BUS STOP CONSOLIDATION ANALYSIS FOR PUERTO RICO'S METROPOLITAN BUS AUTHORITY

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ABSTRACT

The transit planning in the Metropolitan Area of San Juan in Puerto Rico has a challenging problem because of its low sponsorship. Several reasons for the lack of sponsorship discussed among the community are urban sprawl, excess of incentives for private transportation, easy acquisition of a vehicle, relative low prices of gas fuel, and laws and policies that prioritize the use of personal vehicles, among others. The Metropolitan Bus Authority (MBA) of Puerto Rico is aware of these challenges and has been identifying all the inefficiencies that could foster a low sponsorship of the transit system. The results of a study performed in 2014 by graduate students from the University of Puerto Rico at Mayagüez describe the actual condition and accessibility of many of the MBA bus stops and compliance of the sidewalks and shelters within American with Disabilities Act requirements. The observations and preliminary conclusions of the study indicate that the location of bus stops in many places shows little or none ridership which could be due to a possible inefficient placement. To attend that problem, two methodologies were developed in order to identify which bus stops could be consolidated or eliminated from the Route 5 of the MBA. The first methodology analyzes the benefit and cost of removing a bus stop by calculating a benefit-cost ratio for every bus stop. The second methodology consisted of a four-step process where the main purpose is to give a class (i.e. importance) from A to F to each of the stops, A being the more important and F the least important. Preliminarily, the benefit-cost ratio and the four-step process methods recommended 32 and 20 bus stops to be removed, respectively. Both methods are easy to implement and can be considered as a low cost solution for the MBA.

RESUMEN EJECUTIVO

La planificación del transporte colectivo en el Área Metropolitana de San Juan tiene un problema difícil debido a su bajo patrocinio. El desparramamiento urbano, exceso de incentivos para la transportación privada, fácil adquisición de vehículos, precios de gasolina relativamente bajos, y políticas y leyes que otorgan prioridad al uso de vehículos personales son algunas de las razones discutidas entre la comunidad para la falta de patrocinio. La Autoridad Metropolitana de Autobuses (AMA) de Puerto Rico está consciente de estos problemas y ha estado identificando todas las posibles ineficiencias que puedan fomentar el bajo patrocinio del sistema de transporte colectivo. Los resultados de un estudio realizado en el 2014 por parte de estudiantes graduados de la Universidad de Puerto Rico en Mayagüez describen la accesibilidad y condición actual de muchas de las paradas de autobuses de la AMA, y el cumplimiento de las aceras y refugios de las mismas con los requisitos del Acta para Americanos con Discapacidad (ADA, por sus siglas en inglés). Las observaciones y conclusiones preliminares de este estudio indicaron que en muchos lugares las paradas de autobuses muestran poca o ninguna actividad de pasajeros lo cual puede ser debido a la posible localización ineficiente de las mismas. Para atender este problema, se desarrollaron dos metodologías para identificar las paradas de autobuses de la Ruta 5 de la AMA pueden ser consolidadas o eliminadas. La primera metodología analiza el beneficio y costo de remover una parada de autobús calculando una razón de beneficio-costo para cada una de las paradas. La segunda metodología consiste de un proceso de cuatro pasos donde el propósito principal es otorgar una clase (i.e. importancia) de la A a la F para cada una de las paradas; *A* siendo las paradas más importantes y *F* las menos importantes. Preliminarmente, los métodos de la razón de beneficio-costo y el proceso de cuatro pasos recomiendan 32 y 20 paradas de autobuses para eliminar, respectivamente. Ambos métodos son fáciles de implementar y pueden ser considerados como una solución de bajo costo para la AMA.

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LIST OF ACRONYMS

ADA – American with Disabilities Act

DTOP – Public Works and Transportation Department

ITA – Integrated Transport Authority

MBA – Metropolitan Bus Authority

UPRM – University of Puerto Rico at Mayagüez

US – United States

WMATA – Washington Metropolitan Area Transit Authority

I. INTRODUCTION

The organization and planning of transportation systems are vital factors for the economic and social development of cities around the world. A city with good planning and operation of its transportation system can move goods and people efficiently, quickly and cheaply, thus contributing to economic development. People began living in cities to minimize travel time and maximize all potential business and commercial exchanges. However, in some cities this concept has disappeared due to urban sprawl and lack of planning. Scattered urban areas are mainly connected by roads, thus giving higher priority and more attention to the use of private cars than any other method of transportation. Therefore, the road system focuses on providing greater benefits to private transport.

Despite all efforts to guide and convince people of the advantages that come with using public transport or other non-motorized means for commuter trips and other trips, they still prefer to use private transport. There are many reasons that can explain this behavior such as the convenience and flexibility that people have by traveling on their own private cars or the inefficiency and/or lack of a public transport system that is truly accessible, and can adequately meet the needs of users. For this reason, it is imperative for transportation related government agencies to provide a public transport system that is organized, reliable, and efficient.

Buses are among the many options offered by a public transport system. Bus systems have been, historically, a solution to the problem of transportation in cities. But for such a system to be efficient and useful for users, it must have a high degree of organization and maintenance. For transit services is very important that all the lines, networks, stations and stops be well planned and organized according to local needs. This means to have a good management system, to provide a schedule that the operator could meet and users could trust, and an infrastructure of stops and stations where the users can feel safe.

Inside the area of the infrastructure of a line, the bus stops are one of its principal elements because they represent the link between the users and the buses (Figueroa, 2013). A bus stop could be analyzed in several areas of interest. These areas of interest are, but not limited to: landing areas, shelter conditions, information features, traffic and pedestrian safety issues, proper identification and location. The location of a bus stop should be one of the top priorities to any transit agency; if excessive short distances exist between bus stops, the bus would have a longer cycle time and the through passengers will experience more riding time. There are many guidelines in the United States (US) that suggest several optimal spacing between bus stops. A recent study found that 95 of 111 US transit agencies have stop spacing guidelines, with about one-half recommending spacing distances between 200 and 270m (six to eight stops per mile) and closer spacing in business districts. Instead, in places of northern Europe, where transit has a much greater market, the average bus stop spacing is between 400 and 530m (Furth & Rahbee, 2000). By providing more space between bus stops it results in shorter cycle times and less riding times for the through riders. Transit agencies must develop new standards and tools with simple terminologies and implementation methods to know which bus stops could be removed and/or consolidated.

Problem Justification

Puerto Rico can be considered to be in a historical juncture where several public and private agencies are beginning to restructure the public transportation system in the island. The Public Works and Transportation Department (DTOP, due its name in Spanish) has created the new Integrated Transport Authority (ITA) in order to consolidate the efforts that have been carried out in favor of public transport. This new governmental initiative creates a unique opportunity in Puerto Rico. The initiative recognizes the public transport as a necessity and gives authority to a public agency, specialized in public transportation, to consolidate and improve existing efforts.

The Metropolitan Bus Authority (MBA), the largest government provided public transport system in Puerto Rico, is one of the agencies that are implementing substantial changes to its services. These changes include the reorganization of routes and evaluation of bus stops, among other administrative changes that should lead to improvements in the overall services.

Among the recent initiatives and collaborations between the University of Puerto Rico at Mayagüez (UPRM) and MBA, is the evaluation of the stops of the ten routes with highest ridership. This project was conducted during the summer of 2014, where fours graduate students evaluated the physical condition of more than 600 stops. One of the concerns that arose during the course of this project was the current location of the bus stops. When visiting all the bus stops locations it was noted that some did not have a suitable location so that users could easily and safely reach the area. Even more, at some locations, stops were located in places where there were little or no residential and/or industrial areas. This resulted in observing that, at many of the bus stops, there was little or no ridership at all.

MBA currently does not have established standards for choosing the location of stops or to determine if the current locations maximize the sponsorship and service of the bus system. It is extremely important that those responsible for the management and decision making of transit have all the information on the performance of the system. It is possible to create new evaluation standards that indicate if bus stops must be relocated or removed. Knowing the best possible location of stops would be ideal for improving user safety as well as the quality of service of the system.

Main Goal and Specific Objectives

This project aims to develop a standardized process for choosing which bus stops of the MBA should be consolidated (i.e., eliminated). In order to determine this, the sponsorship of passengers in each one of the stops should be considered. Also, the land use around the current bus stops and other possible places should be identified as well as the accessibility of sidewalks. In order to accomplish the main goal of the research, the following objectives were established to:

- Study actual procedures and methods for bus stop consolidation
- Identify previous studies dedicated to the performance of bus systems and bus stops.
- Create a tool for evaluate each bus stop on a specific route (Route 5) and recommend which stops should be eliminated or consolidated.
- Submit a final report that explains in detail the methodology and results of the project.

Expected Results and Benefits

The expected result of this project is to propose an evaluation tool for the possible bus stops location of at least one route of the MBA bus system. This evaluation tool will be developed in a very simple way so it can be used by the public transit agency and their staff as well as any other transit agency, if desired.

One of the benefits of developing a new standard for bus stop locations is that the accessibility to the bus stops will improve. Another benefit is the time reduction of riding the bus stop. Also, if the bus stops are relocated, the operating cost of the entire system could be improved. In the long-term it is expected that the evaluation tool developed will benefit all public transportation systems that incorporate this methodology in order to improve the overall quality of their bus systems.

Overview of Bus Stops Elements of Route 5

This section presents a brief explanation of the concepts and parameters considered through the period of August-December 2014. The information represents a bulk data base of the parameters of the evaluation of bus stops in Route 5 (route selected for this study) to present the progress of the investigation project. This entire data base is documented in photos, Microsoft Access, Excel, Google Earth and ArcGIS.

Evaluation of Bus Stops | Summer 2014 – Description of Route 5

During the summer of 2014 an evaluation and assessment of the physical status of the bus stops of the top 10 routes with more ridership was performed. This work will provide Metropolitan Bus Authority (MBA) with a database that includes a full description of the stop location, landing area, shelter condition, information features, traffic and pedestrian safety, and getting to the bus stop. This database includes information of more than 600 bus stops. As shown in Figure 1, Route 5 provides service to several areas such as Santurce, Isla Verde, the Luis Muñoz Marín International Airport and Los Angeles sector; it has a length of almost 25 miles in both directions and has 98 bus stops. As part of this project the Route 5 was selected for analyzing the reliability of the bus stop locations. Route 5 serves urban and residential areas and has a daily average ridership of 3,350 persons each day.

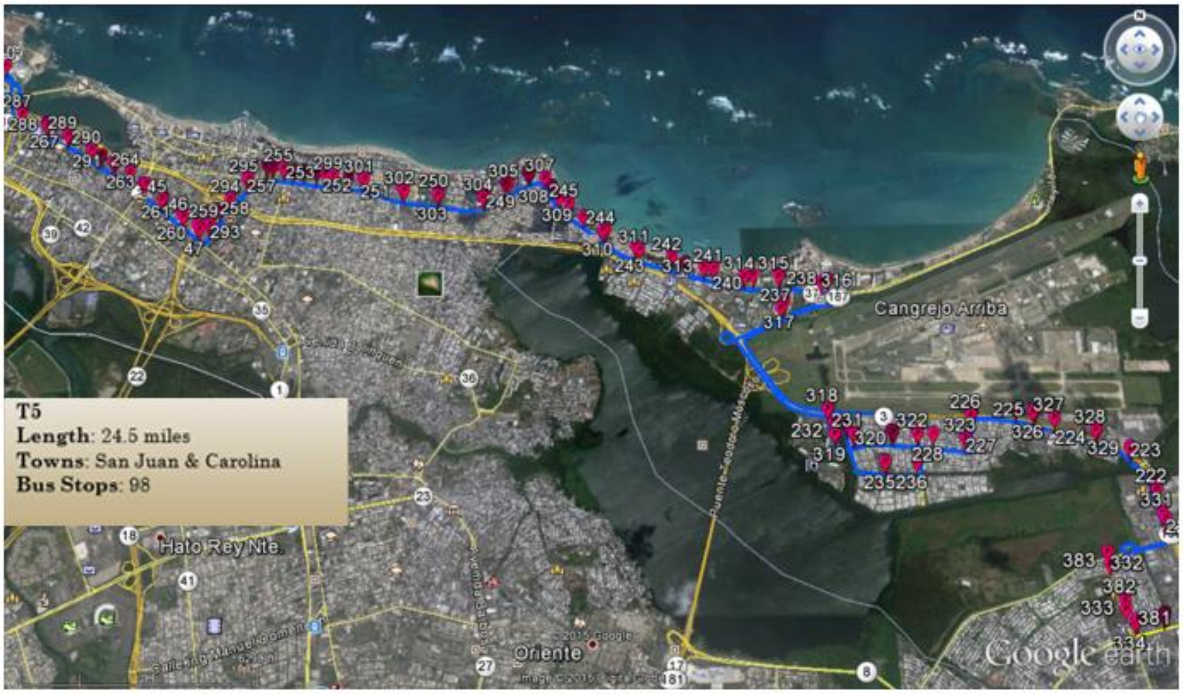

Figure 1: Some Areas that are Serviced by Route 5 (Source: Google Earth, 2015)

The most important parameters that were evaluated in Route 5 were sidewalks' accessibility, shelters, landing areas, and distance between bus stops.

Accessibility in the sidewalks

The American with Disabilities Act (ADA) establishes a minimum width of 5 feet for sidewalks. Although that parameter can change according to the land use, it ensures the possibility that a handicapped person can safely travel on the sidewalk. The evaluation of the accessibility of the sidewalks describes the real space that any pedestrian has to safely walk when is passing near a bus stop. In other words, this measure ensures that two persons in wheelchairs can move at the same time without any problems. Figure 2 shows several examples of the accessibility efficiencies and deficiencies in Route 5.

Figure 3 shows which of the bus stops meet the requirements for accessibility in a sidewalk near to a bus stop. It only takes into account the accessibility that exists around the bus stop, but not the entire segment between each stop which is very necessary to this kind of analysis.

Figure 2: Route 5 Accessibility in Sidewalks – Examples of Efficiencies and Deficiencies

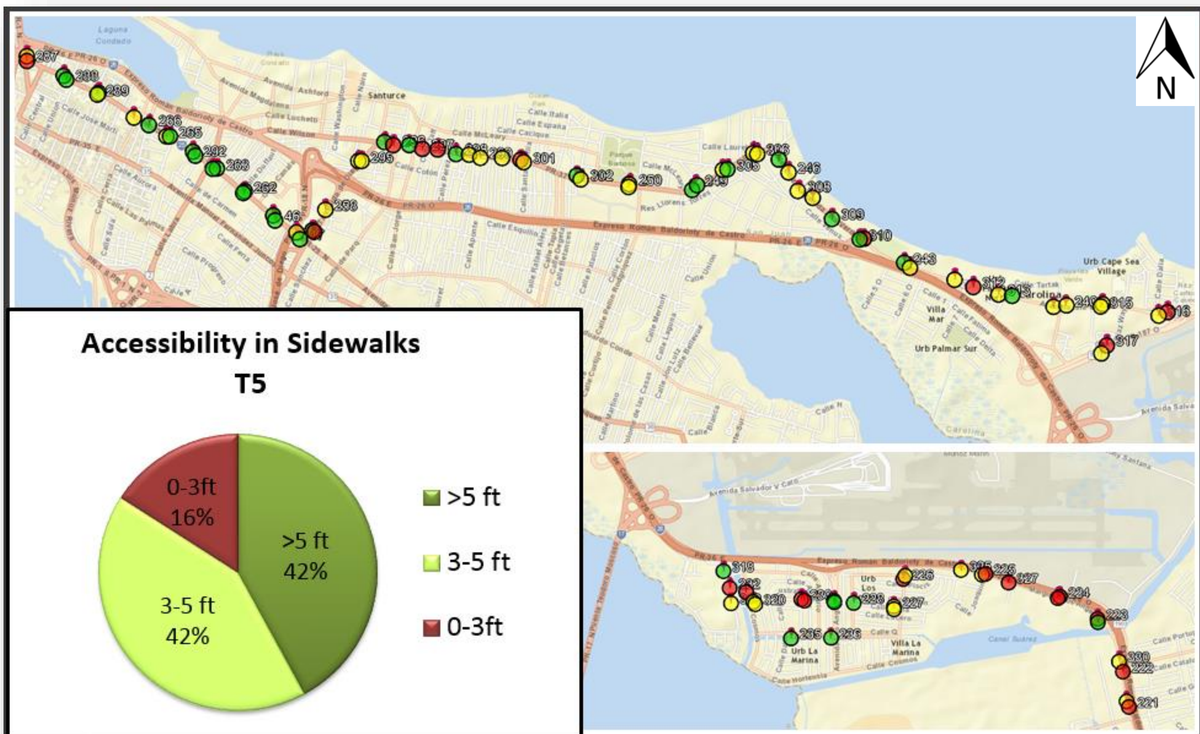

Figure 3: Route 5 Bus Stops Accessibility of Sidewalks - Buffer Zone per Stop (Source: ArcGIS Explorer)

Shelters

Information was collected for every bus stop described as a shelter. Route 5 has 98 bus stops of which 53 of them have a shelter, resulting in 54% of the bus stops. Figure 4 shows some efficiencies and deficiencies that the bus stops of the Route 5 have when considering the existence of shelters. Is important to establish that many places in which bus stops do not have a shelter, they have a different land use. Figure 5 shows how many of the bus stops have shelters and their location.

