street that gives the minimum of minimum distances is selected along with the corresponding coordinate. Thus in this manner a projected point is identified on a street corresponding to a demand point ‘D’.

In essence, once a customer wants to use the bus service, he travels or walks from his designated position (say, from his house or a shop) to the nearest possible point on the street. Thus a typical output of this assignment procedure in MATLAB output plot would look like the one shown below in figure 22 with triangles representing the actual request location and the dots representing the projected request. In the figure 22 below the ‘dots’ appear as aligned into several straight lines which are streets with triangular request locations scattered uniformly.

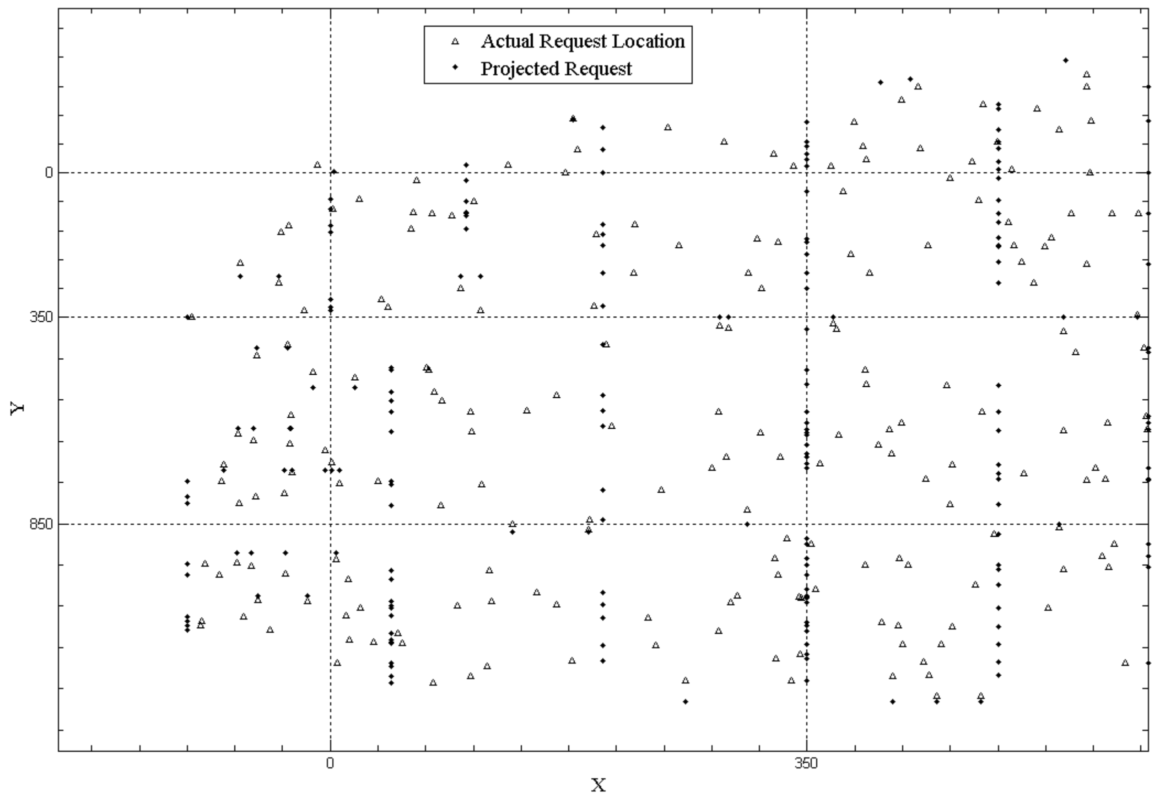


Figure 22: Projected requests and actual request location over El Cenizo area.

Appending Sets of New Nodes

As discussed in the previous section a projected demand point now exists on the nearest street with a lower and an upper bound. Now the next demand point that pops up could also be projected on the same street as the previous one. Thus there could be several situations where a given street has two or more projected demand points on it. These projected nodes are defined by a number and represented in the form of an array or list with every node having a well defined neighbor. This helps in creating another array of distances between one node and the other. It must be noted that creation of these arrays simplifies the procedure for finding the shortest path from one projected point to another. This is done by the use of Dijkstra's algorithm which requires the node-to-node distance as input. The Dijkstra's algorithm finds the shortest paths from the start vertex to all vertices in the network having several nodes.

