

# A Simulation Study to Derive the Optimal Cycle Length for Feeder Transit Services

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## BIOSKETCHES

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Dr. Luca Quadrifoglio graduated with the Laurea in Chemical Engineering (1996) from the Politecnico of Milan and worked for Snamprogetti for five years. He then received his M.S. in Engineering Management (2002) and Ph.D. (2005) degrees from the Daniel J. Epstein Department of Industrial and Systems Engineering at USC in Los Angeles, California. Then he worked as a Postdoctoral Research Associate at the USC's DHS CREATE until August 2006, when he joined the Faculty of the Zachry Department of Civil Engineering at Texas A&M University in College Station, Texas. Dr. Quadrifoglio published several papers in top rated Journals, won the 2006 Pritsker Doctoral Dissertation Award (3<sup>rd</sup> place) and the 2004 CUTC National Student Award for best publication in Science and Technology.

His research interests are related to the broad field of Operations Research and include Transportation Systems Modeling and Design, Performance/Risk/Decision Analysis, Scheduling Algorithms, Innovative Transit/Logistics Solutions.

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## ABSTRACT

In this paper, we present a simulation study to evaluate the capacity and the optimum service cycle time of a demand responsive transit “feeder” service within the colonia of El Cenizo, TX. Demand data are taken from a survey questionnaire conducted to evaluate the existing travel patterns and the potential demand for a feeder service. Results showed that a single shuttle would be able to comfortably serve 150 passengers/day and that a fleet of 7-8 vehicles would be needed to serve the residential area. 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, but also other residential areas, especially those with demographics and geometry similar to our target area of El Cenizo.

*Keywords: demand responsive transit; feeder transit service; optimal cycle length; transit planning; underprivileged communities*

## INTRODUCTION

Colonias are unincorporated settlements outside city boundaries along the US – Mexico border. Texas not only has the largest number of colonias, but also the highest colonia population, more than 400,000 people. Colonias are underprivileged communities whose residents are facing many fundamental problems. For example, most of the housing is not built according to code standards and lack indoor bathrooms or plumbing; there is a lack of a potable water supply and 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 bad, ranging from 20% to 60%. 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 travel 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. In addition, most residents do not own a private vehicle and the existing public transportation system is inadequate. 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.

El Cenizo, adjacent to the Rio Grande River, is a colonia located in Webb County, TX, about 15 miles south of Laredo. There are some transportation services currently provided to El Cenizo's residents. El Aguilar, operated by the Laredo Webb County Community Action Agency, is one of the transportation services operating in this colonia. Medical transportation is provided by LeFleur Transportation and managed by TxDOT-MTP (Medical Transportation Program). There are a couple of other transportation services such as the vans provided by the Texas A&M University Center for Housing and Urban Development (CHUD) and school buses provided by the United Independent School District, a school district headquartered in Laredo. These 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. Consequently, most of them have no means of acceptable transportation.

There are two main objectives that govern the present research study. (I) The first is to analyze the travel demand patterns in El Cenizo and thereby perform a feasibility/design study for the possible implementation of a demand responsive "feeder" transit system in the El Cenizo area. (II) The second objective of this paper is to estimate by simulation analyses the best service time interval between consecutive departures from the terminal (cycle length) in order to maximize the service quality provided to customers, and minimize the disutility function expressed as a weighed sum of travel time and waiting time.

The primary data source used for this analysis is a travel survey conducted in El Cenizo, which has been selected as a representative colonia for this study as the area is easily accessible for collecting data and also it forms a very good representation of a colonia found along the US-Mexico border in terms of demographics.

The results from this study could improve the quality of life of colonias' residents by enhancing their mobility and efficiently responding to their present essential transportation needs. The results could be eventually used to incorporate an efficient transit system also in another area having similar geometry and demographics.

#### LITERATURE REVIEW

A general lack of a concrete transportation system in the colonias encouraged us to perform several literature reviews to identify the status quo of the transportation service in these areas. The Burke et al. (2005) analysis of the TAMU 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. Kuhn and Jasek (2006) 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.

There has been some work on assessing the importance and need of public transportation for rural areas, especially with low-income residents, such as the colonias. The Users' Manual for Assessing Service-Delivery Systems for Rural Passenger Transportation (Burkhardt, 1995) 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. 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. However, a need to cater to a relatively low demand density area for efficient service standards is still missing. Also, there are no tools yet to assess the performance measures of a transit system based on cycle length of the shuttle trips.

A right choice of a transit system, whose performance measure and popularity among its users could be assessed easily is also explored. Thakuriah et al. (2005) have found that an 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 (Thakuriah et al., 2006). It was shown that demand-responsive services are most likely to receive the highest ranking among all services.

The use of simulation for evaluating transit systems has been extensively employed. Lipmann et al.

(2002) and Hauptmeier et al. (2000) evaluated the performance of DRT systems taking traffic conditions into account. Feuerstein and Stougie (2001) and Bailey et al. (1987) have investigated changes of performance using different number of vehicles for the dial-a-ride system. Haghani and Banihashemi (2002) studied the relationship between efficiency of vehicles and town size. McLeod (2007) used the concept of estimating bus passenger waiting times from incomplete bus arrivals data. Mishalani et al. (2006) evaluated the impact of real-time bus arrival information using the passenger wait time perceptions at bus stops. Chien et al. (2000) developed a CORSIM-based microscopic simulation model which could simulate bus operations on transit routes.