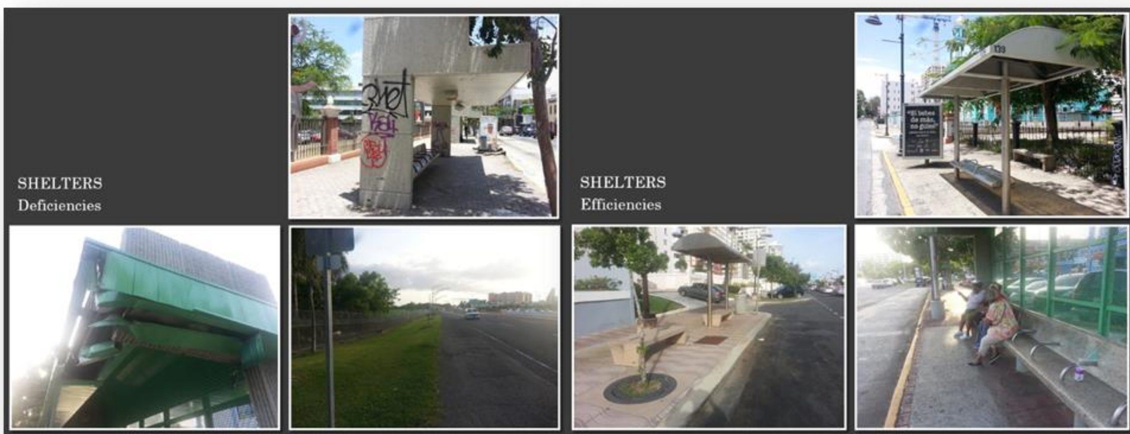

Figure 4: Route 5 Shelters – Examples of Efficiencies and Deficiencies

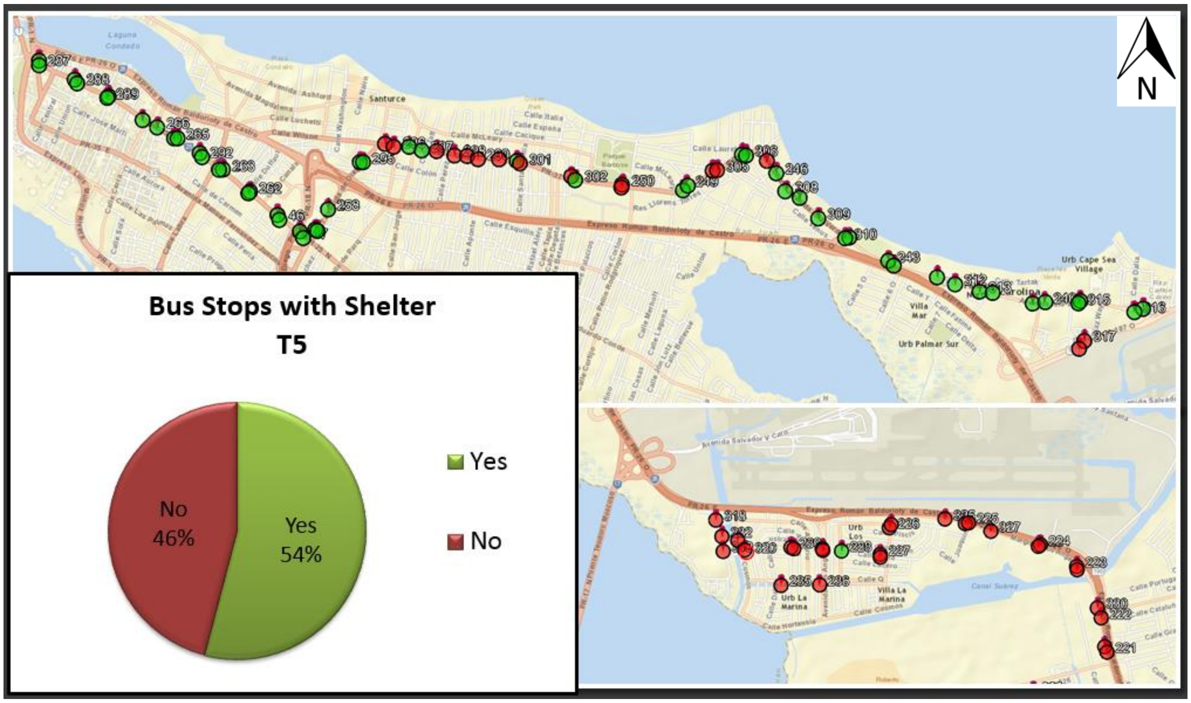

Figure 5: Route 5 Bus Stops with Shelter – Buffer Zone per Stop (Source: ArcGIS Explorer)

Landing Area

ADA requires a minimum space of 5 feet-width and 8 feet-depth at or near the bus stop. The main purpose is to ensure that a handicapped person can have a safe space to enter a bus. This parameter is very important because providing this space can create confidence in the users, with or without disabilities, to feel safe at the stop. Figure 6 shows several examples of the efficiencies and deficiencies that Route 5 have along the route. Figure 7 shows all the bus stops that meet the requirement of the landing area, which helps in identifying what places have problems with this. In many cases the lack of landing area in the stops is bound to the accessibility of the sidewalks.

Figure 6: Landing Area - Efficiencies and Deficiencies

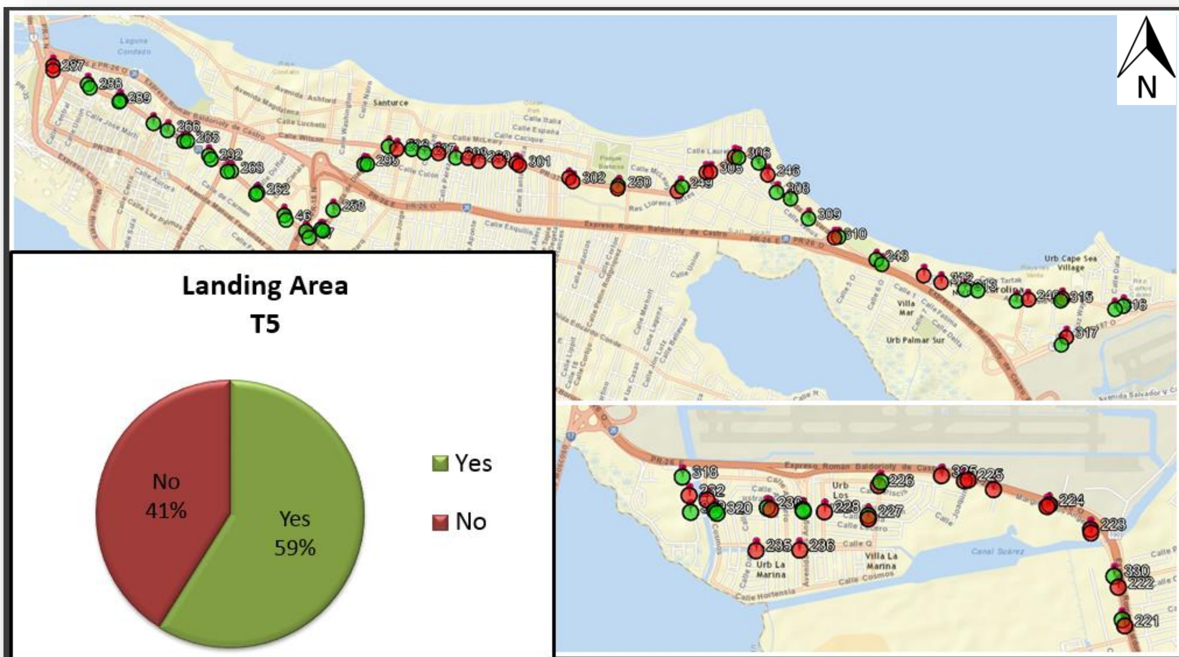

Figure 7: Route 5 Bus Stops with Landing Area – Buffer Zone per Stop (Source: ArcGIS Explorer)

Distance between Bus Stops

According to the literature review a person is willing to walk 0.25 miles (400m) or 5 minutes to their origin or destination to the nearest bus stop. This project intends to study this parameter and provide recommendations for Route 5 bus stop locations. Figure 8 shows information on the distances between consecutive bus stops of the entire Route 5.

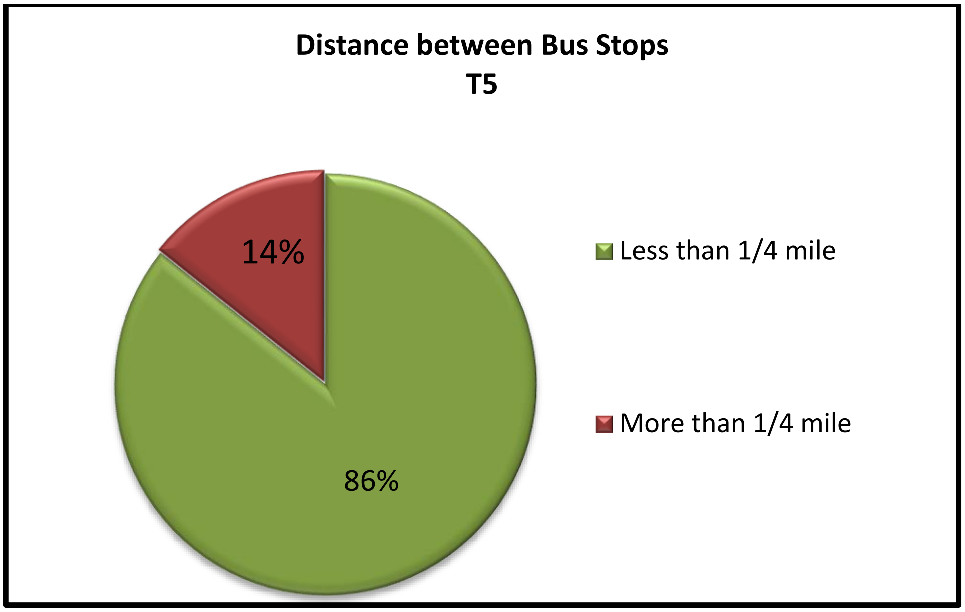

Figure 8: Distance between Bus Stops of Route 5.

II. LITERATURE REVIEW

The efforts for finding an optimal spacing between bus stops have had several approaches, either complex or simple. By removing unnecessary stops, buses will have reduced running times, which can lead to higher frequencies and/or fewer buses on a route (Stewart & El-Geneidy, 2014). Stewart and El-Geneidy (2014) also indicated that current analysis and investigations, regarding optimal spacing or consolidation of bus stops, are too complex for the transit agencies to implement. The main reason to conduct a reliability analysis of the MBA's bus stops' spacing of the MBA is to provide a simple and useful tool that could be used to identify the stops that will be recommended for removal and those stops that may remain in the route. Henceforth a summary of the different studies and investigations on this topic will be presented.

Optimal Bus Stop Spacing through Dynamic Programming and Geographic Modeling

A study performed by Furth and Rahbee (2000) used a discrete approach to model the impacts of changing bus-stop spacing on a bus route. A dynamic programming algorithm was used to determine a bus stop location and compared it with a continuum approach used in the past for the same type of problem. Furth and Rahbee (2000) established and defined three main societal impacts, based on benefit and cost of remove or consolidate a bus stop: riding time, operating costs, and walking time. The riding time of a bus is affected when more frequent stops are placed because the through riders spend more time in the bus. The operating costs are increased when more frequent bus stops are placed increasing the cycle time of the bus, thus increasing the operating cost of the route. The walking time decreases when more frequent bus stops are place due to their proximity.

In the study it was indicated that in US the guidelines of stop locations are intended to help the transit agencies to resist the pressure of locating a bus stop in unnecessary places. Also, compared with some places in Europe where bus stop spacing has an average of 400 to 530 meters, in US the average spacing between stops is between 160 and 230 meters. Due to the short spacing between stops, and the leeway of appliance of agencies guidelines, the authors recommended a scientific framework that could quantify the site-specific impacts, evaluating the social costs and benefits of stop location choices and determine optimal locations.

In the study it was reviewed the continuum approach, pointing that a bus route is modeled as a continuum in one dimension, with a variable distance *x* that describes the starting and final point. This continuum approach modeled the boarding and alighting as a continuous function of *x*. Two mayor shortcomings are related to this approach, as stated by the authors. The first one is that the real application of this approach could be very difficult. For example, if the continuum approach recommends a 300 meters of optimal spacing, and the intersections are at 200 meters, there will be some debating on if the bus stops should be located every other intersection or every two or three intersections. The second shortcoming is that the continuum approach is not a smooth function, instead is a sharply punctuated as each cross-street brings its demand to a specific point on the line.

A discrete approach was also applied to the optimal bus stop location analysis in the study. This discrete approach presumed a discrete number of bus stops in every intersection of the route under analysis. A geographic model that distributes demand all around the street blocks in the service area of the route was used. Several equations were established to calculate the distance that a user would walk by establishing stop shed lines. Once the stop shed lines were established the demand was distributed with the geographic model. This model is a rational way for the redistribution of demands on actual bus stops to the alternate stop locations. Also, the impacts of the operating costs and riding time were divided in variables and independent components, where the variable components are the number of passengers boarding and alighting. Two social costs in the delays were identified related to bus stops; lost time for through passengers and higher operating cost due to increasing cycle time (i.e. the amount of vehicle-hours required for the route). For analyses purposes, an objective function was created with some constrains to calculate the net walking time cost per unit, riding delay costs per unit time, and the operating costs per unit time.

A dynamic programing algorithm was used to find the least expensive solution of bus stop location. The dynamic programming was applied in Visual Basic for Route 37 (length of 4.5 miles) of the Massachusetts Bay Transport Authority. The demand was calculated with historic data of on-and-off counts and transfer volumes. The results showed that, from 37 bus stops, 19 bus stops were reduced or relocated. The spacing between bus stops was improved from 202 meters (8 stops/mi) to 404 meters (4 stops/mi). The results showed that, with the optimal solution, it is saved $132 per hour on social cost, the passengers walking time increased an additional 0.6 minutes, and the through passengers travelled 1.8 minutes less in average. In addition, every bus saved 4.3 minutes of operating time per trip. The authors stated that the differences between the optimum and existing solutions suggest that eliminating bus stops can be a recommended practice for transit agencies.

Effects of Bus Stop Consolidation on Passenger Activity and Transit Operations

The purpose of a study performed by El-Geneidy, Kimpel and Strathman (2005) was to analyze the changes in the passenger activity and operating performance after the implementation of bus stops consolidation in the city of Portland, Oregon. TriMet, the regional transit provider for the Portland metropolitan area, performed extensive studies with collected data of archived bus operations and passenger activity from the automated bus dispatching system. The routes where consolidation of bus stops were made were catalogued as treatment segments and their changes in passenger activity and operating performance were compared to those in segments where no changes in bus stops were made (control segments).

The results of the study indicated that the passenger activity increased in the control segments by 10%, but this was not significantly greater than the small increase that occurred on treatment segments. Also, a reduction in running time was found after the implementation of the bus stop consolidation program. For the treatment segments the running time improved by more than nine seconds (9.6%), and for the control segments it declined by more than three and a half seconds (2.9%). These results represented a net 5.7% reduction in running time attributable to the consolidation of bus stops. The main contribution of this work is related to the empirical orientation; it supports the claims from prior analytical and simulation studies that identify that bus stops are too closely spaced.

Assessment of an Optimal Bus Stop Spacing Model Using High Resolution Archived Stop-Level Data

The purpose a study performed by Li and Bertini (2008) was to develop a stop spacing model that considered two major components: passenger access cost and in-vehicle passenger stopping cost, both combined and optimized to minimize the total cost. The authors established that among the impacts of frequent stops are delays for through riders and shorter walking times parallel to the route. There could be several reasons to explain those impacts. An example is that transit service generally favors bus stop accessibility, sometimes based on past history and tradition rather than based on a true scientific approach. On the other hand, by reducing the number of bus stops, the transit agencies and operators risk making their service inaccessible.

The methodology was based on developing a model to optimize the spacing between bus stops. To develop the model several assumptions were made regarding the number of passenger boarding and alighting (which was assumed to be Poisson distributed), the probability that a bus stops to any board or alight, the uniformity in the travel demand, and the average access distance. This basic model was an optimal spacing analysis that was computed for a route as a basis for transit service improvement. This model was aimed to demonstrate that an abundant set of archived stop-level data can facilitate useful and regular assessments of transit service.

The total cost expression was formulated with two cost components of access cost and riding and stopping cost. The access cost depends on the number of passenger boarding and alighting at each stop, and on the access speed. Stop spacing impacts passenger walking distance, thus, the cost is formulated by unit distance. The riding and stopping cost is comprised of the in-vehicle waiting time for the bus passengers during the boarding and alighting time. These two cost components were statistically analyzed to find an optimal spacing equation based on the passengers on the bus, density of origins and destinations, and headways.