Dijkstra's algorithm can be expressed formally as follows (30).

```
Dijkstra Algorithm (graph G, vertex v0)
{
  S={v0}
  For i = 1 to n
     DT[i] = C[v0,i]
  For i = 1 to n-1
     Choose a vertex w in V-S such that DT[w] is minimum
     Add w to S
     For each vertex v in V-S
          DT[v] = min(DT[v], DT[w] + C[w,v])
}
```

where,

G - arbitrary connected graph

v0 - is the initial beginning vertex

V - is the set of all vertices in the graph G

S - set of all vertices with permanent labels

n - number of vertices in G

DT - set of distances to v0

C - set of edges in G

Thus in figure 21 the existing nodes A and B of the Morales Street of El Cenizo are appended by the projected demand point C for D on the street. This also means that the earlier existing direct link between the two extreme points of the line (for example line AB) was replaced temporarily to create two sets of lines formed by the projected demand point with its neighbors ‘A’ and ‘B’. The new straight lines created are the lines AC and CB with CD being the shortest distance from demand point D to the line AB. As more and more projected demand points are formed they might be projected on the same straight line. Thus a street can have more than one demand point to serve. The entire procedure is repeated for all the sets of the demand points that the transit agency might have. These demand points are located on the streets with a (x, y) coordinates. To successfully implement the simulation strategy three arrays are needed. In the simulation, an attempt is made to reduce time complexity when implanting the shortest path algorithms over the network of streets and nodes. Thus, the use of sparse matrix becomes convenient. In mathematics sparse matrices are used to couple two elements together. In our simulation these elements are the nodes created by the projected demand points on the streets. However for defining node-to-node distances in our simulation we need just a single sparse matrix. This is ensured by creating three different arrays which serve as inputs to creating a general matrix defined by ‘G’.

The sparse matrix defined by ‘S’ could be created by using the general matrix. The first array consists of the node identities in sequence that uniquely identifies each and every node with a (x, y) coordinate. The node elements in this array would be repeated as many times as the number of neighbors it has. For example, as illustrated in figure 23 below, a node having three neighbors could be repeated three times in the first array. Or if it has two neighbors then it’s repeated twice. The second array then consists of the neighbors of the nodes in the first array. The third array has elements as distances between the corresponding nodes in the first and the second array. In figure 23 below, N1, N2 and N3 are nodes and D1, D2 and D3 are the direct distances between the nodes.

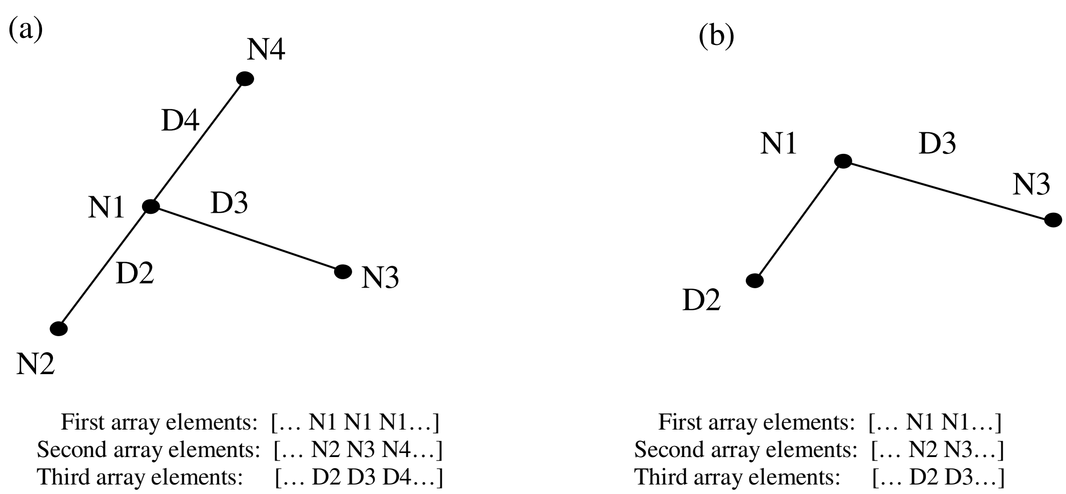
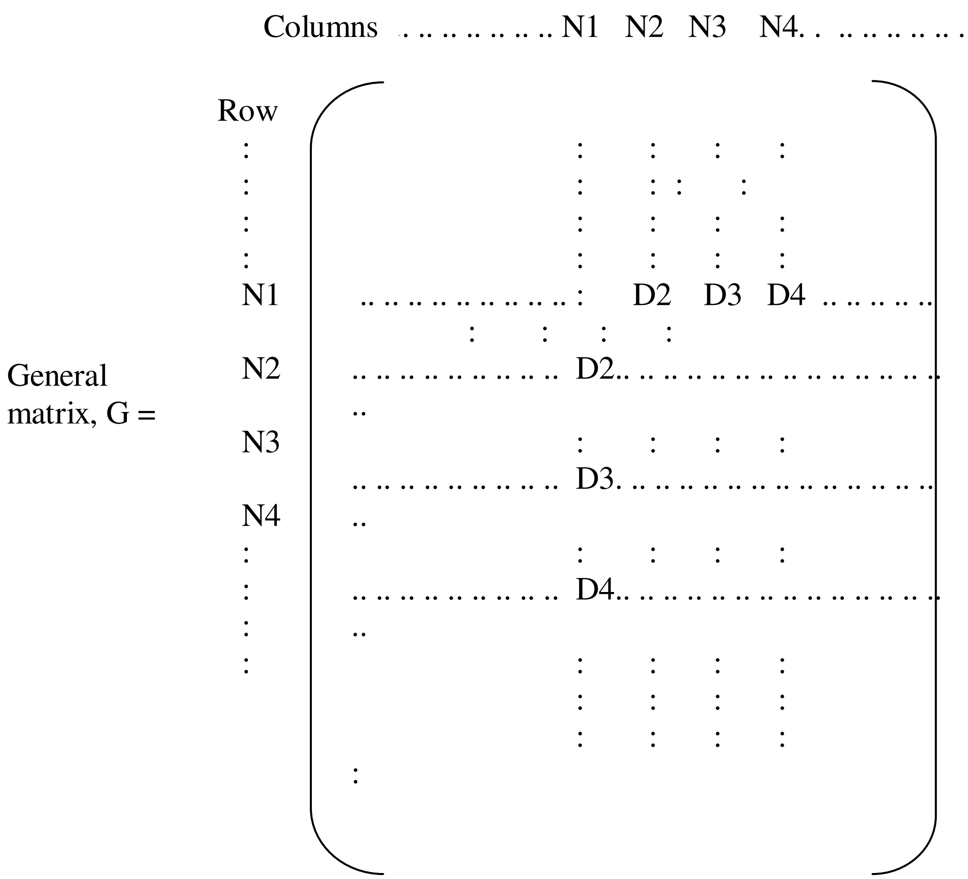