Most scheduling problems such as those involved in demand responsive transit fall under the Traveling Salesman Problem (TSP) category which is known to be a NP-hard problem (very hard to solve to optimality). An important purpose of simulation as a tool is to allow reaching better solutions, hopefully as close as possible to optimality. Studies on artificial intelligence aids to improve the performance of scheduling transit services are various. Barr et al. (1995) has provided reporting guidelines for computational experiments to test heuristic methods. Yepes et al. (2006) used three step local search algorithm for the vehicle routing problem with a heterogeneous fleet of vehicles and soft time windows. Quadrioglio et al. (2007) 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. In another work by Aldaihani et al. (2004) an analytical model was

developed which aids decision-makers in designing a hybrid grid network integrating a flexible demand responsive service with a fixed route service. Campbell et al. (2004) developed an efficient insertion heuristics for vehicle routing and scheduling problems. Jaw et al. (1986) 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.

In the latter part of the paper we study the disutility value of using a public transport system. In this regard, we identified some 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 (Litman, 2008). Quiroga et al. (1998) performed the travel time

studies by using global positioning system (GPS) and geographic information system (GIS) technologies.

## RESEARCH METHODOLOGY

The methodology undertaken to perform the research study and fulfill our intended objectives are primarily based on the necessary steps to perform a realistic simulation analysis. More in particular, Figure 1 shows the steps in a schematic way. The dashed rectangle includes the necessary steps to develop input data for the simulation model; namely: Questionnaire Design, Data Collection, Data Analysis and Demand Modeling. These have been described and carried out jointly in the next section. Once the input data have been defined, they will serve for performing the runs of the simulation analyses to achieve both our intended objectives (I) and (II).

The Simulation Model Development and Validation are described in details in the following sections and are applicable to both our objectives (I) and (II). The last two blocks (Runs and Results) have instead been performed in parallel to achieve objectives (I) and (II) respectively and are described in the last two sections before the conclusions.

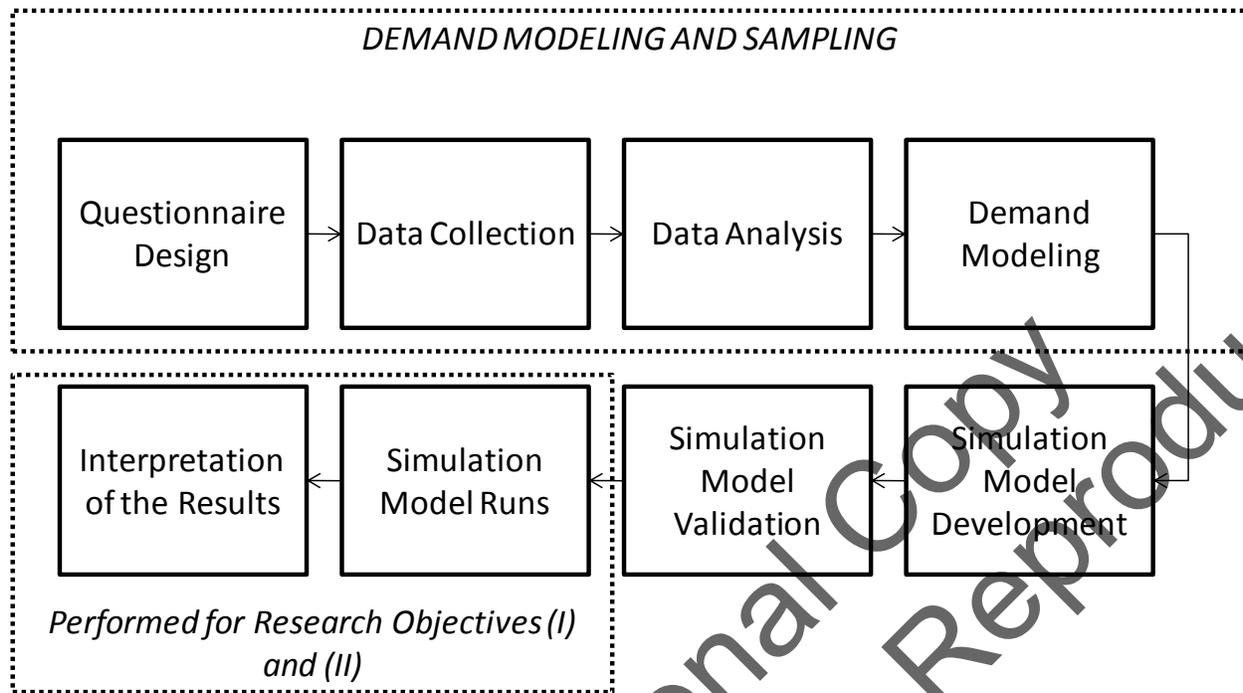


Figure 1: Process flow diagram - Methodology

## DEMAND MODELING AND SAMPLING

### Questionnaire Design

The survey questions were primarily intended to get an idea of the travel patterns of El Cenizo householders. The needs for this research study were primarily to obtain time distributions of departure/arrival trips from El Cenizo. The developed questionnaire (in appendix) also collected other information not specifically useful for this research, but valuable for other purposes. Thus, the questionnaire was primarily divided into two parts. The first part was focused towards obtaining the basic data related to the householders such as number of members in the household, their age and the kind of vehicle they owned for commuting or traveling. The second part of the questionnaire was aimed to obtain the travel demand pattern of the householders. In this part, questions were asked about the time of leaving and returning to their homes, the mode used to

commute and the number of trips that were made per month. Questions regarding a householder's frequency of weekly trips to grocery stores or health related trips to hospitals were also asked in this part. The questionnaire was tested with a group of graduate students within our department.