The application of this model was in a case study on inbound Route 19, in Portland, Oregon, which has a length of 9.27 miles long and 52 bus stops with an average spacing of 942 feet (287 meters). The first analyzed parameter was the current bus stop spacing; basic statistical analyses were applied to characterize the current situation. Afterwards, the next step was to calculate the passenger load on the bus (second parameter) for an entire year every time a bus stopped at each bus stop; this showed that, on average, 7.9 passengers per trip, traveling on the bus. The third parameter was the boarding and alighting, where more than 566,000 passenger movements showed that the mean number of boarding and alighting was 32.2 persons per trip. The fourth parameter was the lost time due to stopping to serve passengers. This included the dwell time for serving passenger boarding and alighting, the time during which the door is opened and closed, and the deceleration and acceleration time. The lost time calculated was 33.6 seconds. The final step was to obtain the optimal bus stop spacing based on the density of origins and destinations, time lost in stopping, and the number of passengers on the bus. For Route 19, given the mean load of 7.9 passengers and a mean of 33.2 passenger movements, an optimal stop spacing of 1,222 feet (372 meters) was determined; this represented an additional 280 feet (85 meters) when compared to the current mean spacing. In addition, based on a benefit/cost assessment, the authors indicated that there was a potential for a $60,000 reduction in annual operating costs. Li and Bertini (2008) concluded that the theoretical stop spacing value can be provided to planners and decision-makers as a powerful performance metric.

Guidelines for the Design and Placement of Transit Stops for the WMATA

The Washington Metropolitan Area Transit Authority (WMATA) presented several recommendations for the overall spacing of bus stops along the route system of the transit agency in 2009. The agency recognized that shorter distances provide users a shorter walk to the nearest stop, but may result in longer rides for customers if the bus stopped too many time across the line. It was established that optimizing the spacing of bus stops was an issue to pursue in order to provide a balance and thus improve reliability of the system.

The bus stop consolidation impact analysis of WMATA provided a broad level analysis that investigated the potential impacts on bus running time and operating costs by consolidating bus stops for 103 Metrobus lines. The factors in this analysis included current spacing between stops by line, average running time by line, and platform cost per hour. The bus stops spacing of the Metrobus lines were calculated through the utilization of supplied ride check data to determine the number of bus stops and GIS software to determine the length of each line. The average running time by line was used with measurements in frequency of service to determine whether the scenarios would provide better service to the riders. The platform cost, that represented the full cost of operating one transit vehicle per hour, was provided by the Metro staff with a value of $99.10.

The analysis was constituted of four different combinations of the two aspects of time savings per removed bus stop along the line and the implementation of new spacing standards. There were two separate values for the amount of time savings achieved by the elimination of a bus stop; 10 and 20 seconds. Then, according to the proposed regional bus stops guidelines, a local Metrobus line should offer its riders between four and five bus stops per mile. Sixty-seven (67) Metrobus lines exceeded the recommended bus stop spacing, so the potential running time and cost savings were determined for those lines. The cost savings were calculated in two ways. The first was a linear cost savings which implied that there was a set of cost savings for any shortening of the overall run time of a bus. The second was a stepped cost savings which meant a more pragmatic method for calculating the potential cost savings of consolidating bus stops.

After using the spacing recommendation of 4-5 bus stops per mile, combined with the 10 and 20 seconds running time saving per consolidated stop, four possible scenarios were developed. Using both the linear and stepped cost savings approaches, the four possible scenarios were analyzed. The first set of scenarios was the more conservative option of consolidating five bus stops per mile. The second set of scenarios was a more aggressive option of consolidating four bus stops. The results suggested that Scenario 4, the most aggressive scenario with 4 bus stops per mile and 20 seconds of time savings, had a greatest running time (18.43%); the total linear and stepped cost savings were $26,191,000 and $21,147,768, respectively.

Benefit-Cost Evaluation Method for Transit Stop Removal

A study explored the development of a tool for determining the optimal spacing between existing bus stops in a bus route in Portland, Oregon (Wagner and Bertini, 2014). In this study, the authors explained that stop spacing involves an inherent tension between access and speed of service. With the proposed tool, the authors compared the benefits that the riders have in using a bus, represented by the travel time savings and the costs represented by the additional cost of access of the riders who use the stop. This research tried to minimize the total user cost when using an entire bus route by removing bus stops.

Wagner and Bertini (2014) used a stop-level approach that compares the benefits and costs of removing a bus stop by determining a benefit-cost ratio. This benefit-cost ratio is *B/C*, where B is the total user benefit of removing a bus stop and C the total user cost. This tool evaluates the consolidation of the stops in a simple way: if $B/C \geq 1$, the bus stop should be removed and if $B/C < 1$, the bus stop should not be removed. The benefit B is a function of the passengers riding through the stop and the time gained from skipping the stop. The cost C of removing a stop is a function of the number of passenger using the stop, increased time to access remaining stops, and ratio of the value of access time to the value of riding time using a private vehicle. The tool created in this research was applied on the TriMet Line 6 bus in Portland, Oregon. The selection of this bus route was made to fulfill several assumptions. The assumptions were: 1) all stops are served; 2) a perfect street grid exists; and 3) stop removal has no effect on ridership. All the data was acquired by TriMet passenger census and interactive system map.

The results of the consolidation bus stop analysis indicated to eliminate 6 bus stops. The authors were very clear that although the results of the analysis were very good, the method still had several limitations that should be attended in further investigations. The first limitation was that the method assumes a grid of small blocks and, if applied in any different scenario, the method may not be accurate at all. The second limitation is that there is no information about the probability of a stop being served, thus the authors established that further studies may be conducted to find a probability factor. A third limitation was that the proposed method does not include any benefit of the consolidation of the bus stops in terms of reduced operating costs. Finally, the method considers only the removal of existing stops and does not offer any recommendation for their relocation.

The authors concluded that the method is a useful tool for service planners who know that there is minimum spacing between bus stops and it should be implemented in urban routes with demand all along the route. Also, it was established that this method could be used as the basis of an iterative model that would run the analysis, remove the stop, reallocate riders, and run the analysis again until all the bus stops have $B/C \geq 1$.

Bus Stop Consolidation 5-Step Process

A research explained one of the simplest methods for consolidating bus stops. The purpose established by Stewart and El-Geneidy (2014) was based in the fact that it is important to find an effective method to consolidate bus stops that reaches a balance between simple and complicated approaches. Most of the simple approaches just use a fixed idea of what would be a solution for bus stops locations and applied it to every single bus stop, forgetting the individual behaviors that each bus stop may have. On the other hand, there are several methods that seek an engineering approach. This means that the methodology used to find an optimal bus stop location was too complicated to transit agencies to follow it, concentrating in specific mathematical details and leaving behind pertinent social realities. Therefore the objective was to create a new methodology for bus stop consolidation that was easy to use and to understand, that could be adjusted to any kind of bus route, and transit agencies could work with easily.

Stewart and El-Geneidy (2014) presented a methodology to choose what bus stop should be eliminated of a bus route; it consists of five steps:

1. *Determining each stop's catchment area.*

    The authors explained that the passenger walking distances should not be considered as fixed distances, but as individual or variable. For that reason they developed a formula that generated a walking distance for each bus stop that depends on several measures such as distances and population. As a result it is created a catchment area around every bus stop along the route. This catchment area is used to develop a fundamental spacing rule between bus stops.

2. *Determining the class of each stop (define its importance).*

    To define the importance of each stop, the authors used four factors: 1) the needs of people with reduced mobility; 2) transit connections; 3) passenger activity at the stops; and 4) whether the stop is the first or last stop on the route. When all these four factors are found, then it is determined which class each bus stop has, categorized into six classes from A to F, where A is a bus stop that must be kept and F is a bus stop that must be eliminated.

3. *Deciding which stops should be removed, based on catchment –area overlap and classes.*

    A removal score is established based on two main factors: catchment areas and classes. The stops which have a removal score greater than zero will be considered for removal. The biggest the removal score of a bus stop, the larger will be the chances of removing it. Also, twin stops and consecutive stops were factors to make a final decision.

4. *Calculating the savings resulting from the removal of these stops.*

    After removing the bus stops it is possible to calculate the savings for the bus route. Using a process that consists of 7 steps it is calculated the running time savings by knowing the number of buses, cycle time, and headway to determine new values of the same variables with the average time saved by removing one stop.

5. *Determining the impact on passengers*.

    The last step consists in determining the impact on passengers that results from removing bus stops. The impacts are calculated in two ways: by decline in service coverage area and by change in overall travel time. For the decline in service coverage area it is necessary to compare the total area covered by the route's catchment areas before and after removing stops. The change in overall travel time can be calculated by finding the average change in walking time, waiting time, and in-vehicle time.

III. PROPOSED METHODOLOGY

The first step of the proposed methodology is to **identify a research problem** related to the bus stop spacing of Route 5 of the Metropolitan Bus Authority (MBA) in the Metropolitan Area of San Juan. This problem arose by an observational study of the physical status of each one of the bus stops of the top eight routes of the MBA. In this study, where field visits were performed to more than 600 bus stops, it was found that the average bus stop spacing was 330 meters, and in one direction of the route with a length of 11.5 miles there are 57 bus stops (Cordero-Cruz, 2014). This information indicates that there are, in average, 5 bus stops per mile.

The **specific goal** of this research project is to develop a methodology that can help determine if a bus stop should be eliminated and/or consolidated. To achieve the specific goal it is necessary to understand what kind of approaches have been studied regarding consolidation of bus stops by conducting a **literature review**. A proposed **methodology** is then developed based on previous studies and applied with the available data applicable to Route 5 of the MBA. A **data collection** and **data analysis** is then performed using the proposed methodology to identify which of the bus stops should be eliminated or consolidated. Finally, the **results** are presented from all the information concerned to the elimination of the bus stops. **Conclusions and Recommendations** are then identified regarding the benefits and costs of the implementation of this proposed methodology.

The methodology developed is based on two different simple studies about consolidation of bus stops. The first one was proposed by Wagner and Bertini (2014), where they developed a benefit-cost ratio (B/C) for each bus stop under consideration. Although one of the limitations of this methodology is that it should be applied to a grid of small blocks, it was still selected for this project because many areas along Route 5 did fulfill with this requirement. The second methodology was developed by Stewart and El-Geneidy (2014) and it consists on a four step process for deciding which stops to consolidate along a bus route.

For this particular research both methodologies were applied to the data. The results were then compared against each other in order to identify any similarities as well as discrepancies. Figure 9 shows a flowchart explaining all the step of both methodologies.

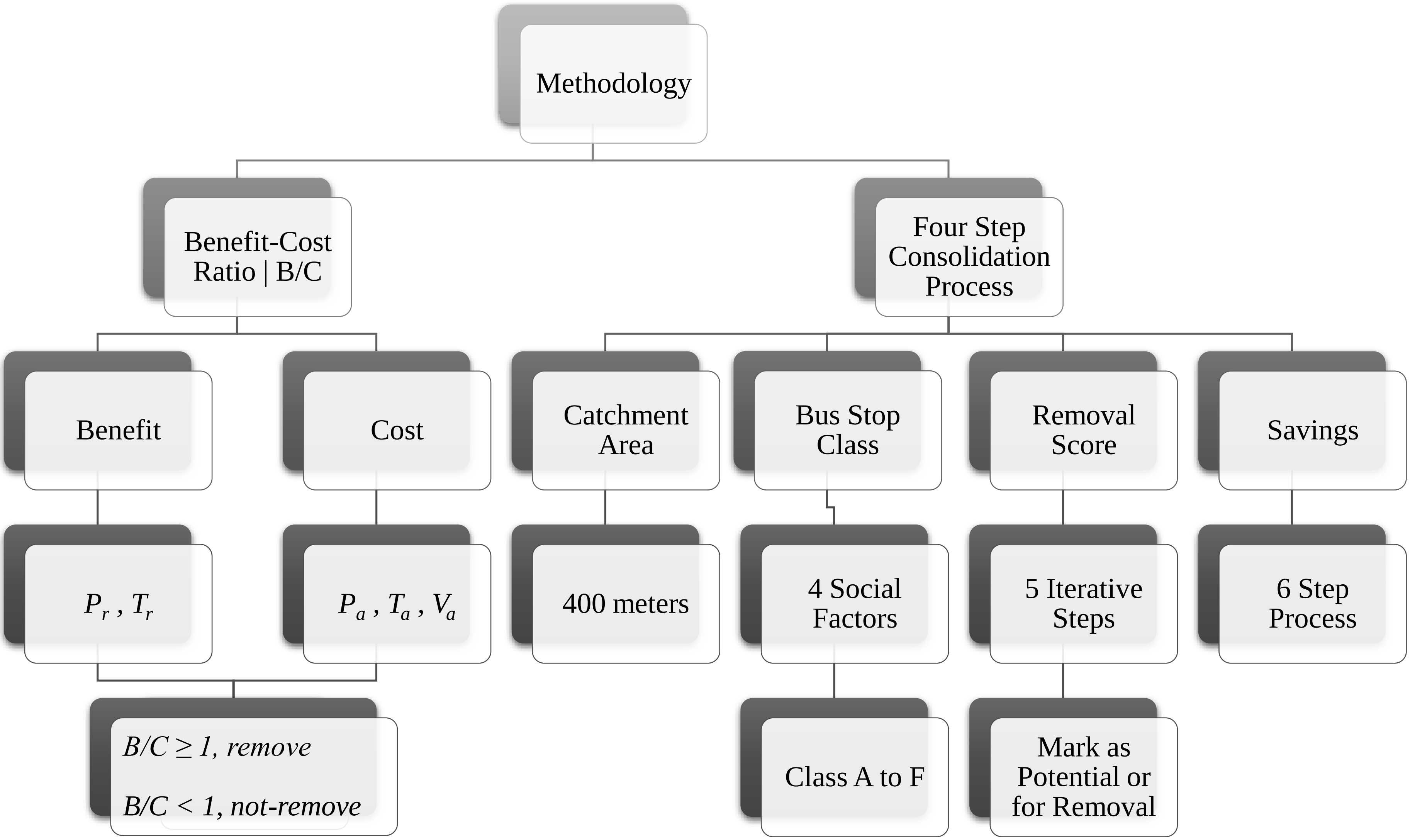

Figure 9: Flowchart Explaining the Steps of the Proposed Methodology.

Benefit-Cost Ratio

The first part of the methodology consists of calculating a benefit-cost ratio. The result will indicate if a bus stop should be eliminated or not. The formula used to compute the benefit-cost ratio is shown in Equation 1.

$$\boldsymbol{benefit\ to\ cost\ ratio = \frac{B}{C}} \tag{1}$$

Where:

$\boldsymbol{B}$ = total benefit for the user of removing a bus stop

$\boldsymbol{C}$ = total cost for the user of removing a bus stop

The total benefit $\boldsymbol{B}$ is calculated using Equation 2,

$$\boldsymbol{B = P_r * T_r} \tag{2}$$

Where:

$\boldsymbol{P_r}$ **=** number of passengers riding trough

$\boldsymbol{T_r}$ **=** additional ride time because of the stop in seconds

Equation 2 shows that the benefit $\boldsymbol{B}$ is a function of the passengers riding through the stop and the time gained from skipping the stop (Wagner & Bertini, 2014).

For the total cost $\boldsymbol{C}$, Equation 3 is then applied.

$$\boldsymbol{C = P_a * T_a * V_a} \tag{3}$$

Where:

$\boldsymbol{P_a}$ = quantity of passengers accessing the bus stop by boarding and alighting

$\boldsymbol{T_a}$ = net increase in travel time per person to access remaining stops

$\boldsymbol{V_a}$ = value of access time relative to riding time

Equation 3 shows that the cost $\boldsymbol{C}$ of removing a stop is a function of the number of passengers using the stop, increased time to access remaining stops, and ratio of the value of access time to the value of riding time (Wagner & Bertini, 2014).

The values for the variables $\boldsymbol{P_r}$ and $\boldsymbol{P_a}$ have already been obtained by a passenger load study performed by 14 students of UPRM. The study started at 6:00 AM and ended at 1:00 PM, and it took place in San Juan, PR, in the Route 5 from Covadonga Terminal to Iturregui Terminal. The formulas to obtain these values, showed in Equation 4 and Equation 5, are:

$$\boldsymbol{P_r = load\ arriving - alighthings}\ \textbf{or}\ \boldsymbol{load\ departing - boarding} \tag{4}$$

and

$$\boldsymbol{P_a = boardings + alightings} \tag{5}$$

To obtain the value of $\boldsymbol{T_a}$ is necessary to find $\boldsymbol{D_w}$ and $\boldsymbol{v_w}$. $\boldsymbol{v_w}$ is the average walking speed of an average person, using a default value of 3.5 ft/s (MUTCD, 2009; TCRP Report 112, 2006). And $\boldsymbol{D_w}$ is the average additional walking distance to remaining stops when some stops are removed from the line. Equation 6 shows how to calculate the average additional travel time by passengers within the evaluated service area of the stop when they have to access the closest remaining stop.

$$\boldsymbol{T_a = \frac{D_w}{v_w}} \tag{6}$$

Equation 7 shows a weighted average where $\boldsymbol{D_n}$ is the distance to the nearest stop and $\boldsymbol{D_f}$ is the distance to the farthest stop.

$$\boldsymbol{D_w = \frac{(D_n D_f)}{(D_n + D_f)}} \tag{7}$$

The last two variables are the additional riding time because of the stop, $\boldsymbol{T_r}$, and the value of access time relative to riding time, $\boldsymbol{V_a}$. The additional-ride-time variable has a range of values between 10 and 20 seconds, choosing a midrange of 15 seconds to describe the time that a bus may save for skipping a stop. This is the value generally used by transit planners (Wagner & Bertini, 2014). The value-of-access-time variable is a factor usually chosen to be two (2). This value corresponds to the behavior of the users of giving twice the value of walking and/or waiting time in a bus stop compared to in-vehicle time.