Figure 23: Array representation for creating the sparse matrix.

These inputs as three arrays create a sparse matrix using the elements in the first array as its columns and the second array elements are used as the columns. The elements of the sparse matrix are the elements of the third array. For example, corresponding to the arrays in figure 23 (a), we have a general matrix 'G' as illustrated below:



The sparse matrix form 'S' of the above general matrix 'M' would yield 'S' as

(N2, N1) = D2
(N3, N1) = D3
(N4, N1) = D4
(N1, N2) = D2
(N1, N3) = D3

$$(N1, N4) = D4$$

The elements of the sparse matrix are sorted by columns, reflecting the internal data structure. This principle of creating a sparse matrix is applied in our simulation as well. We have a master sparse matrix which remains unchanged throughout the simulation. This master sparse matrix consists of the node-to-node information of the original set of street networks of El Cenizo. This information is essentially the node identity number and the distance between each of the nodes neighbors. The new nodes which are created by the projected demand points are appended to the existing master sparse matrix. At the end of every simulation the master sparse matrix is set to its original state for use in the next simulation.

Trip Scheduling

The street networks of El Cenizo serve as a good example for performing the analysis of the study represented by a large number of nodes formed by the straight and oblique streets. Even the residents living beyond the outskirts of El Cenizo had their houses close to the outer streets and could be projected easily to the nearest one. A very small number of houses were too far from the outer streets.

Problem Definition

A transit bus is assigned for pick up/drop off starting from the depot to the customer demand points. The bus would stop at each point just once and in a manner to cover all the points in its way back to the depot. This is a TSP problem with the additional time constraint that the vehicle needs to be back at the depot every given interval (cycle length). As mentioned, the distance and the path between any two consecutive nodes/elements of the list of nodes were computed using the Dijkstra's algorithm.

There are a number of algorithmic approaches that could suggest a possible route that the bus should follow during its journey, such as the local search algorithm, the neighborhood search techniques and insertion heuristics that perform the task of deciding the most efficient sequence of the order of requests for service. The local search algorithm, for example, is a metaheuristic approach for solving optimization problems which are computationally hard. Local search is used on maximizing problems that can be formulated by using a criterion among a number of solutions. These solutions are particularly known as the candidate solutions. Local search algorithms use the search space looking for a solution by moving from one solution to another until a solution which could be optimal is found. If the optimal solution is still at large, time bound criteria is used to converge the search. There are lists of criteria that relate to various aspects of an algorithm performance. These criteria decide the evaluation of any heuristic method based algorithm on running time, quality of solution, ease of implementation, robustness and flexibility.

However, the insertion heuristic has proven to be a popular method for solving a variety of vehicle routing and scheduling problems, since it guarantees a good solution with less computational time when the numbers of nodes present are numerous, and has thus been adopted in this research study for simulation.