Our target was to achieve as much information as possible to carry out analysis of the of departure and arrival timings of the El Cenizo residents for work and school trips. A resident's departure time is defined as the time at which he/she leaves his/her home for work or school. Similarly, arrival time is defined as the time of return to home from work or school. Given a large population size and an impractical idea of surveying every household, we statistically determined that under the assumption of a 5% margin of error, the number of households in El Cenizo being 730, a minimum of 250 survey questionnaires would suffice for a 95% confidence level.

### Data collection

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. Homes were randomly selected. We collected 250 completed survey questionnaires for our analyses. We summarize the survey results in the following and the detail demographic information of the survey can be found in the chapter four of the report (Quadrioglio et al., 2009). First, the average household size in El Cenizo is 4.25 persons and the number of private vehicles per household is 1.13. The departure and return time of work trips are mainly during 6 to 8 a.m. and 5 to 8 p.m. respectively; the

departure and return time of school trips are mainly during 6 to 9 a.m. and 3 to 5 p.m. respectively. Private vehicles are most used by trips of work, health, and groceries. The only exception is that nearly half of the school trips use the school buses. The majority of all trips (excluding school trips) travel to Laredo City, which is the regional center of that area.

### Data Analysis

The survey data obtained was used to plot the data for the arrival and departure times as shown in Figure 2 and Figure 3. Figure 2 shows the data of the school trips and Figure 3 shows the data for the work trips.



Figure 2: Probability density function (PDF); school trips.

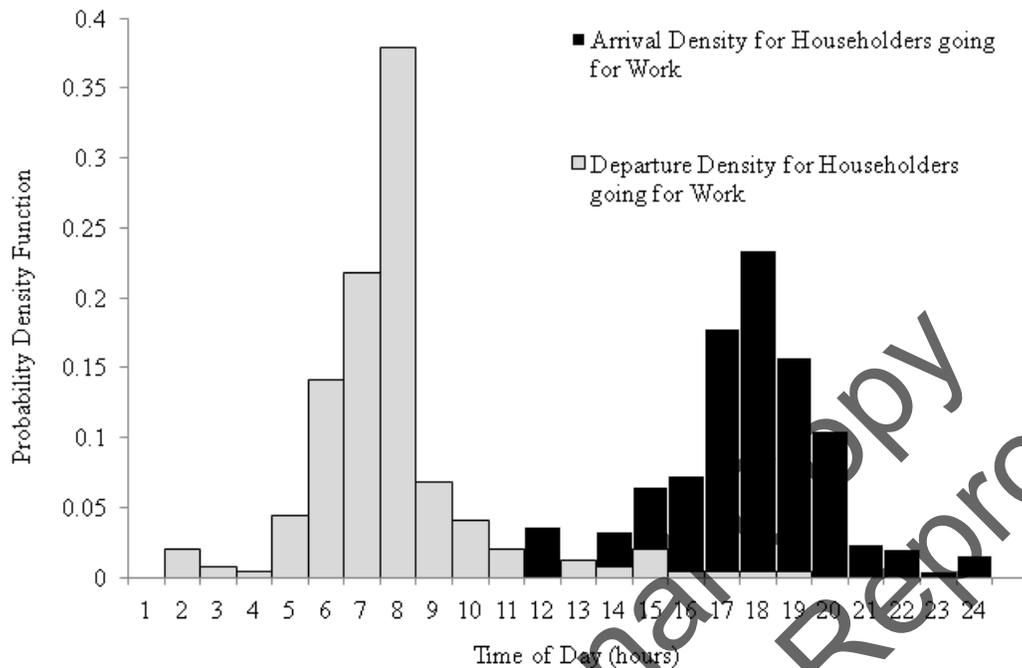


Figure 3: Probability density function (PDF); work trips.

### Demand modeling

The next step is to fit or construct probability distribution, in accordance to the collected data, which can be used as input for the simulation model. Several known probability distribution functions (PDF) were tested to fit the obtained demand data from the survey. The distribution functions used for checking work trips data were Log-Logistic, Rician, Weibull, Lognormal, Extreme Value, Nakagami, and Logistic. The visual test for the available data with these distributions appeared to fit satisfactorily. However, a 95% Chi-Square test failed. This simply meant that no existing theoretical PDF fit our data.