When all the variables and formulas are established, the next step is to create an Excel spreadsheet to calculate the benefit-cost ratio for each one of the bus stops of Route 5 and, according to the value for each, decide which bus stop is a candidate to be removed.

Four Step Process for Bus Stop Consolidation

Compared to the benefit-cost ratio methodology, the bus stop consolidation methodology can be considered more complex and time consuming due to the social information that is required to obtain. Stewart and El-Geneidy (2014) developed this methodology which consists of a five-step process for determining if bus stop consolidation is recommended for the improvement of a bus route. The five steps consisted of the following: 1) determine the **catchment area** of each bus stop; 2) determine the **class (or importance)** of each bus stop; 3) decide **which stops should be removed** by looking for overlaps in catchment area and bus stop classes; 4) calculate the **savings** of removing the selected bus stops; and 5) determine the **impact on passengers**. However, since the last step of this methodology was beyond the scope of the present study, only the first four steps were applied to the data.

Step 1 | Determining the Catchment Area of Each Stop

The authors established that the walking distance that a user is willing to walk should not be considered as a fixed distance for every bus stop, but as an individual or variable distance. This is because every bus stop has a different way of access that depends on several factors, such as accessibility by sidewalk, population around the bus stops, intersections near the bus stops, nearest bus stop to downtown, and waiting time at the stop. For this study, and mainly due to lack of data, a 400 meters radius was established as the catchment area around every bus stop in Route 5.

Step 2 | Determining the Class of Each Stop (define its importance)

The first step is to identify the bus stops that are considered for removal. In the second step the main goal is to define the importance of each bus stop by sorting them in different classes. These classes are calculated using four factors: the needs of people with reduced mobility, transit connections, passenger activity, and whether the stop is the first or last stop on the route.

Reduced mobility

Bus stops that serve people with reduced mobility should have priority above all others, because the impact of removing a bus stop will be greater for them that all the other users.

Therefore health care centers, senior residences and hospitals that are inside the calculated catchment area of each stop have to be identified. In addition, it was verified that there were direct accesses from these locations to the bus stops inside the catchment area.

Transit connections

In order to keep providing connectivity to any major transit line, it is necessary to assure that the bus stops that serve any major transit connections should not be considered to be removed. For this project a major transit connection is defined as a connection to any station to the *Tren Urbano* and Metro Bus within the catchment area.

Passenger Activity

It is important to know which bus stops have a high volume of passenger activity, but it is also important to know the variability of this activity. For that reason, a *passenger activity* ("pax") *quality* variable is used to distinguish stops with high pax and low variation from those with low pax and high variation. Equation 8 shows how to calculate the *pax quality* variable.

$$\boldsymbol{PaxQuality} = \frac{\boldsymbol{Average\ pax}}{\frac{\boldsymbol{Standard\ Deviation}}{\boldsymbol{Average\ Pax}}} \tag{8}$$

First and last stops

This last part is simply to keep the first and last stops of the route as it is assumed that the first and last stops were located for strategic reasons related to the layover of the bus drivers.

The four factors that were explained are used to create a bus stop class that describes the bus stop importance. All the stops will be categorized in six (6) classes from A to F, with A being the most important, and F being the least important. The criteria for each class are as follows:

- Class A: Serves reduced-mobility facilities *or* connects to the metro, train or to major buses (frequent/express/shuttle) *or* is a first or last stop.
- Class B: Fourth (top) quartile of *pax quality.*
- Class C: Connects to regular bus network.
- Class D: Third quartile of *pax quality.*
- Class E: Second quartile of *pax quality.*
- Class F: All other stops.

Step 3 | Deciding Which Stops Should be Removed, Based on Catchment Area Overlap and Classes

The third step consists of developing a simple *removal score*. Bus stops with a removal score greater than zero will be considered for removal and, logically, the higher the score the greater chance of being removed. Two others factors are taking into account for a final decision: twin stops and consecutive stops.

Twin stops are defined as those stops that share the same intersection. The rule with twin stops is that both of them should be considered to be removed in order to actually be removed. In other words, if only one of the twin stops is chosen to be removed, then both of them will be kept. The only way to remove the twin stops is that both are considered to be removed.

Consecutive stops will not be removed to avoid creating an excessive distance between stops. If consecutives stops obtained a removal score, the even or odd stops will be the one to be removed, and that depends on which one has the higher average removal score. The following process is to describe the steps that must be followed to give a removal score to the bus stops:

1. Give each bus stop in the system an initial *removal score* of 0.
2. For route **R**, for each direction **D** in **R**, and for each stop **S** along **D**:
    a. Find the stops on route **R** in direction **D** that fall within **S**'s catchment area.
    b. Find the most important stop before and after **S** within the catchment area; importance is determined first by class and second by pax quality.
    c. If there are other stops within **S**'s catchment, *and* if they are of lower importance than **S**, *and* if they are not Class **A** stops, add one point to their removal scores.
3. For each stop **S** with a removal score of at least 1:
    a. If **S** has a twin stop, and the twin of **S** has a removal score greater than zero, mark **S** and its twin *under consideration.*
    b. If **S** has no twin stop, mark it as *under consideration.*
4. For each stop **S** *under consideration* that is *not* beside other stops *under consideration:* Remove **S**
5. For all the groups of *consecutive* stops on a route that are *under consideration*:
    a. Calculate the average removal score of the odd and even bus stops.

b. If the odd-numbered stops have a higher average score, remove them, and vice versa. Break ties on average pax quality.

Step 4 | Calculating the Savings Resulting from the Removal of These Stops

It is possible to calculate running time savings by using schedule data. To calculate those savings, the following process can be used:

1. Calculate the number of buses.
2. Calculate the average *cycle time.*
3. Calculate the average *headway* by dividing the average cycle time by the current number of buses.
4. Determine the time savings expected from removing the selected stops; the average time saved by removing one stop is approximately 12 seconds.
5. Calculate the new cycle time by subtracting the total time savings from the cycle time.
6. Calculate the new headway by dividing the new cycle time by the current number of buses.

IV. ANALYSES AND RESULTS

This section presents in detail all the required computations and analysis for the development of this project. First the data used for the evaluation of the bus stops along MBA's Route 5 is presented. The results of the application of both methodologies, the benefit-cost ratio and the four step process, are then explained.

Passenger Load Study

In order to apply both of the methodologies to perform all the analyses, it was necessary to perform a boarding and alighting analysis to the Route 5 of the MBA. This boarding and alighting study was conducted on March 2015, from 6:30AM to 1:00PM, by 14 graduate students of the University of Puerto Rico at Mayaguez. There are two principal reasons for the data collected in a time period of 6 hours; the first one being a budget limitation as there were not enough people to perform the on-and-off count study. The second is that it is important to identify the temporal variations in transit travel; it is expected that the peak volume in the morning is larger than in the afternoon (Vuchic, 2005). There were six teams of two persons who counted the number of people inside and outside of the bus in each one of the bus stops; three teams traveled from Covadonga to Iturregui Terminal and the other three teams from Iturregui to Covadonga. Figure 10 shows the distribution of the teams along Route 5. The information about the time schedule for each bus is shown in Figure 11.

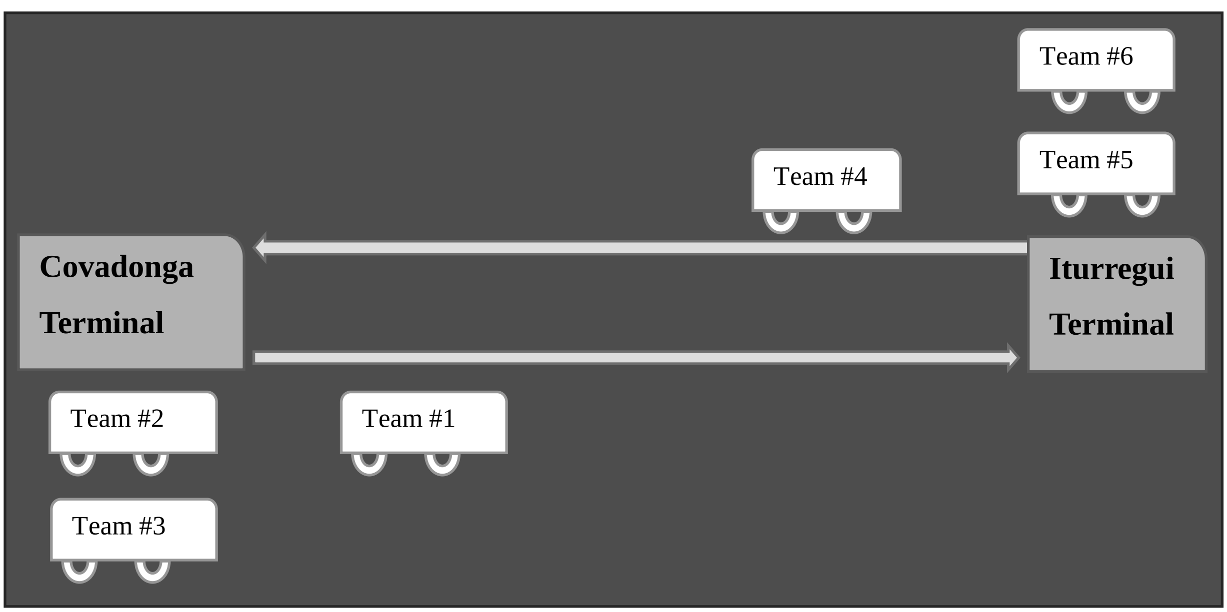

Figure 10: Distribution of Teams for the Boarding and Alighting Study of the Route 5

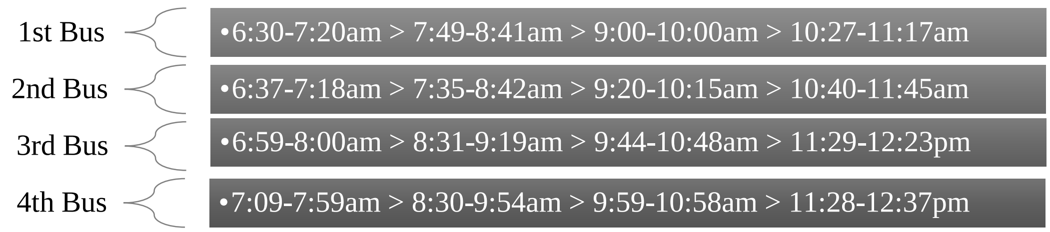

Figure 11: Time Schedule of Buses in the Route 5 (6:30AM to 12:37PM)

Each one of the teams took several trips between both stations and on every trip the amount of people that entered and exited of the bus at every bus stop was counted. There were over 120 bus stops in the two way trip and the bus stopped at almost every one of them. There were several bus stops that never got served by the bus, but others were consistently served. Figure 12 and Figure 13 show the passenger activities from Covadonga to Iturregui Terminal and vice versa. For each one of the bus stops it is shown how many users entered and exited of the bus. By considering the number of passengers on Route 5 in that day from 6:30am to 1:00pm (Table 1 and Table 2), it was observed a maximum of 338 users between two stops from Iturregui to Covadonga Terminal and a maximum of 198 from Covadonga to Iturregui Station. This means that more than 500 users rode Route 5.

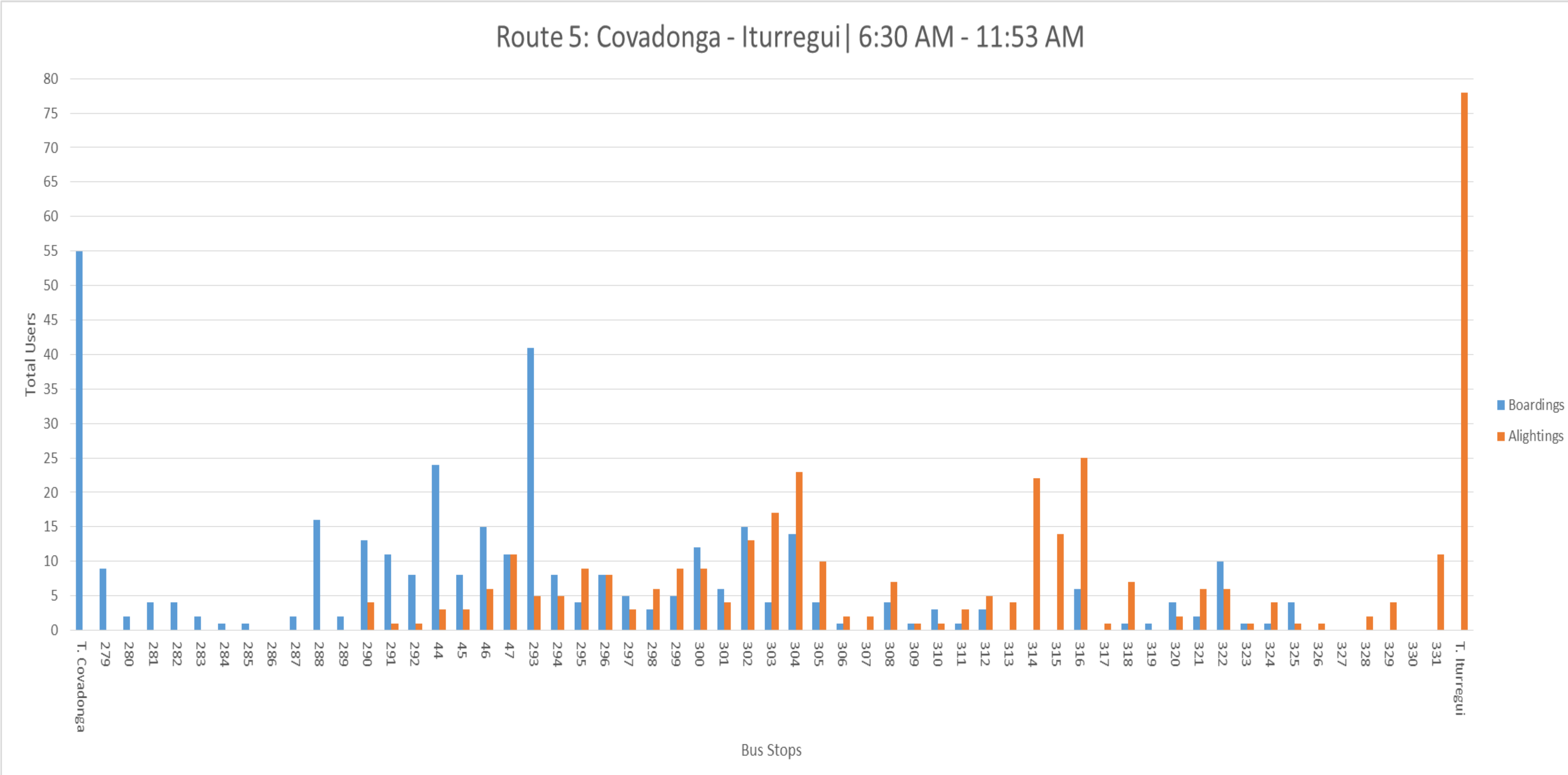

Figure 12: Graphics of Boarding and Alighting from Covadonga to Iturregui Station