The insertion heuristic algorithm involves a list or array estimation in MATLAB that would assign a route for the transit bus. The shortest distance for example 'DT' obtained using the Dijkstra's algorithm discussed earlier is used as input to the insertion heuristic algorithm as 'Distance (i, j)' with 'i' and 'j' being the two nodes. Insertion heuristics evaluates and computes a sequence of the order of the requests for using the bus service in a given bus service time interval. The output is stored in the form of a list.

The algorithm for the insertion heuristic is outlined below [10] where p^*, i, j and r are variables

```
N = set of unassigned customers
R = set of routes; contains the empty route;
initially contains only the empty route
while N ≠ j do
p* = -∞
for j ∈ N do
 for r ∈ R do
  for (i-1,i) ∈ r do
   if Feasible (i, j) and Distance (i, j) > p*
     r* = r
     i* = i
     j* = j
     p* = Distance (i, j)
   end if
  end for
 end for
end for
Insert (i*, j*)
N = N \ j*
Update (r*)
end while
```

The insertion heuristic analyzes the feasibility and total distance if a node is inserted between two existing nodes. At the beginning there are only two nodes both being the depot locations represented as start point and the end point of the bus trip. The projected demand nodes as they pop up are inserted between the start and end point (depots) in the corresponding time windows. The feasibility is evaluated depending on the time taken to serve the node within a given time window of the bus service. If the trip is feasible the insertion heuristic gives an order of service. This is performed for the next node that appears in the order it appeared in a given time frame. The second node is inserted between two such nodes that minimize the total distance for the scheduled trip. This procedure is repeated for the entire set of projected demand nodes that have appeared. As an example, an output form of the procedure described above is [DP 4 5 1 7 DP] which is in the form of a list. This means that the transit bus starts its journey from the point DP (depot) and comes back at DP via nodes 4,5,1,7 in the same order. The cost of this path is simply the total distance the bus has to travel from the depot (DP) via the four nodes and back to the depot. Assuming that this is the order of scheduling obtained using insertion heuristic for a given time window of bus service, the route the bus would utilize is decided starting from the depot and ending at the depot through nodes 4 => 5=> 1=>7. The example discussed above is executed for any route selection scheme needed in the simulations.

Saturation Point Estimation

In this section the principles of the insertion heuristics described earlier are utilized for our actual simulation. A set of demand points or requests for using the transit bus service are created and sorted for pick up and drop off using the insertion heuristic approach. The total requests used as input was varied from 20 passengers up to 280 passengers who would need a ride and to be picked up and dropped off from their points of request. A stop time of 30 seconds is assumed for the bus at the depot and the stop where a passenger gets on or off the bus. A uniform speed of 20 miles per hour is assumed for the speed of the transit bus as the area of El Cenizo is a residential one. The bus service time interval is assumed to be 30 minutes to start with. This allows us to obtain an estimate of the number of passengers that the bus can service easily by picking them up from their nearest street and dropping them off at the depot or vice versa. There were 12 replications performed for each of the number of customers. The margin of error for these replications was mostly found to be less than 0.05 for all the data sets than for lesser number of replications assuming a 95% confidence level. The assumptions underlying the simulation input have been compiled below.

<u>Simulation Assumptions for saturation point estimation</u>

Service network: *El Cenizo street network*

Depot Location: *Intersecting of streets Espejo Molina Rd. and Rodriguez.*

Total Number of Customers: *Variable (range 20 -280)*

Vehicle speed: *20 mph*

Request time distribution within each bus service interval: *Uniformly Random*

Fleet size: *1*

Vehicle capacity: *Infinite*

Time Taken for a Pick up: *30 seconds*

Time Taken for a Drop off: *30 seconds*

Dwell time at the depot before leaving for pick-up/drop-off: *30 seconds*

Cycle length or the bus service time interval: *30 minutes*

Each individual passenger has the freedom to choose any time between 6 am to 8 pm for making a request and this too is decided by the cdfs as shown previously in figure 18 and 19. If the choice of a random number does not give a departure or arrival time within 6 am to 8 pm another random number is generated so that finally his service request falls between 6 am to 8 pm. This is done primarily because it is based on the assumption that once the requests for using the bus service are ready, the transit agency would start its operation of dispatching a bus from 6:30 am onwards till 8:30 pm. Thus this process is repeated for entire range of passengers from 20 to 280 in number with an interval of 20. An outline of the above discussion is presented below in figure 24.