Thus, a custom distribution was constructed. A manual sketch for defining a distribution is performed

on the cumulative density functions for PDF graphs for school goers and work trips. This generalized distribution is a linear approximation of the actual departure and arrival times. The assumed cumulative density function obtained through piecewise linearization is shown in Figure 4 and Figure 5 along with the actual existing cumulative density functions. The Chi-Square tests gave a positive outcome for accepting this customized distribution with the data for survey. This customized manual approach simplified the analysis as in it did not require any parameters to be estimated. These custom distributions were ultimately used to feed our simulation model, developed in MATLAB.

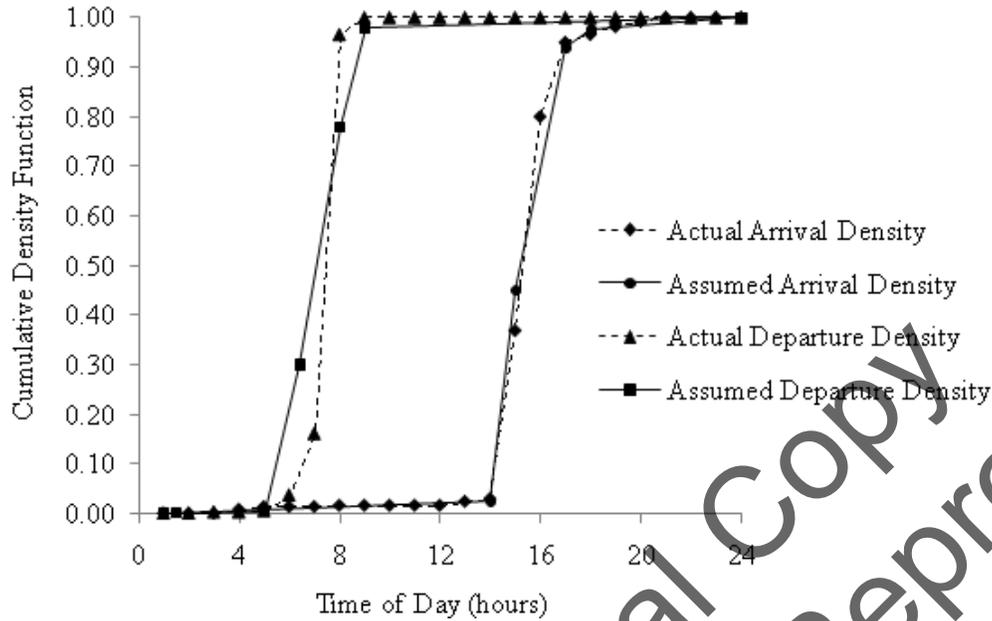


Figure 4: Actual and assumed piecewise linear cumulative density function (CDF) for the school trips.

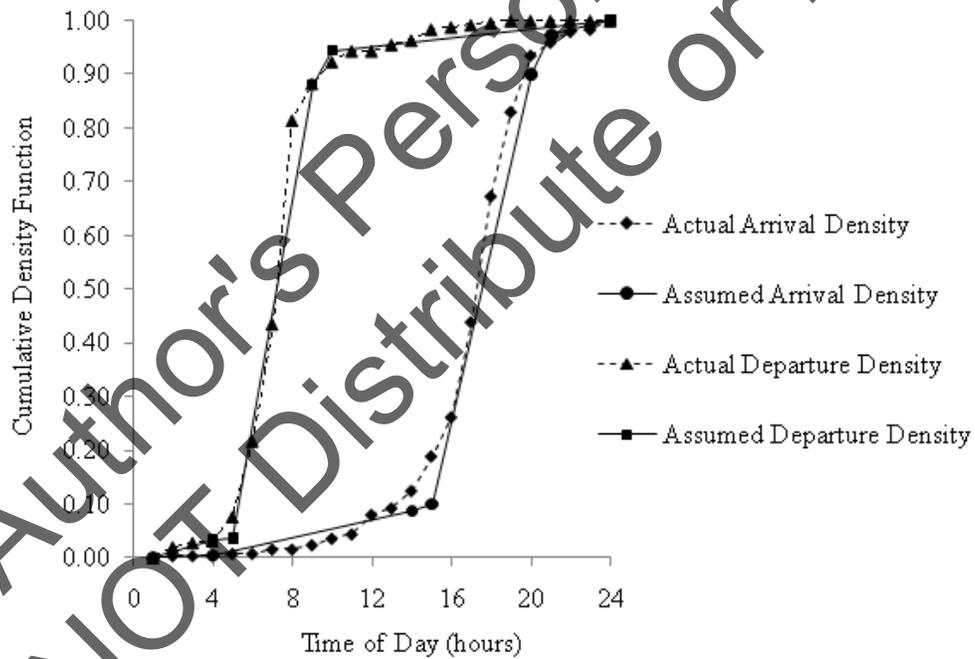


Figure 5: Actual and assumed piecewise linear cumulative density function (CDF) for the work trips.

## SIMULATION MODEL DEVELOPMENT

### Proposed Transportation System and Model

The simulation model was developed in MATLAB and replicated the operations of a Demand Responsive

Transit (DRT) service serving El Cenizo. Passengers call for service to be picked up or dropped off within the area. Vehicles do not operate on a fixed route or on a fixed schedule, but depart from and return to the

connection terminal at constant time intervals. It is a shared ride door-to-terminal (or vice versa) service.