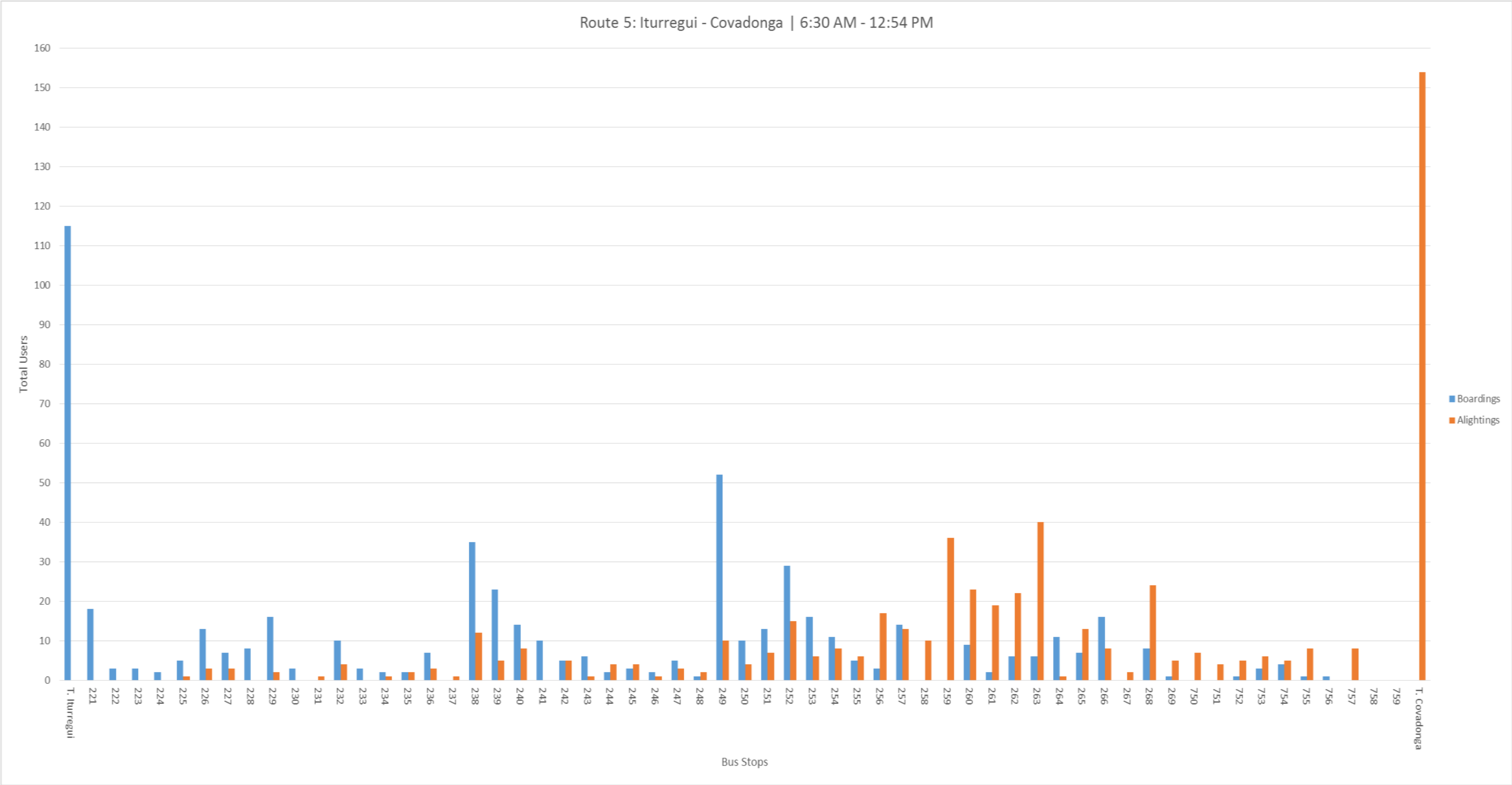

Figure 13: Graphics of Boarding and Alighting from Iturregui to Covadonga Station

Table 1: Total Boarding, Alighting and Load by Each Bus Stop from Covadonga to Iturregui Terminal from 6:30AM to 1:00PM

COV-ITU | 6:30 AM - 11:53 AM			
Bus Stop	Total Boarding	Total Alighting	Total Load
T. Covadonga	55	0	55
279	9	0	64
280	2	0	66
281	4	0	70
282	4	0	74
283	2	0	76
284	1	0	77
285	1	0	78
286	0	0	78
287	2	0	80
288	16	0	96
289	2	0	98
290	13	4	107
291	11	1	117
292	8	1	124
44	24	3	145
45	8	3	150
46	15	6	159
47	11	11	159
293	41	5	195
294	8	5	198
295	4	9	193
296	8	8	193
297	5	3	195
298	3	6	192
299	5	9	188
300	12	9	191
301	6	4	193
302	15	13	195
303	4	17	182
304	14	23	173
305	4	10	167
306	1	2	166
307	0	2	164
308	4	7	161
309	1	1	161
310	3	1	163

COV-ITU | 6:30 AM - 11:53 AM			
Bus Stop	Total Boarding	Total Alighting	Total Load
311	1	3	161
312	3	5	159
313	0	4	155
314	0	22	133
315	0	14	119
316	6	25	100
317	0	1	99
318	1	7	93
319	1	0	94
320	4	2	96
321	2	6	92
322	10	6	96
323	1	1	96
324	1	4	93
325	4	1	96
326	0	1	95
327	0	0	95
328	0	2	93
329	0	4	89
330	0	0	89
331	0	11	78
T. Iturregui	0	78	0

Table 2: Total Boarding, Alighting and Load by Each Bus Stop from Iturregui to Covadonga Terminal from 6:30AM to 1:00PM

ITU-COV | 6:30 AM - 11:53 AM			
Bus Stop	**Total Boarding**	**Total Alighting**	**Total Load**
T. Iturregui	115	0	115
221	18	0	133
222	3	0	136
223	3	0	139
224	2	0	141
225	5	1	145
226	13	3	155
227	7	3	159
228	8	0	167
229	16	2	181
230	3	0	184
231	0	1	183
232	10	4	189
233	3	0	192
234	2	1	193
235	2	2	193
236	7	3	197
237	0	1	196
238	35	12	219
239	23	5	237
240	14	8	243
241	10	0	253
242	5	5	253
243	6	1	258
244	2	4	256
245	3	4	255
246	2	1	256
247	5	3	258
248	1	2	257
249	52	10	299
250	10	4	305
251	13	7	311
252	29	15	325

ITU-COV | 6:30 AM - 11:53 AM			
Bus Stop	**Total Boarding**	**Total Alighting**	**Total Load**
253	16	6	335
254	11	8	338
255	5	6	337
256	3	17	323
257	14	13	324
258	0	10	314
259	0	36	278
260	9	23	264
261	2	19	247
262	6	22	231
263	6	40	197
264	11	1	207
265	7	13	201
266	16	8	209
267	0	2	207
268	8	24	191
269	1	5	187
750	0	7	180
751	0	4	176
752	1	5	172
753	3	6	169
754	4	5	168
755	1	8	161
756	1	0	162
757	0	8	154
758	0	0	154
759	0	0	154
T. Covadonga	0	154	0

Benefit-Cost Ratio Analysis

This first methodology is simple to apply and is very useful to identify the possible bus stops to eliminate or consolidate. As mentioned before, this methodology consists of finding the benefits and costs of removing a bus stop from any bus route. The benefit of removing a bus stop is a function of how many passengers are riding through two bus stops and the time earned by those riders as a result of the removal of the bus stop. The cost is a function of how many users are actually accessing the bus stops and how difficult is to walk to the next bus stop when a stop is removed.

The Benefit

There are two variables for obtaining the benefit of removing a bus stop: the number of passengers that are riding through the bus stop that is being evaluated for removal (P_r), and the additional riding time that the passenger saves from the bus stop removal. Clearly this benefit is for the people who are inside a bus; if a bus stop is removed, there is less time spent in the boarding and alighting of the users at the bus stops.

The quantity of passengers riding through two bus stops (**P_r**) is calculated by adding the passengers inside the bus and those who are boarding in the next stop, and subtracting the alighting at that stop. In other words, the load arriving minus alighting. The information used to perform these computations was previously shown in Table 1 and Table 2.

The additional riding time because of the stop (**T_r**) or the average time lost per stop regardless of stop activity was set to 15 seconds. Transit planners commonly use values between 10 and 20 seconds, therefore for this project a midrange value of 15 seconds was used.

The Cost

The first variable to calculate is the **cost**. For this is necessary to calculate the passenger activity on each bus stop (**P_a**), the net increase in saving travel time for removing a bus stop (**T_a**) and the value of access time relative to riding time (**V_a**). To calculate how many people are accessing every bus stop, the total boarding and total alighting on every bus stop were added, as shown in Table 3. This would indicate how high the passenger activity around the bus stop is and will identify the places that the users are willing to go.

Table 3: Example of the Calculation of the Variable P_a for 10 Bus Stops of the Route 5 from Iturregui to Covadonga Terminal

Bus Stop	**Total Boarding**	**Total Alighting**	**P_a**
250	10	4	*14*
251	13	7	*20*
252	29	15	*44*
253	16	6	*22*
254	11	8	*19*
255	5	6	*11*
256	3	17	*20*
257	14	13	*27*
258	0	10	*10*
259	0	36	*36*
260	9	23	*32*

The next variable to calculate is the average additional travel time experienced by the passengers within the evaluated stop's service area when they have to access the closest remaining bus stop ($\mathbf{T_a}$). $\mathbf{T_a}$ is calculated by the division of the average additional walking distance to the remaining stop ($\mathbf{D_w}$) and the average walking speed of the people ($\mathbf{v_w}$).

$\mathbf{D_w}$ is a weighted average of the distance to the nearest stop ($\mathbf{D_n}$) and the distance to the far stop ($\mathbf{D_f}$) that a user has to walk if a bus stop is removed. These two distances are calculated based on the available walking distance. Figure 14 shows the nearest and farthest bus stop from the stop 305 of the Route 5. Here the nearest and farthest walking distances towards the nearest bus stops, 304 and 306, were 725 feet and 889 feet, respectively.

The average walking speed, $\mathbf{v_w}$, is 4.4 ft/s for a healthy person and approximately 2.5 ft/s for elder people (Carey, 2005). In this case it was assumed a value of 3.5 ft/s to take into account all the people around every bus stop. Having $\mathbf{D_w}$ and $\mathbf{v_w}$ calculated, the next step is to calculate $\mathbf{T_a}$ by dividing the last two variables. The value of access time relative to riding time, $\mathbf{V_a}$, is set to 2. This means that the users of the Route 5 value twice the walking and waiting time compared with in-vehicle travel time.

Figure 14: Example of the Process of Measure of D_n and D_f (not to scale; Source: Google Earth, 2015).

Benefit-Cost Ratio

After calculating the values of the benefit and cost of removing a bus stop, the benefit-cost ratio was calculated. This value was calculated by dividing the benefit between the costs. In Table 4 an example of the benefit-cost ratio results of the bus stops 250 to 260 is shown. According to the results, the bus stops 254, 255, 256 and 258 are selected for removal since the B/C is greater or equal than one.

Table 4: Example of Benefit-Cost Ratio for 10 Bus Stops of the Route 5 from Iturregui to Covadonga Terminal

Bus Stop	**B/C Ratio**
250	0.9
251	0.7
252	0.3
253	0.9
254	1.4
255	2.8
256	1.4
257	0.7
258	2.2
259	0.7
260	0.7

Figure 15 shows the bus stops from 250 to 260 that were selected for removal from the Iturregui to Covadonga terminal. It can be noted that bus stops 254, 255 and 256 are consecutive stops. It is important to establish that consecutive bus stops cannot be removed because it would cause a greater distance between the other stops. For example, if the bus stops 254, 255 and 256 were removed, the distance between bus stops 253 and 257 would be too long for a person to walk. To address this issue it is proposed to analyze every group of consecutive bus stops by reviewing each one of their benefit-cost ratio and decide which the best candidates to be removed are.

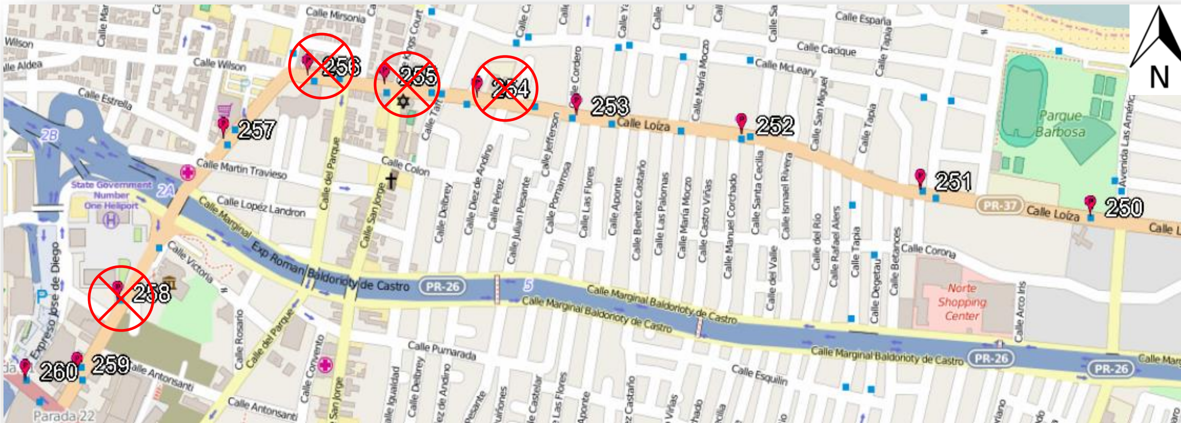

Figure 15: Top View of Bus Stops 260 to 250 of the Route 5 from Iturregui to Covadonga Terminal (Not to scale; Source: ArcGIS Explorer)

The average benefit-cost ratio for the even and odd bus stops was calculated. Then, the even or odd bus stops that had the greater average benefit-cost ratio were selected to be removed. Table 5 shows the process of calculating the average benefit-cost ratio of the even and odd bus stops. In this case, bus stop 255 was the one selected to be removed, while bus stops 254 and 256 were not. The result of this first analysis is summarized in Table 6; it shows all the bus stops that were selected for removal.

Table 5: Example of the Process of Decision Making to Choose Odd or Even Consecutive Bus Stops

Stop ID	B/C	Ave. Even Stops	Ave. Odd Stops
250	2.8	-	-
251	0.7	-	-
252	0.3	-	-
253	0.9	-	-
254	1.4		
255	2.8	1.4	2.8
256	1.4		
257	0.7	-	-
258	2.2	-	-
259	0.7	-	-
260	0.7	-	-

Table 6: All the Bus Stops Selected for Removal by the Benefit-Cost Ratio Method

Bus Stops	B/C Ratio
222	2.3
224	2.9
228	1.8
231	9.8
234	4.1
237	2.7
242	1.1
244	1.9
246	5
248	6.3
255	2.8
258	2.2
264	1.5
267	5.3
289	3.1
292	1.2
298	1.8
301	1.4
307	6.3
309	5.1
311	1.6
313	2.6
317	1.8
319	7.3
323	2.3
326	9.2
328	2.1
330	4.9
Total	**28**

Figure 16 to Figure 21 show each of the bus stops that were selected to be removed from Iturregui to Covadonga and from Covadonga to Iturregui terminal, respectively.

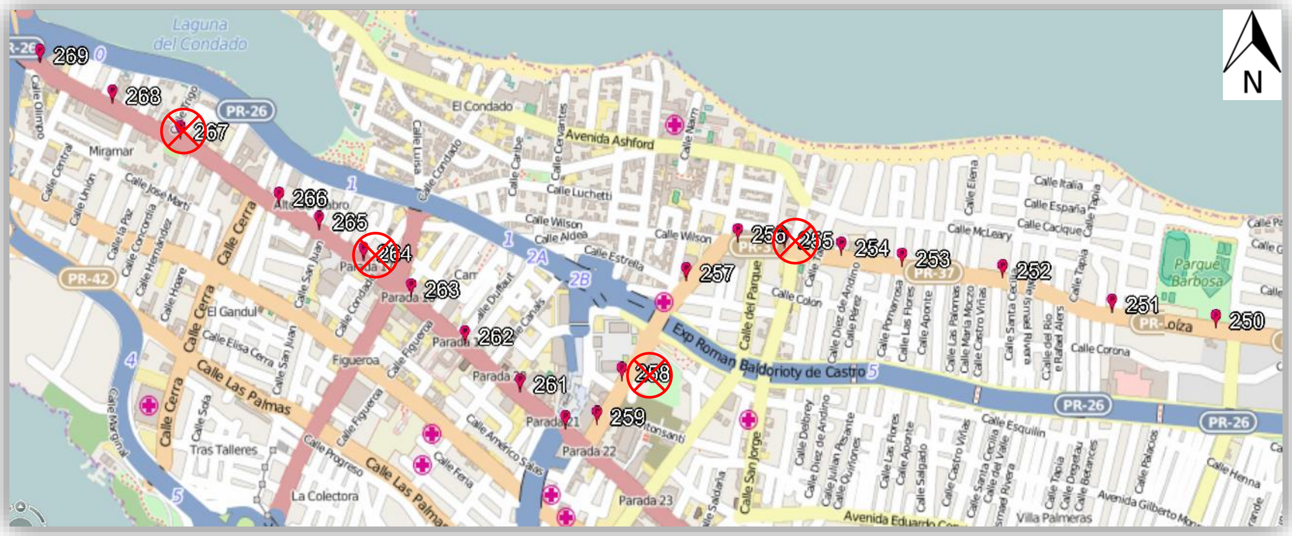

Figure 16: Bus Stops Selected for Removal from Iturregui to Covadonga Terminal – Bus Stop 269 to 250 (Not to scale; Source: ArcGIS Explorer)

Figure 17: Bus Stops Selected for Removal from Iturregui to Covadonga Terminal – Bus Stop 250 to 237 (Not to scale; Source: ArcGIS Explorer)

Figure 18: Bus Stops Selected for Removal from Iturregui to Covadonga Terminal – Bus Stop 232 to 221 (Not to scale; Source: ArcGIS Explorer)