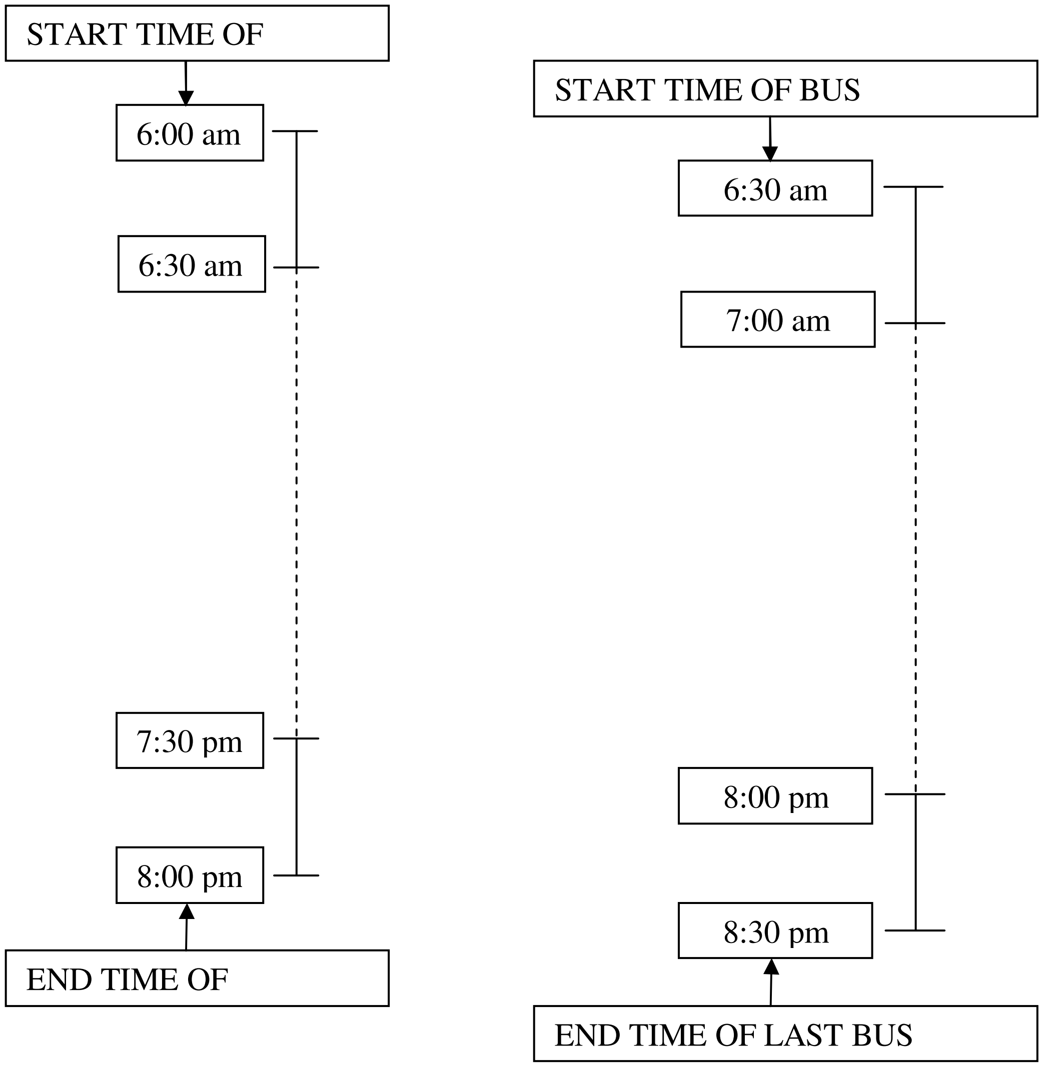


Figure 24: Schedule representation

The graph is plotted for the average waiting time versus the number of passengers who made the advance requests for using the transit service. A point known as the saturation point is identified where the system becomes unstable with a sudden rise in the average waiting time in the graph. This means that a single demand responsive vehicle is not able to serve the increasing demand and the corresponding queues become unstable. Graph in figure 25 shows this saturation point to be around 150 numbers of passengers.