### Assignment of Requests

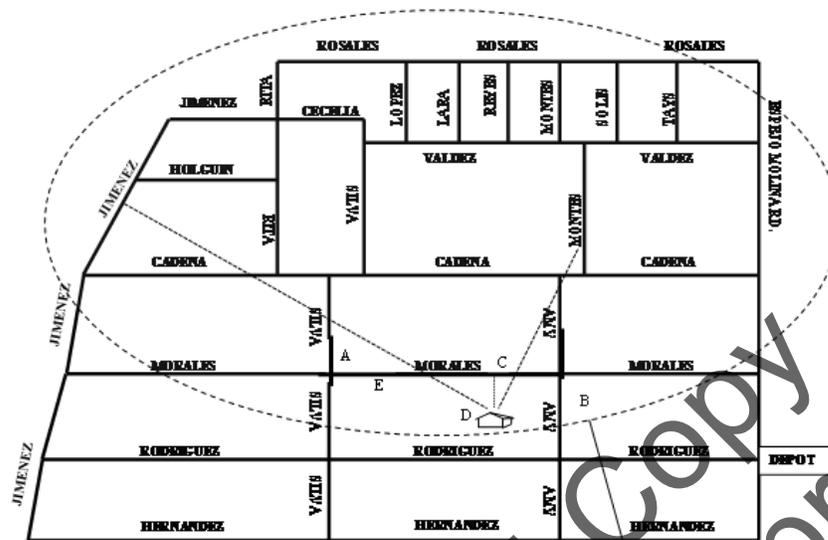
The request times for service are obtained through the customized CDFs in Figure 4 and Figure 5. The location of the demand points are also generated along with their request times and is assumed to be uniformly distributed across the enclosed area of El Cenizo, as the town is quite densely and homogeneously developed for its residents and we have no motive to assume an a priori uneven distribution location-wise. Therefore, passengers may pop up anywhere on the map of El Cenizo. Although it is realistically assumed that a customer is picked up and dropped off at the same place when returning home. 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. Consequently, we have a departure time, an arrival time and the location of individual customers as input for our simulation study. 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 bus or 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. The assignment procedure over the street network of El Cenizo is illustrated through the sketch as shown

below. Point D is the location at which the request is made for pick-up or drop-off and point C is the projected point on the line AB 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.

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.



- Variable line from demand point 'D'.
- Shortest distance from demand point 'D'.
- → Point of minimum distance from demand point 'D'.
- → Point of arbitrary distance from demand point 'D'.

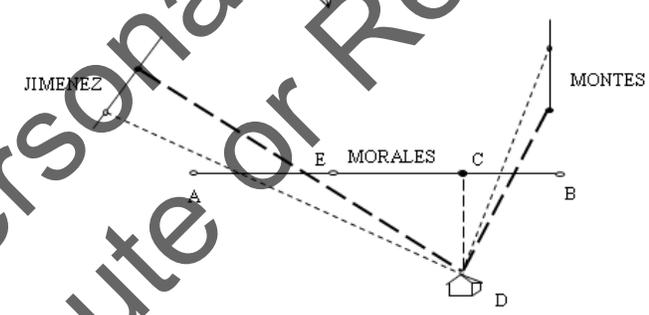


Figure 6: Assignment Example

### Trip Scheduling

The vehicle performing the service 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). The shortest paths between any two 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 (Vanitchakornpong et al., 2008), the

neighborhood search techniques (Bräysy, 2003) and insertion heuristics (Quadrifoglio et al., 2007) that perform the task of deciding the most efficient sequence of the order of requests for service. 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 "inserts" one customer at a time within the vehicle's current schedule to minimize the total distance until there are no feasible insertions to

perform. The assumptions underlying the simulation input have been compiled below.

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 (El Cenizo is a residential area)*

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 (Assumed as initial starting input for cycle length)*

Service: *from 6:30am to 8:30pm*

Number of replications: *12*

Infinite bus capacity is assumed for simplicity in the simulation coding, as it very seldom poses a problem in vehicle routing problems, since time constraints are generally binding much earlier than capacity constraints. Moreover, it is observed that within a constrained cycle length limit and a spatial distribution of the demand locations the bus can pick a maximum of 8-10 customers. In fact, actual capacity of the bus never exceeded reasonable realistic values in our simulation runs.

In the event the bus fails to serve a customer due to high demand levels (during peak hours or because of randomness), the customer will wait to be picked-up or dropped off at the next cycle.

## SIMULATION MODEL VALIDATION

It is generally impossible to carry out model validation procedures completely. This is because some parts of the actual system do not exist for straightforward comparison. The model verification and validation in this paper is concerned with determining if the simulation computer program is working as intended and if there is a good proximity of the simulation model to the actual system. Our model verification and validation efforts included the following steps (Law, 2007):

- a. The model was programmed for simulation and debugged.
- b. For model validation, the following steps procedures were performed.
  1. All model assumptions (such as DRT bus speed, idle time etc.) made were reviewed by the authors multiple times for validity.
  2. Different data sets (such as those generated randomly) were tested for homogeneity and used only if appropriate.
  3. All fitted probability distributions were tested for correctness using the Chi-Square tests.
- c. Model output results were evaluated for reasonableness. For the simulation model proposed we use the most widely used mathematical reasoning. Specifically, we performed three checks in this step:
  1. Our model adopted the inputs such as those for arrival time and departure time for the school trip as well as work trips. The customized cumulative distribution function used as inputs for these arrival and departure times did not reject the null hypothesis that the

data followed from the one actually collected through the survey.