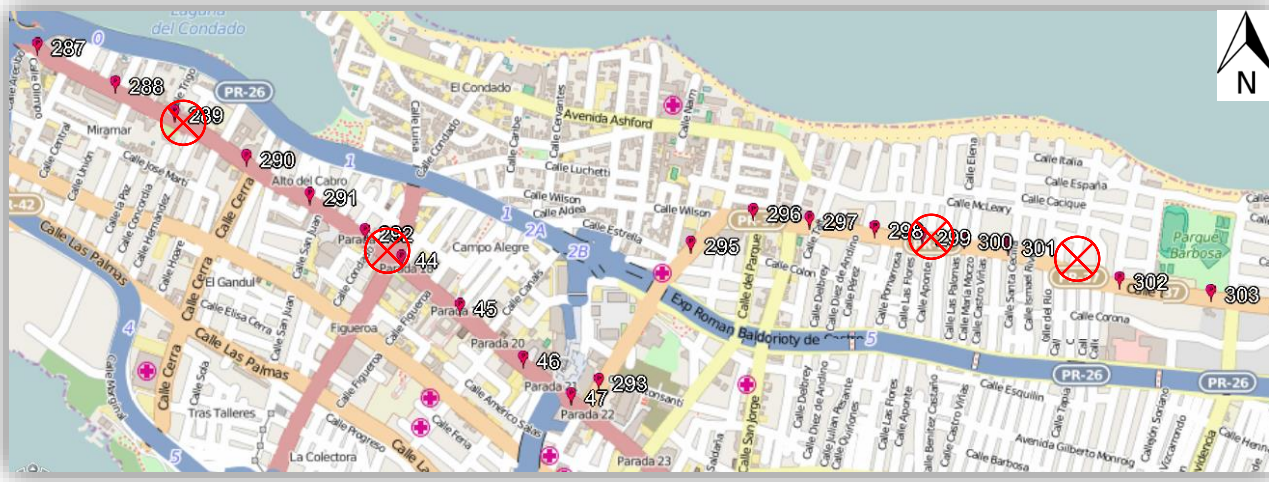

Figure 19: Bus Stops Selected for Removal from Covadonga to Iturregui Terminal – Bus Stop 287 to 303 (Not to scale; Source: ArcGIS Explorer)

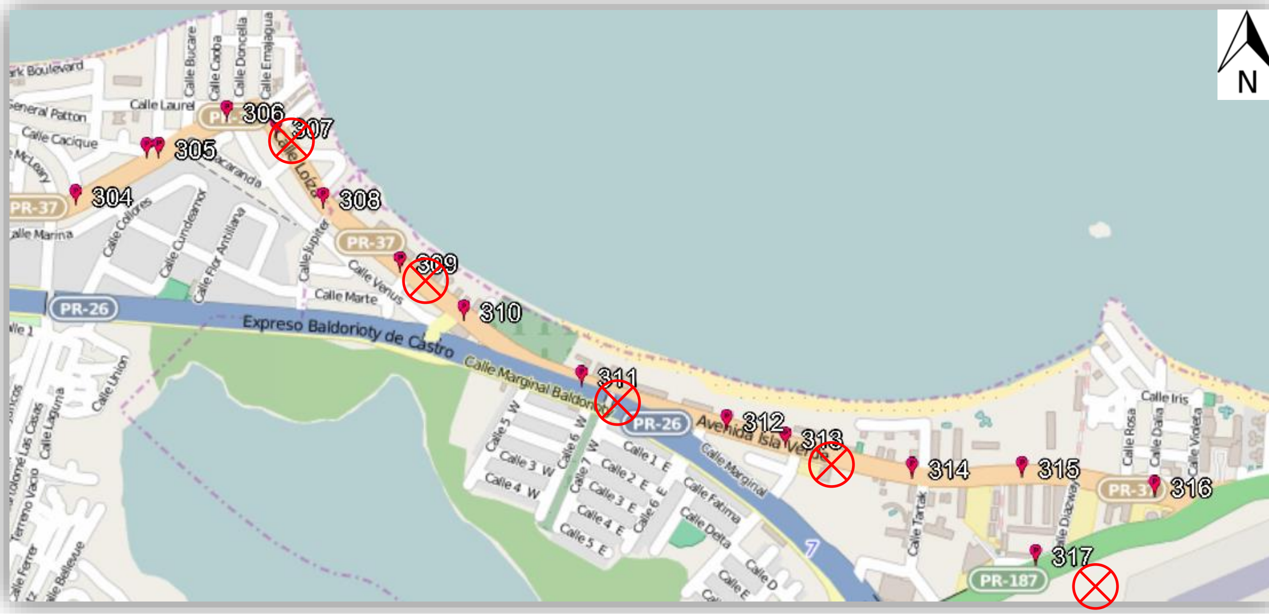

Figure 20: Bus Stops Selected for Removal from Covadonga to Iturregui Terminal – Bus Stop to 304 to 317 (Not to scale; Source: ArcGIS Explorer)

Figure 21: Bus Stops Selected for Removal from Covadonga to Iturregui Terminal – Bus Stop to 318 to 331 (Not to scale; Source: ArcGIS Explorer)

Four Step Process Analysis

The second analysis performed to identify the bus stops to be removed was the "four step process". This process, compared with the benefit-cost ratio analysis, is more complex and shows more sensibility with people with reduced mobility and the needs to reach health care services and hospitals. The method is aimed to decide which bus stops should be removed based on the social importance of those bus stops.

Catchment Area

This process started with the determination of each bus stop catchment area; that is, a buffer of 400 meters around every bus stop that represents a standard walking distance that people are willing to walk to a transit stop (Walker, 2011). For every bus stop on the Route 5 from Iturregui to Covadonga terminal, and vice versa, a catchment area with a 400 meters radius was created. Figure 22 shows every buffer zone for each one of the bus stops in both directions of Route 5. With this illustration it can be shown how close all the bus stops are; there is an excess of overlapping of the catchment areas.

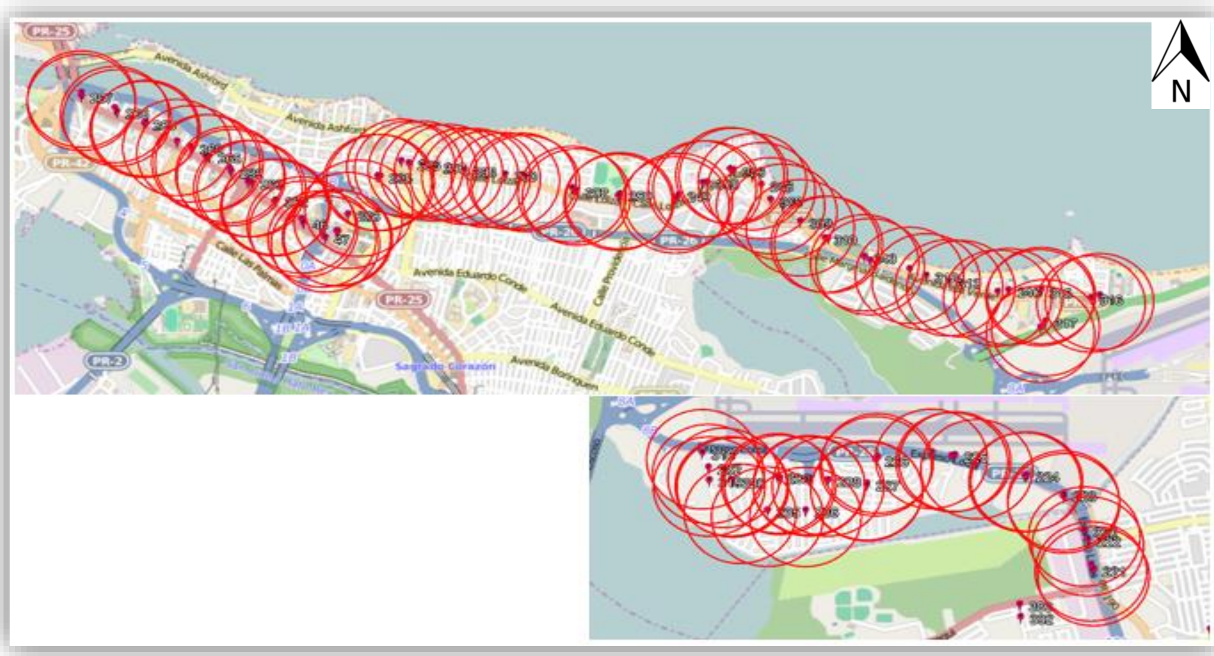

Figure 22 : 400 Meters Catchment Area for Each Bus Stop of the Route 5 (Not to scale; Source: ArcGIS Explorer)

Class of Each Stop

The second step of this process is to classify each one of the bus stops. Four factors are taken into account to decide which bus stops have a greater classification. These factors are: users with reduced mobility, transit connections, passenger activity, and first and last stops.

Reduced Mobility

The bus stops that serve people with reduce mobility have to be classified with a high class and are not considered to be removed. It is important not to remove the bus stops that are necessary to people with disabilities. These bus stops have to provide connection to hospitals, health care centers, and nursing homes. Nineteen hospitals, 17 health care centers and 56 nursing homes around the Metropolitan Area of San Juan were identified. Other locations that could generate trips were not considered as the methodology studied did not specify it. Figure 23 shows all the places with people with reduced mobility including hospitals, health care centers and nursing homes.

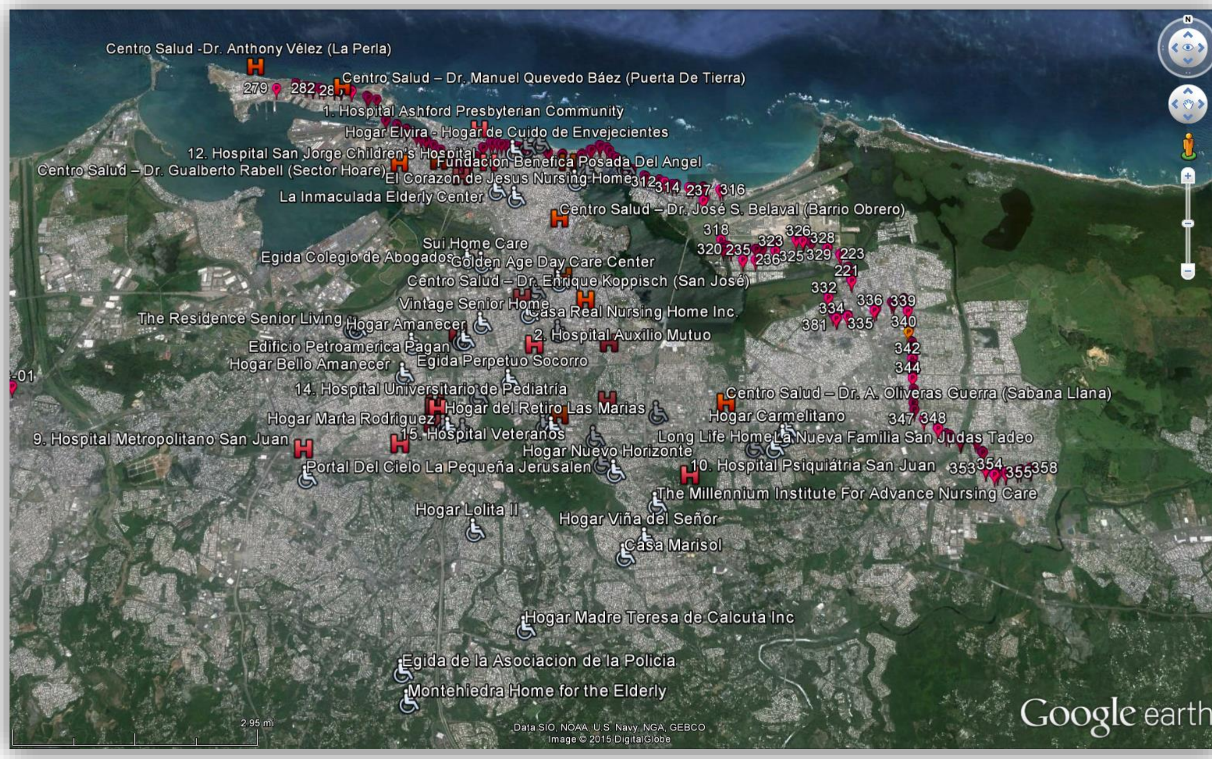

Figure 23: Locations of Hospitals, Health Care Centers and Nursing Homes in the San Juan Metropolitan Area (Source: Google Earth, 2015)

Transit Connection

It must be ensured to keep a bus stop that is serving a major transit connection, since is important to provide continuity and connection to the transit system. A major transit connection is defined as other transit systems besides the MBA system. These systems could be *Tren Urbano,* public carriers, and terminals and transfer centers of the MBA transit service. Figure 24 shows all the terminals and transfer centers of the MBA in the Metropolitan Area of San Juan. Route 5 does not have any *Tren Urbano* station nearby, so only the terminals and transfer centers of MBA were taken into account.

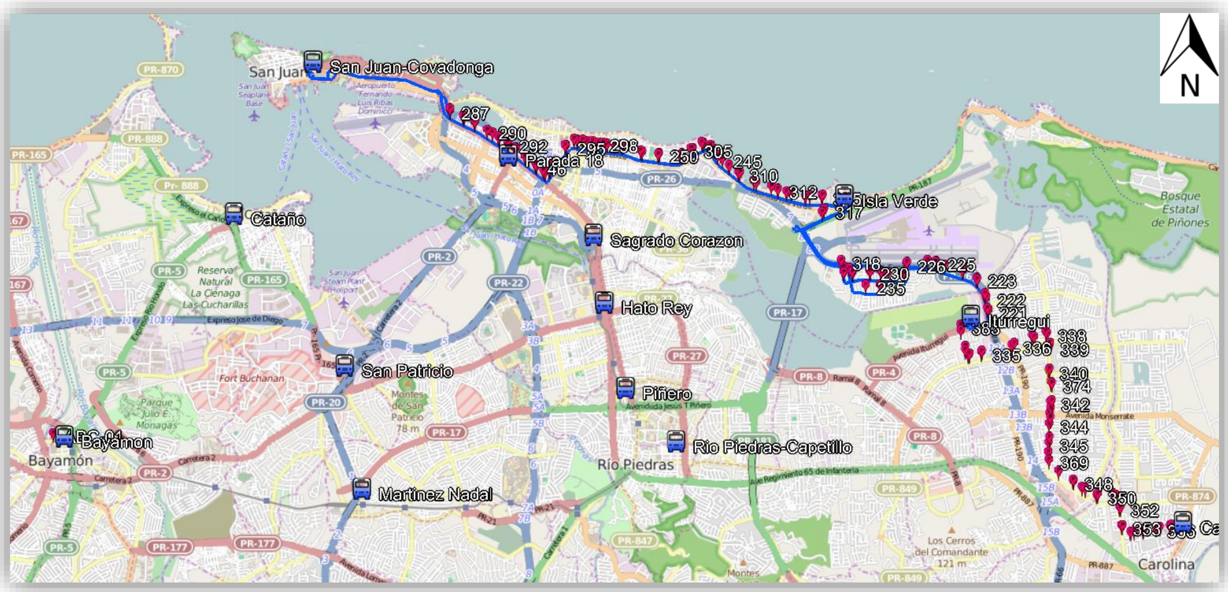

Figure 24: Terminals and Transfer Centers of the Metropolitan Bus Authority (Not to scale; Source: ArcGIS Explorer)

Passenger Activity

In this third step it is analyzed the passenger activity ("pax") by the creation of a variable called Pax Quality. This variable is used to distinguish bus stops with high pax and low variation from those with low pax and high variation. The larger the Pax Quality value, the more reliable is the bus stop passenger activity. To calculate the Pax Quality is necessary to calculate the average passenger activity (**μ**) around every bus stop and the standard deviation of those data (**σ**) Using Equation 8 the Pax Quality variable for each bus stop is calculated. Table 7 shows an example of the calculation of each one of the variables to calculate the Pax Quality.

Table 7: Example of the Pax Quality for Each Bus Stop.

Bus Stop	**μ**	**σ**	**μ/ σ**	**PaxQuality**
T. Covadonga	6.88	3.681518	0.53549346	12.83862549
279	1.13	1.125992	1.00088145	1.124009247
280	0.25	0.46291	1.8516402	0.135015431
281	0.50	1.414214	2.82842712	0.176776695
282	0.50	0.755929	1.51185789	0.330718914
283	0.25	0.707107	2.82842712	0.088388348
284	0.13	0.353553	2.82842712	0.044194174
285	0.13	0.353553	2.82842712	0.044194174

First and Last Stop

This last step consists of avoiding the elimination of the first and last stop of Route 5. The reason for this is because those first and last stops were designed for strategic reasons due to bus drivers' layovers.

Stop Class

When all four factors are determined, then each bus stop can be classified. An example of the classification of several bus stops is shown in Table 8. Table 9 shows the classification distribution of the 98 bus stops of Route 5.

Table 8: Example of Several Bus Stops with their Classification.

Bus Stop	**Quartile**	**Class**
T. Iturregui	4	
221	3	A
222	1	F
223	1	F
224	1	F
225	2	E
226	3	D
227	3	D
228	2	E
229	3	D
230	1	F
231	1	F
232	3	D
233	1	F
234	1	F
235	1	F
236	3	D
237	1	F
238	4	B
239	3	D
240	3	D
241	2	E
242	2	E
243	1	F
244	1	A
245	2	A

Table 9: Distribution of Bus Stop Classes.

Class	Criteria	Qty.	Percent
A	Bus stops that serve people with reduced mobility or that serves major transit connections or first and last stops.	37	38%
B	Fourth (top) quartile of pax quality	8	8%
C	Bus stops that serves terminals and/or transfer centers of the MBA	2	2%
D	Third quartile of pax quality	17	17%
E	Second quartile of pax quality	16	16%
F	All other stops	18	18%
	Total	**98**	**100%**

Removal Score

The third step of this consolidation process is to give a removal score to the bus stops according to their classes. For this it is necessary to analyze stop by stop following the process established in the methodology. Table 10 shows the process of granting the removal score for every bus stop. For example, the bus stop 228 has two bus stops before and three bus stops after, as shown in Figure 25. The bus stops before bus stop 228 (227 and 226) have the same class D, but bus stop 227 has a lower Pax Quality, thus is granted one point to the removal score. The bus stops after bus stop 228 (229, 230 and 231) have D and F classes. In this case, the bus stop with the highest classification (bus stop 229, class D) does not have a removal score point, but the other bus stops remaining (bus stops 230 and 231) both are bus stops class F, and bus stop 231 have the lowest Pax Quality, thus is granted one point to the removal score.