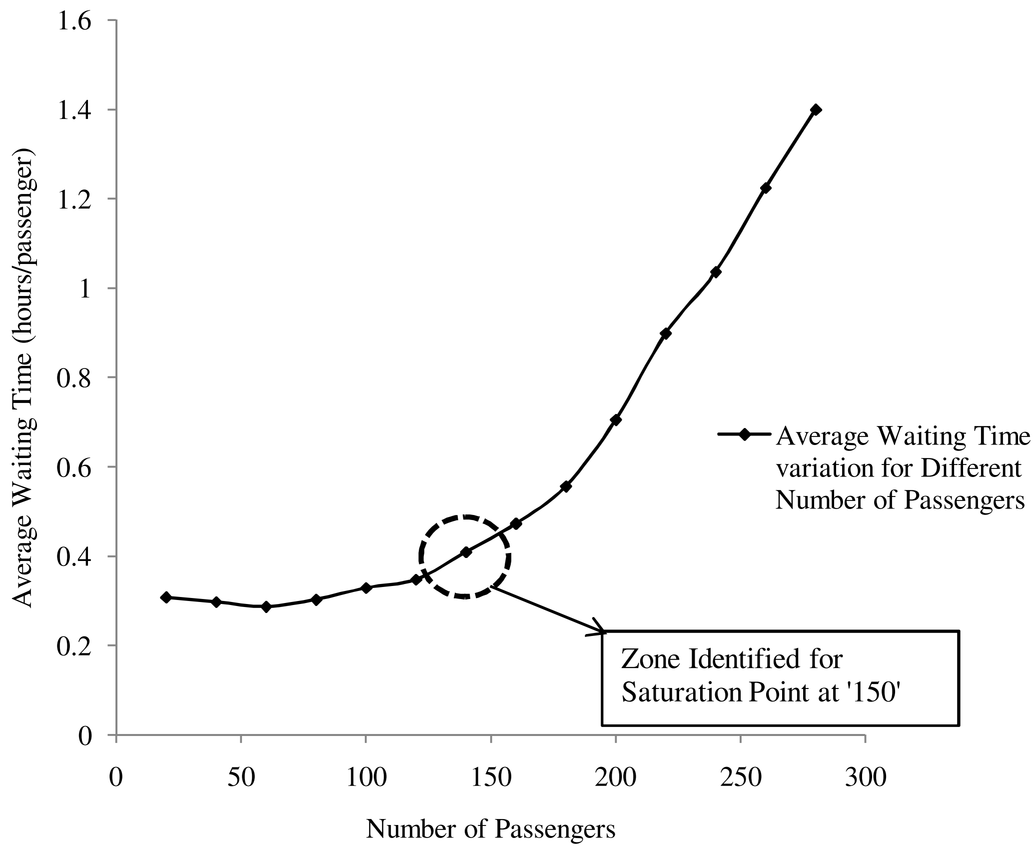


Figure 25: Saturation point estimation using average waiting time versus number of passengers using the transit bus.

The analysis is further extended to get a big picture of the proposed demand responsive system. The U.S. Census Bureau gives total households of 730 for the residential city of El Cenizo. By using the trip rates obtained from our survey data, the trips for entire households of El Cenizo would be approximately 1,834. These trips would consist mainly of the work trips and school trips. Our proposed demand responsive system can handle 150 daily trips (saturation point), which corresponds to approximately 8% of trips generated in El Cenizo. This percentage is very high compared to a 3.81% of combined commuters using the buses, rail and transit in the United States as per the 2005 estimates of the Bureau of Transportation Statistics. We could conclude that a single vehicle DRT service would suffice for serving the transportation needs of El Cenizo, assuming that residents' behavior would fall within national statistics.We would, however, expect a transit usage above average for Colonias because of the poverty level (less private cars) and because of the demand responsive characteristic of the proposed service.

In figure 26 the average riding time is plotted. It is observed that the values of the average riding time is relatively low compared to the average waiting time values for the same set of numbers of passengers.