2. Up to a feasible point of 20 customers hand calculations were performed for computing the average waiting time and average riding time (Figure 7 and Figure 8) and was cross checked with the values obtained using the proposed model. There was a total match for the two results.
3. Next, we tested our model for extreme case scenarios such as for an exceptionally high and low bus service time intervals or cycle lengths. It will be later shown (with the help of graph in Figure 8) that for extremely high values of the cycle time intervals the disutility is an increasing function, since the vehicle would spend most of its time performing pick-up/drop-off operations and return to the depot very seldom.. For very low values of the cycle time, close to the minimum feasible value, the service is intuitively not efficient, as only 1 or 2 customers can be served in a trip; the vehicle would spend too much of its time driving to/from the depot, without taking advantage of the ridesharing effect, and the queue of customers would build up causing the average waiting time to increase.

These two intuitive effects would anticipate a convex shape of  $U$ , as the results show. The interesting outcome is to identify the minimum of the curve, representing an estimate of the optimal cycle length representing the least overall disutility function values as expressed through the proposed model.

### **SERVICE DESIGN (Objective I)**

In order to estimate the fleet size needed to serve an area like El Cenizo, the simulation model was used to replicate the operation at various demand level. We run the model with a total demand fluctuating from 20 to 280 passengers per day (at intervals of 20). The simulation output is shown through the graph (Figure 7) plotted for the average waiting time versus the number of passengers who made the advance requests for using the transit service. 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 7 shows this saturation point to be estimated around 150 passengers per day.

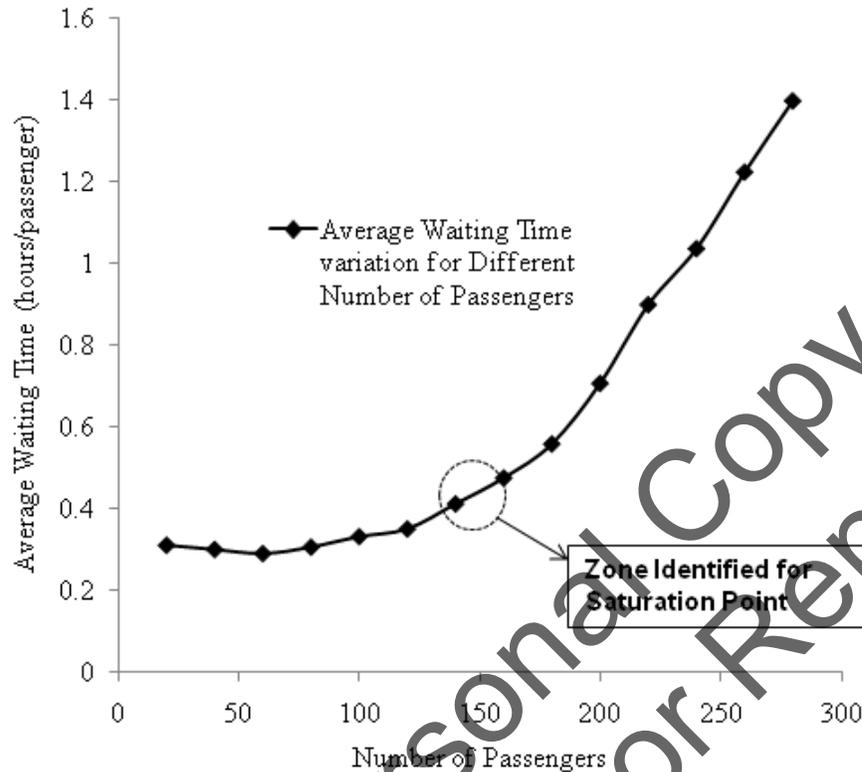


Figure 7: Saturation point estimation.

It is important to understand the computation of this saturation point for further simulation and analysis. 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 or travelers using the buses, rail and transit in the United States as per the 2005 estimates of the Bureau of Transportation Statistics. Assuming that

residents' behavior would fall within national statistics, we could conclude that a single vehicle DRT service would suffice for serving the transportation needs of El Cenizo. We would, however, expect a transit usage above average for Colonias because of the poverty level (less private cars) and because of the more appealing demand responsive characteristic of the proposed service. In fact, a rough estimate from our survey indicating that 60% of El Cenizo residents would be "definitely" willing to use the new service would suggest that 7-8 shuttle buses would be needed to properly serve the area.