Table 10: Example of Granting Removal Score to the Bus Stops.

Stop Name	Class	PaxQuality*	Stops Before	Stops After	Removal Score
T. Iturregui	N/A	-	-	-	-
221	A	0.67	0	1	-
222	F	0.12	1	1	-
223	F	0.15	1	1	-
224	F	0.14	1	0	-
225	E	0.26	0	0	-
226	D	0.63	1	2	-
227	D	0.53	1	1	1
228	E	0.44	2	3	2
229	D	0.60	1	3	-
230	F	0.15	2	5	4
231	F	0.06	1	4	6
232	D	0.60	1	2	-
233	F	0.12	3	1	6
234	F	0.17	4	1	4
235	F	0.19	4	1	3
236	D	0.50	4	0	-
237	F	0.07	0	2	-
238	B	0.93	0	0	-
239	D	0.72	1	1	3
240	D	0.74	2	1	-

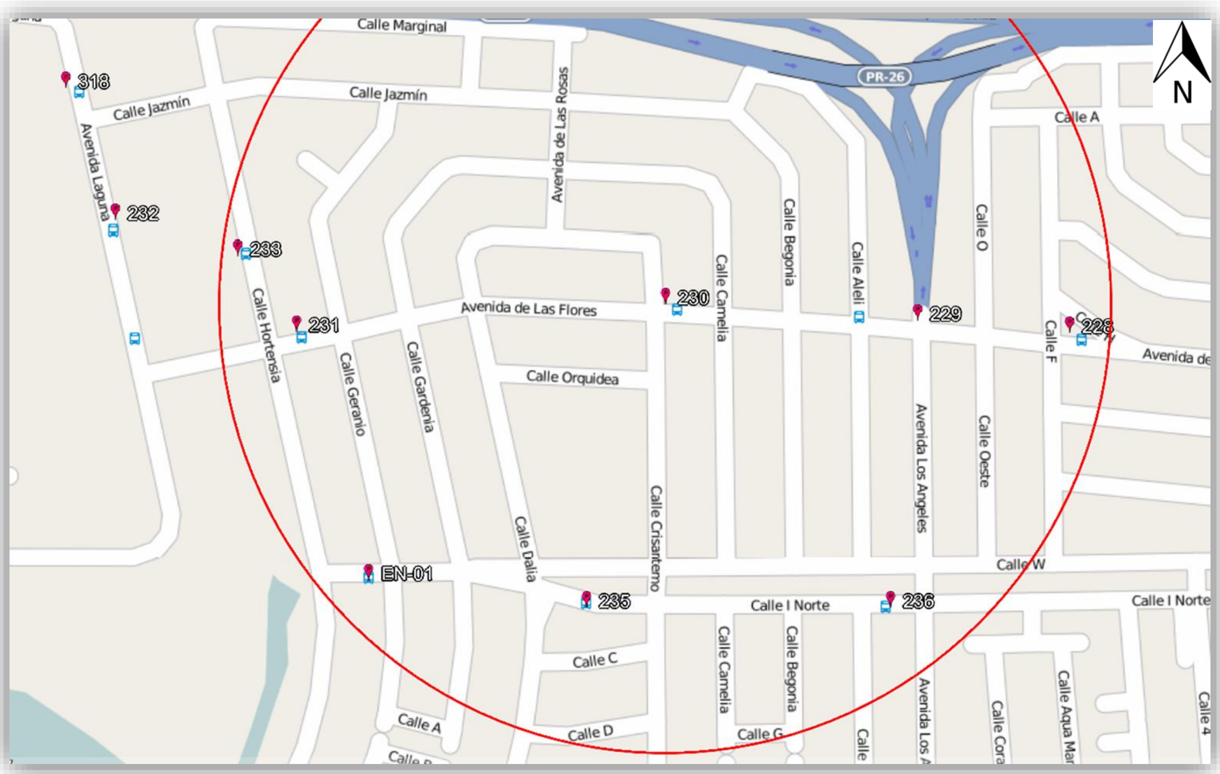

Figure 25: Example of Several Bus Stop inside the Catchment Area of the Bus Stop 230 (Source: ArcGIS Explorer).

An interesting result of this removal score was to realize that several consecutive bus stops were too close and had a classification of A. The main reason for these results is because several bus stops serve the same hospital, health care centers or nursing homes, thus giving the bus stops a high classification. Table 11 shows an example of five consecutive bus stops. For those bus stops a reevaluation of the class was performed. For example, Figure 26 shows that bus stops 297 to 301 serve the same nursing home, *Hogar Elvira*. This raises the question of which of those bus stops is actually serving the nursing home, or at least which of those has the greatest probability. To identify which bus stop, the walking distance of each bus stop to the nursing home is measured, and the nearest bus stop that serves the nursing home is chosen to be the Class A bus stop. Table 12 shows the walking distances of each of those bus stop to the nursing home. After analyzing every consecutive bus stop with Class A, the classification changed for some of them, as shown in Figure 27. With this reevaluation the different classes of bus stops changed, as shown in Table 13.

Table 11: Consecutive Class A Bus Stops.

Stop ID	Class	Pax Quality
297	A	0.59
298	A	0.58
299	A	0.66
300	A	0.85
301	A	0.58

Table 12: Walking Distance from Bus Stops to Nursing Home Hogar Elvira.

Reduced Mobility Center	Stop ID	Walking Distance
Hogar Elvira	297	1437.14
	298	703.7
	299	657.71
	300	1130.95
	301	1616.07

Table 13: New Distribution of Bus Stop Classes After Reevaluation of Consecutive Class A Bus Stops.

Class	Criteria	Qty.	Percent
A	Bus stops that serves people with reduced mobility or that serves major transit connections or first and last stops.	25	26%
B	Fourth (top) quartile of pax quality	14	14%
C	Bus stops that serves terminals and/or transfer centers of the MBA	1	1%
D	Third quartile of pax quality	24	24%
E	Second quartile of pax quality	16	16%
F	All other stops	18	18%
	Total	**98**	**100%**

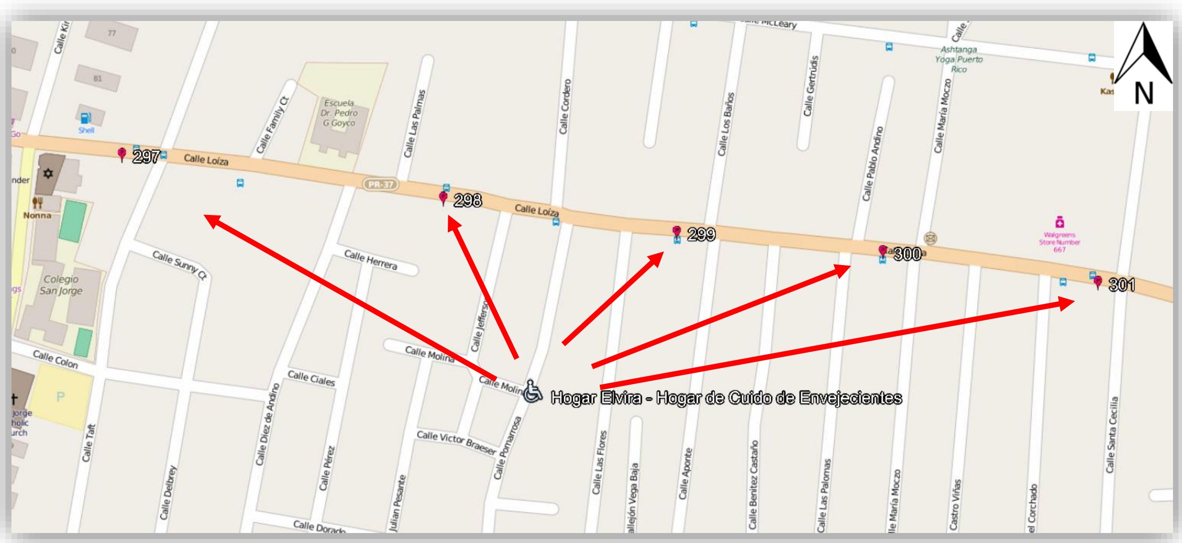

Figure 26: Bus Stops 297 to 301 Serving the Same Nursing Home, Hogar Elvira, *Along Route 5 (Source: Google Earth, 2015)*

Bus Stop	Class	PaxQuality*	Stops Before	Stops After	Removal Score
45	A	0.57	1	1	-
46	A	0.67	1	2	-
47	A	0.74	1	2	-
293	A	0.93	2	1	-
294	A	0.63	2	1	-
295	A	0.79	1	1	-
296	A	0.87	1	1	-
297	A	0.59	1	2	-
298	A	0.58	1	2	-
299	A	0.66	2	2	-
300	A	0.85	2	1	-
301	A	0.58	2	1	-
302	A	0.88	1	1	-
303	A	0.77	1	0	-
304	A	0.93	0	1	-

Bus Stop	New Class	PaxQuality*	Stops Before	Stops After	Removal Score
45	A	3	1	1	
46	A	3	1	2	
47	A	3	1	2	
293	B	4	2	1	3
294	A	3	2	1	
295	A	4	1	1	
296	B	4	1	1	
297	D	3	1	2	
298	D	3	1	2	3
299	A	3	2	2	
300	A	4	2	1	
301	A	3	2	1	
302	B	4	1	1	
303	A	4	1	0	
304	B	4	0	1	

Figure 27: Example of the Reevaluation of Consecutive Class A Bus Stops.

An example of the final removal score is shown in Figure 28. In this example from bus stop 291 to 319, seven bus stops are marked for removal. Table 14 summarizes all the bus stops that were selected to be removed. There are 16 bus stops to be removed, eight less bus stops compared with the 28 bus stop to be removed according to the benefit-cost ratio method.

Stop Name	Class	PaxQuality*	Stops Before	Stops After	Removal Score	Mark as Potential	Mark for Removal
291	D	0.57	1	2	1	Potentail removal	-
292	C	0.54	1	1	1	Potentail removal	For Removal
44	B	0.89	2	1	-		
45	A	3	1	1	-		
46	A	3	1	2	-		
47	A	3	1	2	-		
293	B	4	2	1	3	Potentail removal	For Removal
294	A	3	2	1	-		
295	A	4	1	1	-		
296	B	4	1	1	-		
297	D	3	1	2	-		
298	D	3	1	2	3	Potentail removal	For Removal
299	A	3	2	2	-		
300	A	4	2	1	-		
301	A	3	2	1	-		
302	B	4	1	1	-		
303	A	4	1	0	-		
304	B	4	0	1	-		
305	B	0.79	1	2	-		
306	E	0.36	1	2	1	Potentail removal	-
307	F	0.22	2	1	3	Potentail removal	For Removal
308	D	0.73	2	1	-		
309	A	0.24	1	1	-		
310	A	0.50	1	1	-		
311	E	0.39	1	0	-		
312	D	0.59	0	1	-		
313	E	0.38	1	1	-		
314	B	0.80	1	1	-		
315	D	0.74	1	2	1	Potentail removal	For Removal
316	B	0.89	1	1	-		
317	F	0.18	2	0	1	Potentail removal	For Removal
318	D	0.69	0	2	-		
319	F	0.20	1	1	2	Potential removal	For Removal

Figure 28: Example of the Final Removing Score for the Bus Stops.

Table 14: Bus Stops Selected for Removal from the Route 5 of the MBA.

Bus Stops Selected for Removal
228
231
233
235
239
255
260
265
292
293
298
307
315
317
319
327

From Figure 29 to Figure 34 shows each of the bus stops that were selected to be removed from Iturregui to Covadonga and from Covadonga to Iturregui terminal, respectively by the four-step process.

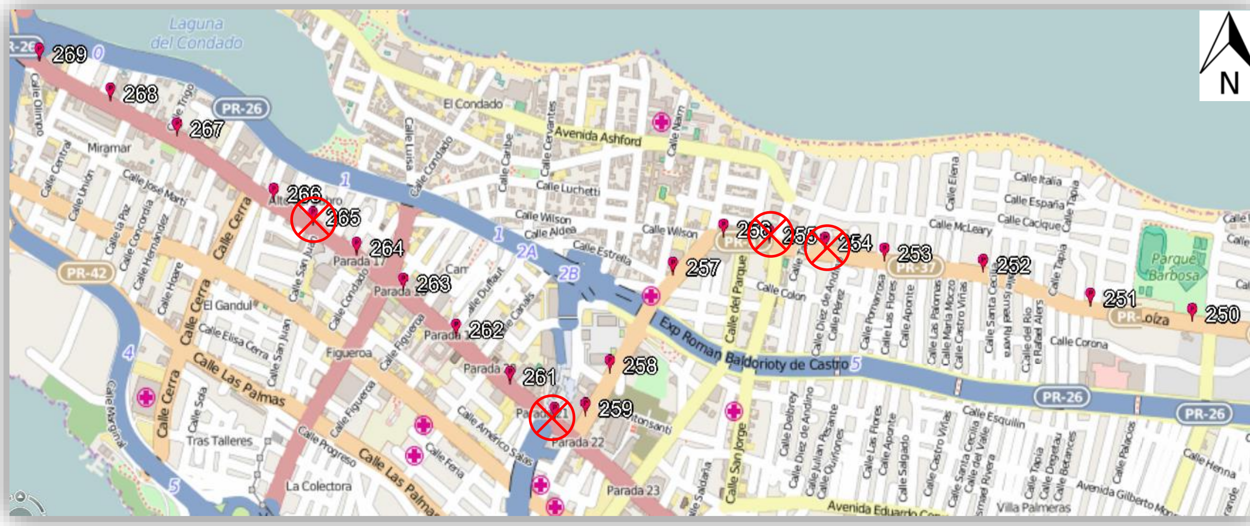

Figure 29: Bus Stops Selected for Removal from Iturregui to Covadonga Terminal – Bus Stop 269 to 250 (Not to scale; Source: ArcGIS Explorer)

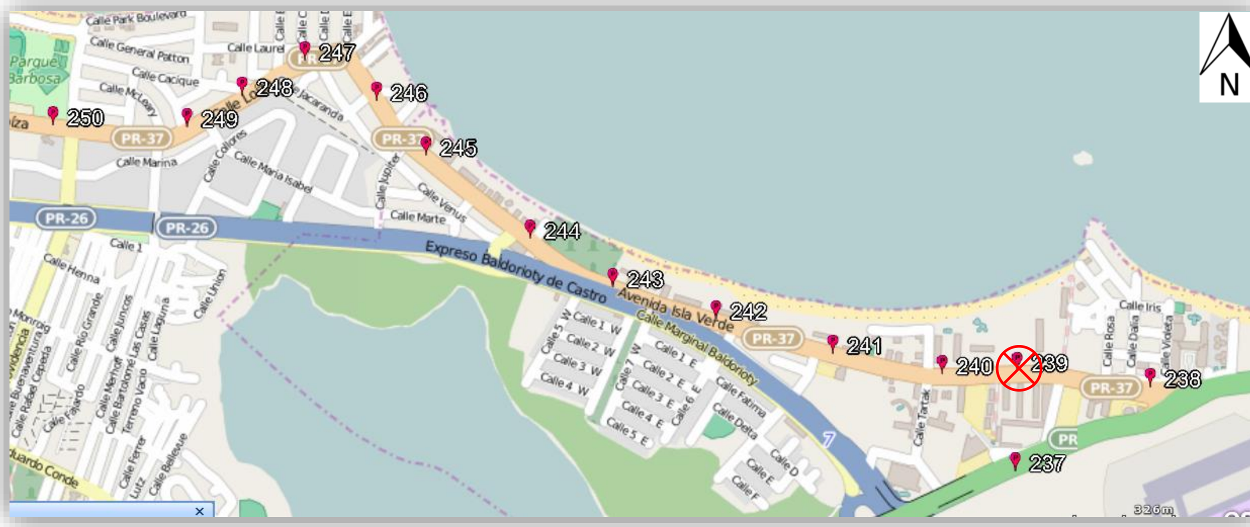

Figure 30: Bus Stops Selected for Removal from Iturregui to Covadonga Terminal – Bus Stop 250 to 237 (Not to scale; Source: ArcGIS Explorer)

Figure 31: Bus Stops Selected for Removal from Iturregui to Covadonga Terminal – Bus Stop 232 to 221 (Not to scale; Source: ArcGIS Explorer)