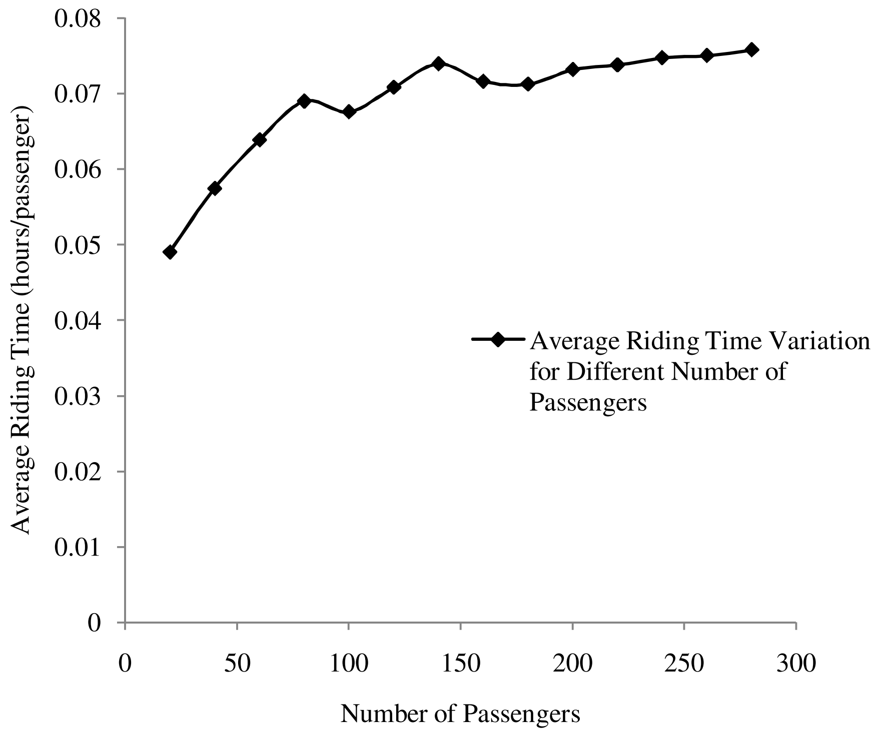


Figure 26: The average riding time variation with the total number of passengers using the transit bus.

Estimating Optimum Bus Service Time Interval

The bus service time interval or the cycle length can make a considerable difference in the waiting time or the riding time for the passengers. Three sets of simulations are carried out by restricting the bus service time interval or cycle length at several fixed values and using the total number of passengers such as 80, 100 and 120 as input for each of the three sets. The charts in figure 26 and figure 27 represent the average waiting time and the average riding time variation for a series of bus service time intervals. The graphs have been plotted for these total numbers of passengers assuming they use the bus service on a given day. The simulation assumptions for saturation point estimation remain the same as for the saturation point previously estimated except for the cycle length and the total number of customers.

The total numbers of passengers for this part of simulation (namely 80, 100 and 120) have been chosen such that they lie below the approximate saturation point of 150 estimated using the curve in figure 25. Figure 27 shows the variation of average passenger waiting time with various bus service time intervals obtained using the simulation results. The bus service time interval varies from 7.75 minutes to 12 minutes for every 15 seconds. And from 12 minute to 50 minutes the bus service time interval varies for every 4 minutes or 240 seconds. The minimum time interval of 7.75 minutes is selected to start with primarily due to the fact that this cycle length happens to be the minimum time the bus could take to traverse from the depot to the farthest demand point possible in a single pick up or drop off of a passenger. The upper limit on the bus service interval is fixed at 50 minutes as the average waiting time starts to increase beyond 22 minutes for all the total number of passengers chosen for the simulation. In other words the 50 minute bus service time interval serves as the upper limit for the cycle length.

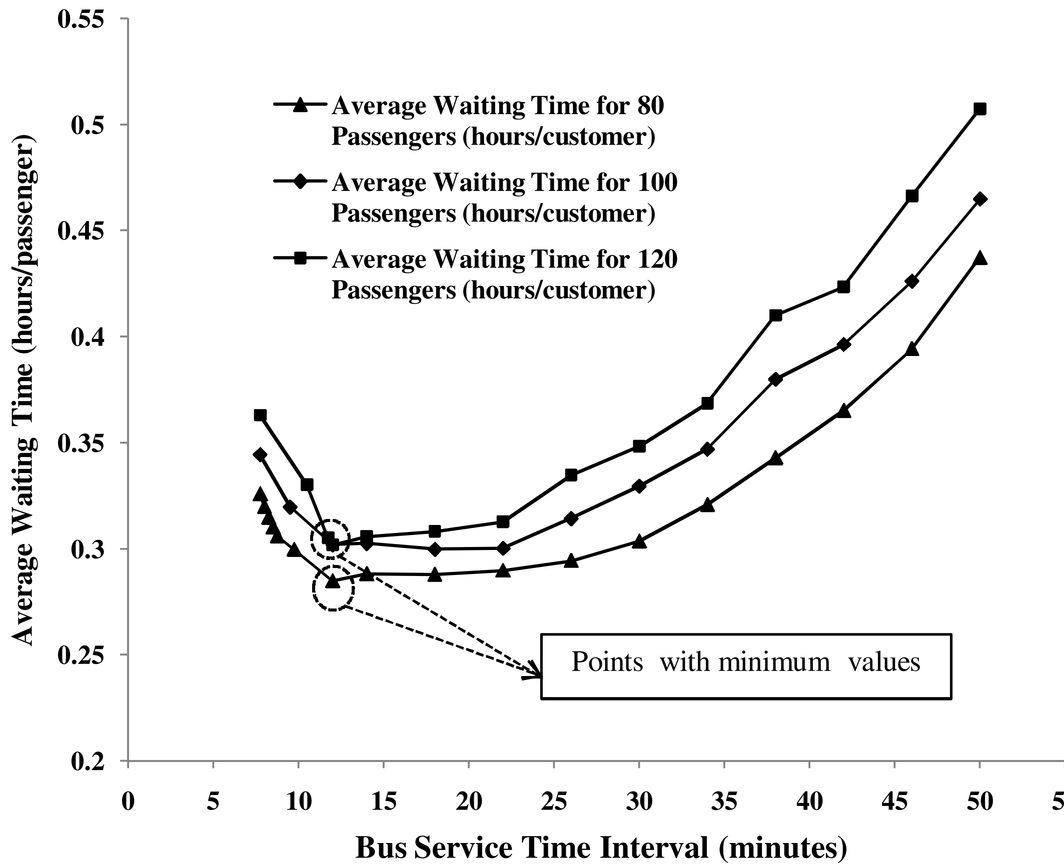


Figure 27: The average waiting time variation versus the bus service time interval.