#### OPTIMAL CYCLE LENGTH (Objective II)

Objective (II) of our research study is to estimate, for planning purposes, the cycle length which would

maximize the service quality provided to customers within El Cenizo. The most commonly used process for evaluating the level of service for customers is using the concept of the utility maximization or disutility minimization. A mathematical model existing in the theory of consumer behavior could be built to illustrate this fact (Meyer and Miller, 2001). The individual's decision making could be considered to be the minimizing process of a disutility function ( $U$ ) defined in equation (1)

$$U = \alpha w_1 + \beta w_2 + \varphi w_3 + \dots + \delta w_n \quad (1)$$

The parameters  $\alpha$ ,  $\beta$ ,  $\varphi$  and  $\delta$  are the weights to the factors  $w_1, w_2, w_3, \dots, w_n$  that influence the disutility function  $U$ . The factor  $w_i$  ( $i = 1, 2, 3, \dots, n$ ) could be waiting time, riding time, fare or anything that affects the mode choice of the users.

The users evaluate the bus service or any transit service based on a number of factors. The users are assumed to assign at least an ordinal ranking to the mode choice available in terms of their utility. It is reasonable to say that when it comes to the transit choice users try to minimize the waiting and the riding time. This is assumed with the view that minimizing the waiting time and the riding time would eventually lead to maximizing comfort and convenience.

We further extend the use of our simulation model to capture the idea discussed above. We observed that the bus service time interval or the cycle length could make a considerable difference in the waiting time or the riding time for the passengers. Thus 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 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 7. The assumptions underlying this part of simulation input have been compiled below. The cycle length or the bus service cycle interval is varied from 7.75 min to 12 min (at intervals of 15 sec) and from 12 min to 50 min (at intervals of 240 sec). The minimum time interval of 7.75 minutes is selected as this is 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 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. There is an intuitive minimum between these two extremes, which we seek to find by simulation. All curves show the presence of a minimum value which would be desirable for optimal service quality. We performed 12 replications for each curve.

We assume a ratio of 1:1.8 between waiting time and riding time based on the study of Wardman (2004). Thus, our disutility function takes the form of an equation (2) shown below.

$$U = 1.8w + r \quad (2)$$

Where:

$U$  = disutility function

$w$  = average waiting time  
 $r$  = average riding time

A graph for the above disutility function is shown in Figure 8 below.

It is evident from the graph that the disutility function achieves a minimum for a bus service time interval of around 11-13 minutes for the 80, 100 and 120 numbers of passengers. The graphical output for Figure 8 is summarized in the Table 1 below for the selected number of passengers used in the simulation.

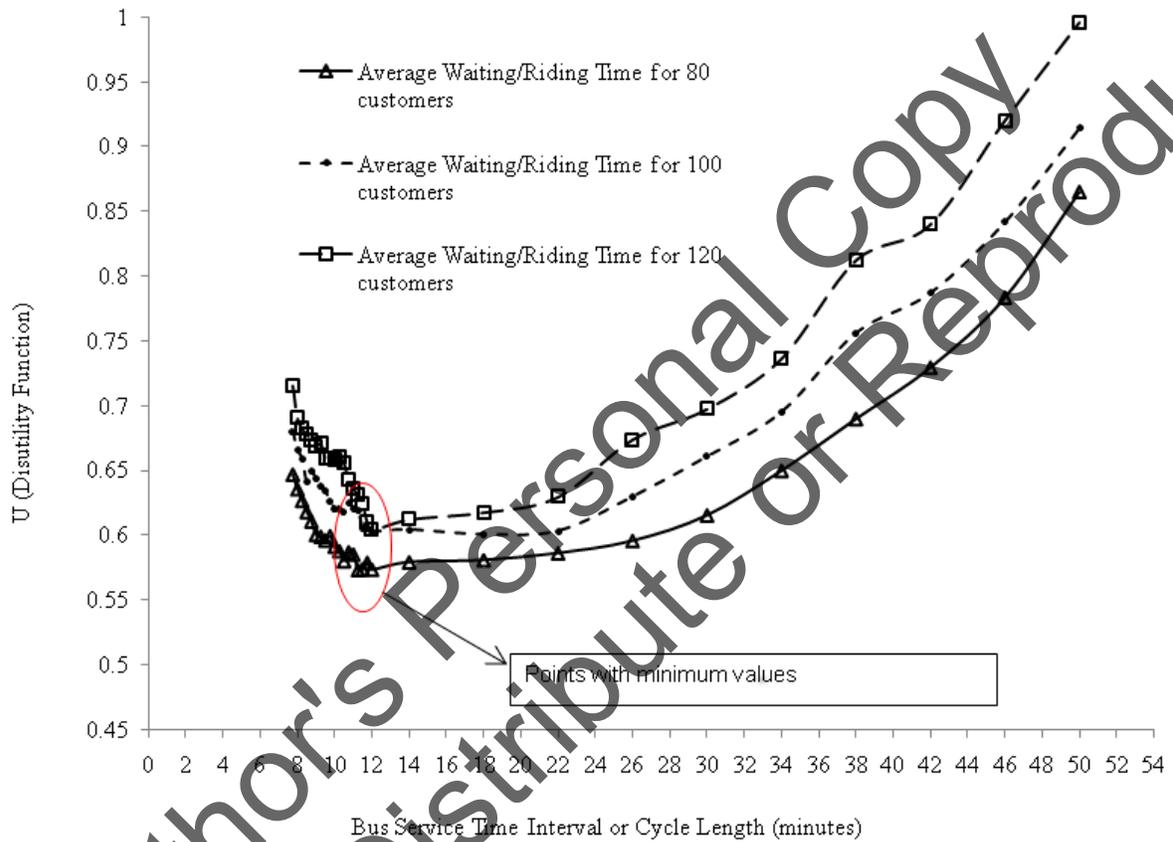


Figure 8: Disutility function vs. cycle length.