It is evident in all three curves from the graph in figure 27 that there is a sharp decrease in the average waiting time from 7.75 minutes of bus service time interval to 12 minutes of bus service time interval. Then, it becomes steady with a slight rise till 20 minute interval and then it rises sharply beyond the 20 minute interval to 50 minute interval. In fact, with too low service time interval, there is too much time spent to come back to the depot and no time for an efficient ridesharing; with too high time interval, customers wait too much time waiting for service. All curves show the presence of a minimum value which would be desirable for optimal service quality. The graphical output of figure 27 is summarized in the table 2 below for various number of passengers used in the simulation.

Table 2: Minimum average waiting time and bus service time interval

SN	**Number of Passengers**	**Minimum average waiting time (hours/passenger)**	**Bus service time interval (minutes)**
1	80	0.28	10-12
2	100	0.30	10-12.5
3	120	0.30	12.5

Similar simulations were carried out to observe the average riding time variations. The graph in figure 28 shows the average riding time variation with the bus service time interval. And there is an increase in the average riding time from 10 minutes onwards though this increase is undulating over the 10 to 50 minute service time interval.

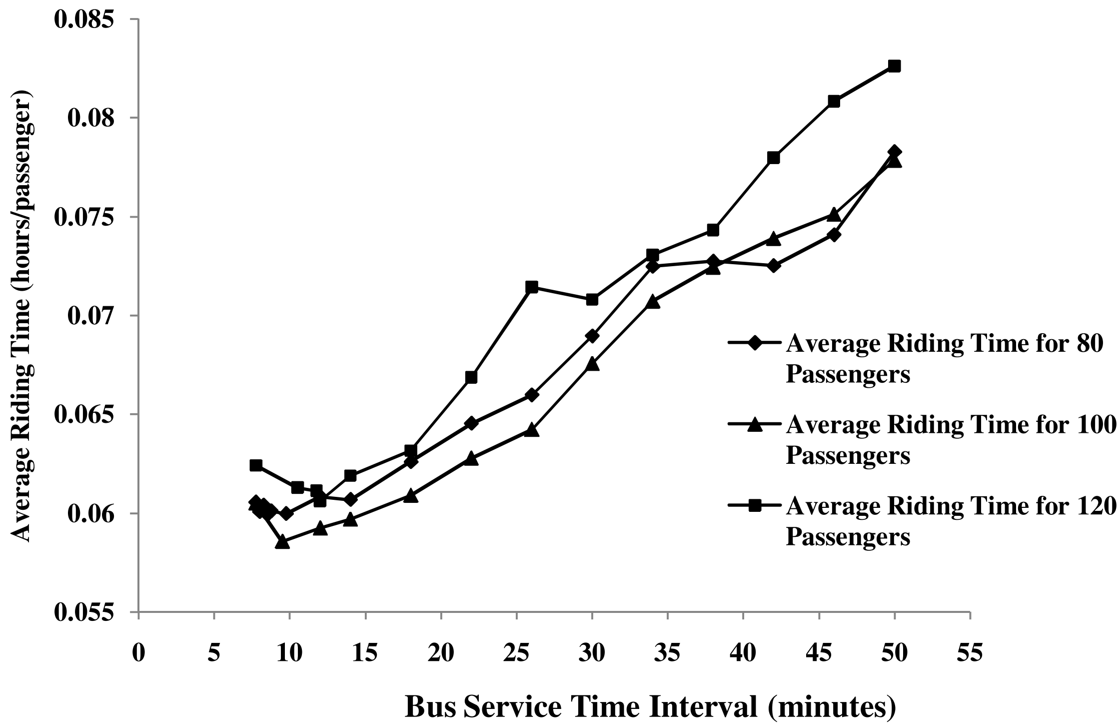


Figure 28: The average riding time variation versus the bus service time interval.

Cost Function

One of the important characteristics of the transportation demand is the aggregation of the decisions of the trips within a given area. The user demand for a service could be predicted by modeling the individual trip makers and summing up all trip makers to obtain the aggregate demand predictions. This is all the more important in the planning for evaluation purposes. The most commonly used process for evaluating an individual