Table 1. Minimum disutility function and bus service time interval

Number of Passengers	$U$	Bus service time interval or cycle length (minutes)
80	0.38	11-12
100	0.41	11-12.5
120	0.42	11-13

## CONCLUSIONS

The first objective (I) of this research was to analyze the travel demand patterns in El Cenizo and to perform a feasibility/design study for the possible implementation of a demand responsive “feeder” transit system in the El Cenizo area. The survey results were useful to better understand the current travel demand patterns of El Cenizo and were used as input for the subsequent simulation study. A customized demand distribution was developed for generating the demand timings of El Cenizo commuters. In this manner, we ensured that there is a minimal deviation from the survey data.

Results obtained by employing the MATLAB R2008b version of the software indicated that a single demand responsive feeder transit service would be able to comfortably serve about 150 passengers/day (maximum capacity), corresponding to about 8% of the total daily demand in El Cenizo and a total of 7-8 shuttle buses would be needed to properly serve the area.

A more interesting result for our second research objective (II) is the identification of the optimal cycle time between consecutive vehicle’s trips to maximize service quality provided to customers. It is found that a value ranging between 11 and 13 min represent an estimate of the optimal value. The results can be used by planners for design purposes of a new transit bus service within El Cenizo or areas with similar demographics and geometry.

Future research would include an analytical modeling of the service, which would allow developing a close-form expression of the utility function. This would enable planners to easily compute the optimal cycle time without performing a possibly lengthy simulation study.

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Q3. How many times **per month** do you or any other member of your household need to take a trip for **health related activities** (such as hospital check-ups or doctor appointments)?

- 1-3
- 4-6
- 7-10
- 11-15
- 16 or more

Q4. What kind of mode do you use the most for health related activities?

- |                                      |                                     |  |
|--------------------------------------|-------------------------------------|--|
| <input type="checkbox"/> Car         | <input type="checkbox"/> Motorcycle | <input type="checkbox"/> Paratransit   |
| <input type="checkbox"/> Bus/Shuttle | <input type="checkbox"/> SUV/Van    | <input type="checkbox"/> Others: _____ |
| <input type="checkbox"/> Bicycle     | <input type="checkbox"/> Truck      |  |

Q5. Where do you most often go for health related activities?

(Cities/Hospitals, please specify)

\_\_\_\_\_/\_\_\_\_\_  
\_\_\_\_\_/\_\_\_\_\_  
\_\_\_\_\_/\_\_\_\_\_  
\_\_\_\_\_/\_\_\_\_\_

Q6. How many times **per week** do you or any other member of your household need to take a trip to a store for **groceries/food**?

- 1     2     3     4     5     6     7 (or more)

Q7. What kind of mode do you use the most to shop for groceries/food?

- |                                      |                                     |  |
|--------------------------------------|-------------------------------------|--|
| <input type="checkbox"/> Car         | <input type="checkbox"/> Motorcycle | <input type="checkbox"/> Others: _____ |
| <input type="checkbox"/> Bus/Shuttle | <input type="checkbox"/> SUV/Van    |  |
| <input type="checkbox"/> Bicycle     | <input type="checkbox"/> Truck      |  |

Q8. Where do you shop the most for groceries/food?

(Local supermarkets or other cities, please specify)

\_\_\_\_\_/\_\_\_\_\_/\_\_\_\_\_  
\_\_\_\_\_/\_\_\_\_\_/\_\_\_\_\_

Q9. Do you or any other member of your household leave the house and come back regularly for any other activity (such as recreation, sports, church, etc...)?

- Yes, go to Q10
- No, go to Next Page

Q10. For each of those activities, please complete the following table.

Type of activity	Number of trips <u>per week</u>	Mode*	Destination (Location/Town)

\* Car, SUV/Van, Truck, Motorcycle, Bicycle, Bus/Shuttle, others (please specify)

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### Third Part - Potential Travel demand pattern:

Assume that a **new shuttle transit service** is available for you to use.

The shuttle service would *pick you up at home*, would take you to any location you need to reach in the El Cenizo/Laredo area and surrounding area and would *bring you back home*, without the need of using other modes of transportation. One or more transfers between shuttles might be needed, depending on what location you need to reach.

Q1. For each activity, how likely would you consider switching from your current mode of transport to the new shuttle transit service (assuming that the *cost* and the *time* to reach destination would be *no more* than what you are experiencing now)?

Likelihood \ Activity	Definitely	Likely	Maybe	Unlikely	Definitely Not
Work					
School					
Health					
Grocery					
...					
...					
...					
...					

Q2. Please rank in order of importance the following characteristics of the new shuttle service. [Put **1** for the most important and **6** for the least important in your opinion]

- Fare \_\_\_\_\_
- Waiting time before pick-up \_\_\_\_\_
- Ride time to destination \_\_\_\_\_
- Punctuality \_\_\_\_\_
- Level of comfort \_\_\_\_\_
- Safety \_\_\_\_\_