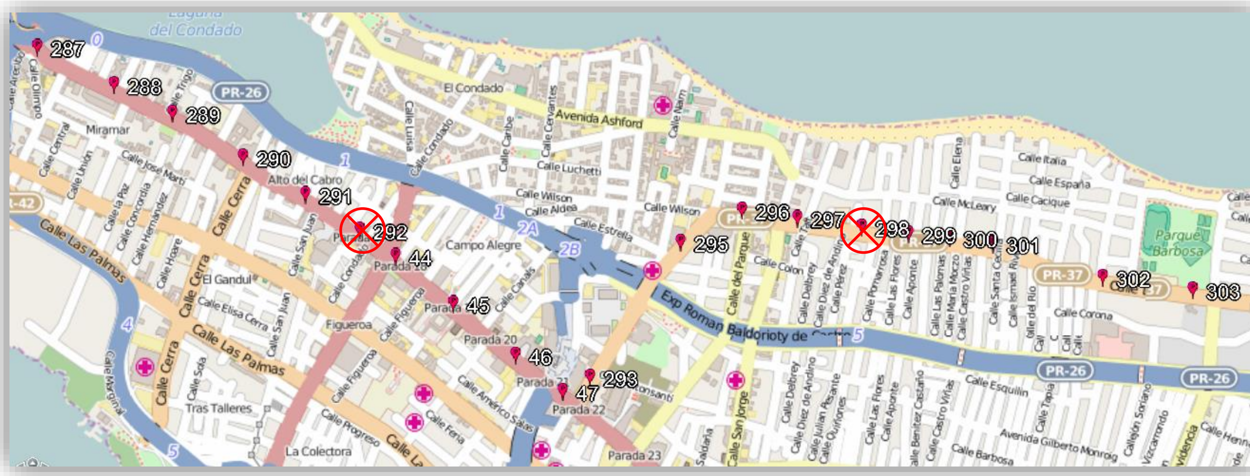

Figure 32: Bus Stops Selected for Removal from Covadonga to Iturregui Terminal – Bus Stop to 297 to 303 (Not to scale; Source: ArcGIS Explorer)

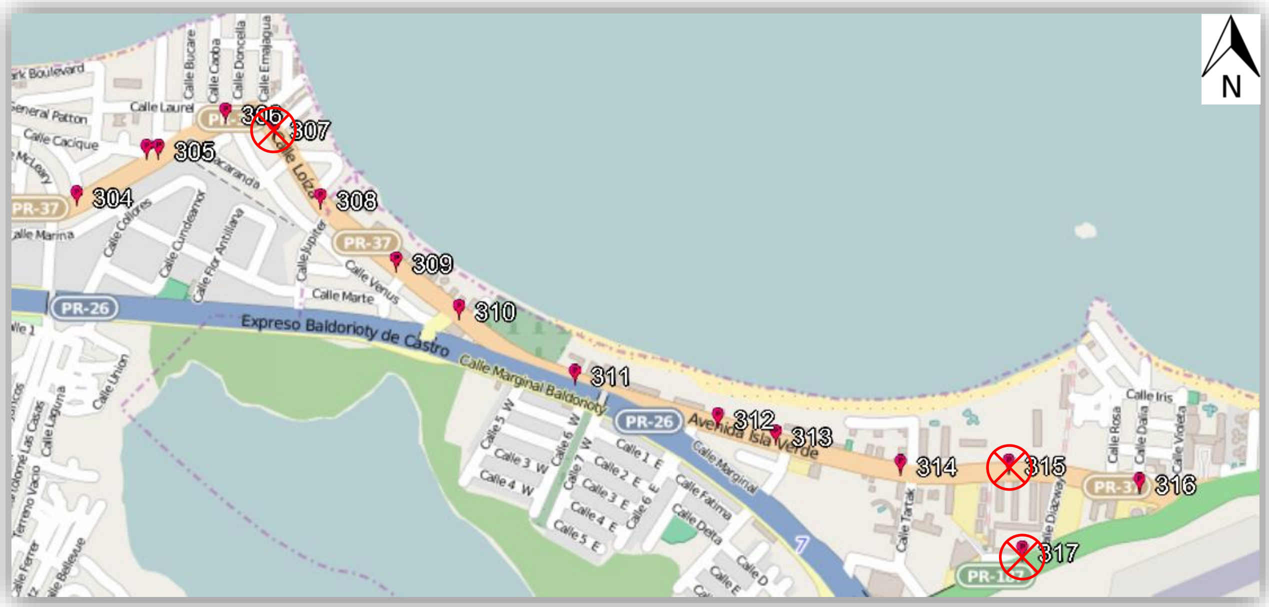

Figure 33: Bus Stops Selected for Removal from Covadonga to Iturregui Terminal – Bus Stop to 304 to 317 (Not to scale; Source: ArcGIS Explorer)

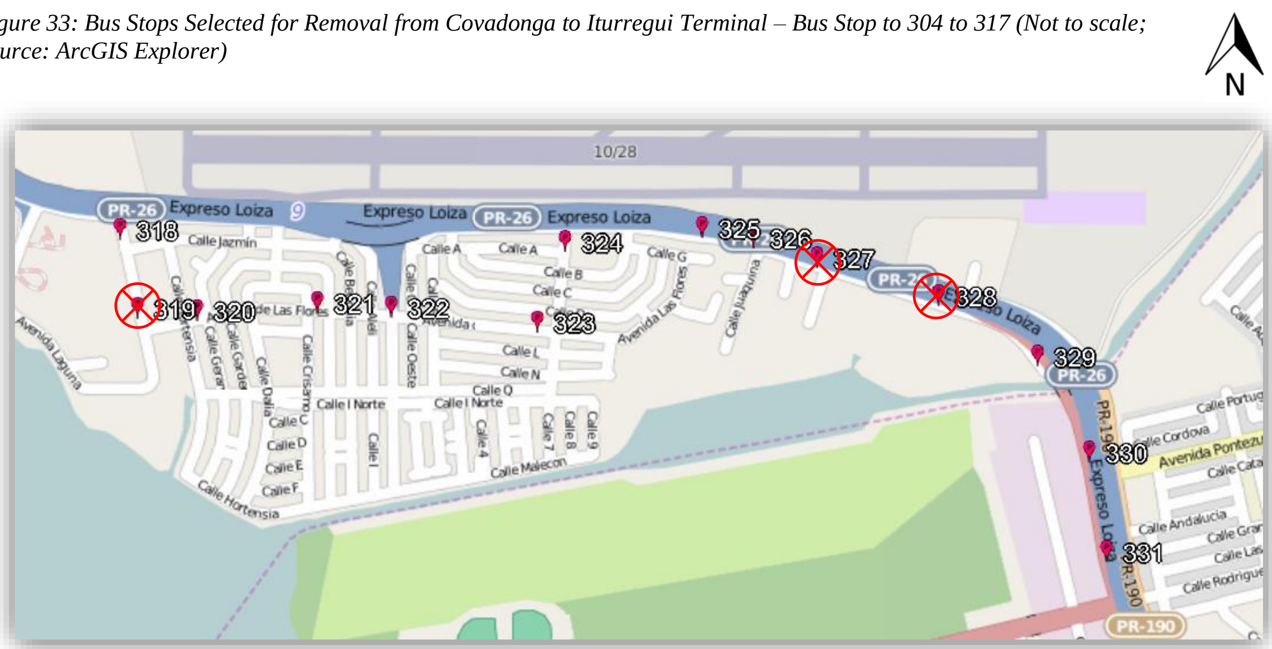

Figure 34: Bus Stops Selected for Removal from Covadonga to Iturregui Terminal – Bus Stop to 318 to 331 (Not to scale; Source: ArcGIS Explorer)

Savings Resulting From the Bus Stop Removal

The last step of this process is to calculate the savings of removing the selected bus stops. These savings are function of the time earned from the removal of the bus stops. The time saved from removing a bus stop is set to 12 seconds, only if the Pax Quality is higher than 1. If the Pax Quality is less than 1, the savings will be 12 second multiplied by the Pax Quality. For example, in Table 15 the bus stop 228 has a Pax Quality of 0.75, thus the saving time for removing this bus stop is 0.75 x 12 seconds, resulting in a saving time of 9 seconds.

Table 15: Example of the Time Savings for Each Bus Stop Selected to be Removed.

Stop ID	Class	Pax Quality	Saving Time
228	E	0.75	9
231	F	0.04	0.48
233	F	0.11	1.32
235	F	0.27	3.24
239	D	2.94	12
255	D	1.24	12
260	B	4.53	12
265	B	2.41	12
292	C	1.27	12
293	B	6.35	12
298	D	0.77	9.24
307	F	0.14	1.68
315	D	1.67	12
317	F	0.04	0.48
319	F	0.04	0.48
327	F	0	0

The main objective of these savings is to calculate how much time is saved from the cycle time of Route 5. For this it is necessary to know the actual cycle time of Route 5 and how many buses are in that route. Table 16 shows the runtime of each cycle from Iturregui to Covadonga terminal, and vice versa, the layover for each bus, and the total cycle time (runtime + layover). Table 17 shows all the results of this process. First, the quantity of buses, the average cycle time and the average headway are shown. Then, using the results of the saving times from Table 15, a new cycle time and headway are calculated.

Table 16: Total Cycle Time for Route 5 of the MBA.

ITU-COV			
Cycles	Runtime (min)	Layover (min)	Cycle Time (Min)
1	50	29	79
2	61	31	92
3	67	38	105
4	84	5	89
5	60	27	87
6	64	41	105

COV-ITU			
Cycles	Runtime (min)	Layover (min)	Cycle Time (Min)
1	41	17	58
2	50	31	81
3	52	19	71
4	48	25	73
5	55	25	80
6	59	30	89
7	50	36	86

Table 17: Calculations Process of the Savings from Removing a Bus Stop.

1. Buses	4
2. Average Cycle Time (min)	84.23
3. Average Headway (min)	21.06
4. Time Savings from Removing Stops (12 sec per stop)	109.92
5. New Cycle Time (min)	82.40
6. New Headway (min)	20.60

Iteration for Both Methods

An extra step was made after the implementation of the benefit-cost (B/C) ratio and the four-step process method. This extra step is applied as an iteration of both methodologies and the main idea lies in two reasons. The first reason is to verify the veracity of both methods. The second reason is to re-evaluate the bus stops with a B/C ratio bigger than 1, but not selected to be removed as well as those bus stops with a potential removal score from the four-step process, but not selected to be removed.

Benefit-Cost Ratio Iteration

The iteration began eliminating the 28 bus stops recommended to be removed and applying the method of B/C ratio with the new set of bus stops. This new set of bus stops has several new distances between them due to the elimination of 28 bus stops. Figure 35 shows an example of before and after the application of the B/C ratio in the Isla Verde Avenue from Covadonga to Iturregui station, representing the new set of bus stops.

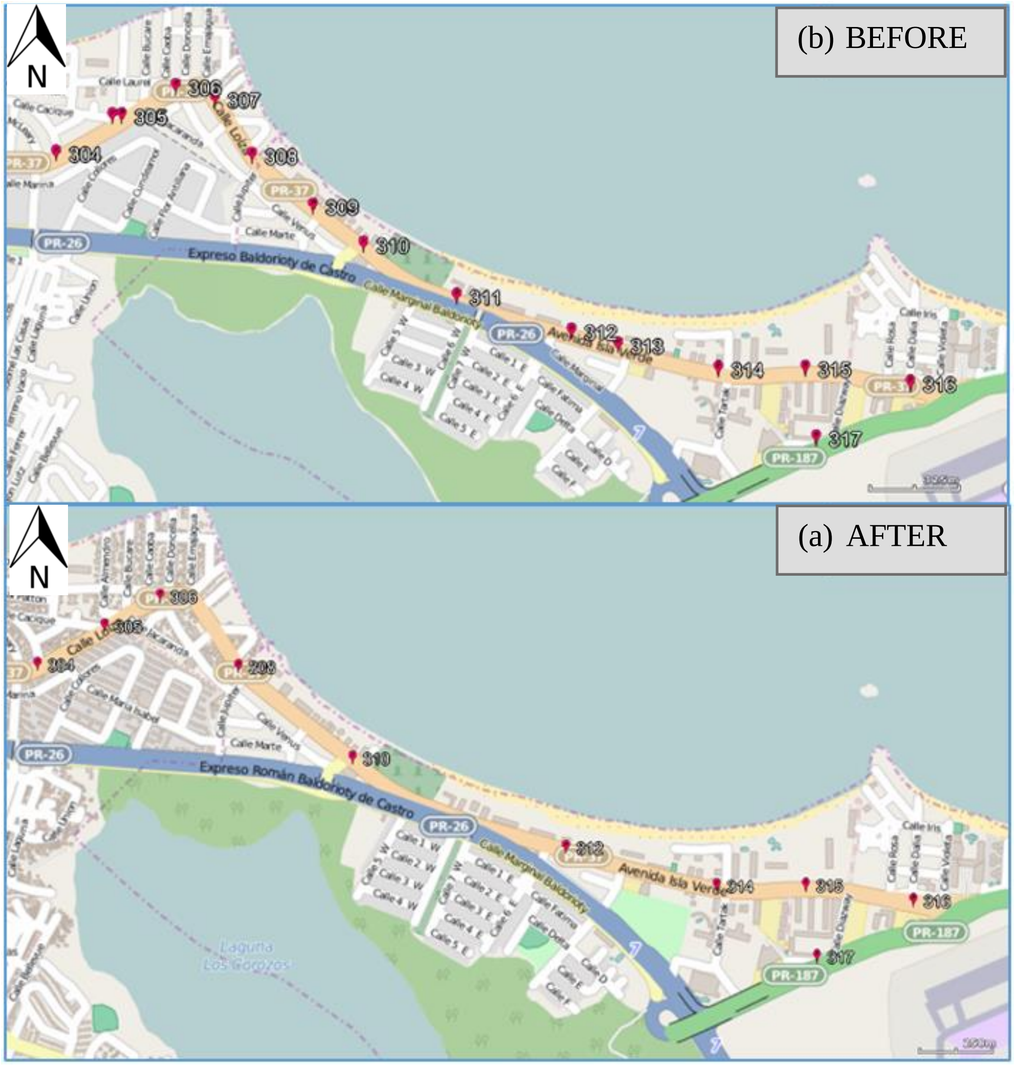

Figure 35: (a) Before and (b) After of the Benefit-Cost Ratio Application (Source: ArcGIS Explorer)

After the iteration every bus stop of the new set of bus stops obtains a new B/C ratio, as shown in Table 18. In Table 18 the cells in red represent the bus stops that were selected to be removed the first time that the B/C ratio method was applied. The yellow cells represent the bus stops that after the second iteration remained with a B/C ratio greater than 1.

Generally all B/C ratios of bus stops decreased, except in one case only. Before the iteration, several bus stops had B/C ratios greater than 1, but were not selected to be removed because they were consecutive bus stops. Therefore, those bus stops showed again B/C ratios greater than 1.

Taking into account that the B/C ratio method consistently showed the same bus stops that already had B/C ratios greater than 1, it is worthy to analyze each case individually. For this, every bus stop with a B/C ratio greater than 1 in the second iteration is assumed to be removed and the distance from the bus stops that remain are calculated, as shown in Table 18. For example, the bus stop 306 in Table 18 has a B/C ratio of 4.5 and 3.6 from de first and second iteration, respectively. In that case, bus stop 306 was selected to be removed, and now bus stops 306 and 307 are recommended to be removed. Therefore it is necessary to calculate the distance between the remaining bus stops 305 and 308; that distance is 645.97 meters. This distance between the remaining bus stops meets the requirements of the 400 meters around every bus stop that represents the standard walking distance that people are willing to walk to a transit stop (Walker, 2011). Therefore, the elimination of bus stops 306 and 307 should not be a problem to the MBA users. Another example in Table 18 is with bus stop 310, which similar to bus stop 306, it has a B/C ratio greater than 1 in both iterations. In this case, if bus stop 310 is selected to be removed, the distance between the remaining bus stops, 308 and 312, is 1,330.64 meters. Unlike the case of bus stop 306, the distance between the bus stops 308 and 312 does not meet the requirements of 400 meters around every bus stop. Thus, bus stop 310 should not be considered to be removed.

After applying this analysis with each one of the bus stops the final results of the B/C ratio method recommend a total of 32 bus stops to be removed. This represent 4 more bus stops compared with initial 28 bus stops to be removed due to the first iteration. The bus stops to be removed by the second iteration are 254, 297, 299 and 306.

Table 18: Benefit-Cost Ratio Method Iteration.

Stop ID	1st Time B/C	2nd Time B/C	Range between bus stops	Distance	Stop ID	1st Time B/C	2nd Time B/C	Range between bus stops	Distance
T. Iturregui	-	-			287	1.5	1.5		
221	0.4	0.2			288	0.4	0.3		
222	2.3	-			289	3.1	-		
223	2.1	1.0			290	0.4	0.3		
224	2.9	-			291	0.7	0.6		
225	0.7	0.5			292	1.2	-		
226	0.4	0.4			44	0.5	0.3		
227	1.0	0.8			45	0.8	0.7		
228	1.8	-			46	0.5	0.5		
229	0.9	0.6	Distance between 229-232	834.62 m	47	0.7	0.7		
230	3.6	3.0			293	0.4	0.3		
231	9.8	-			294	0.9	0.7		
232	0.7	0.5	Distance between 232-236	975.30 m	295	0.9	0.9		
233	3.1	2.5			296	0.9	0.9	Distance between bus stops 296-300	720.54 m
234	4.1	-			297	1.9	1.5		
235	3.3	2.1			298	1.8	-		
236	0.6	0.6			299	1.4	1.1		
237	2.7	-			300	1.0	0.7		
238	0.1	0.1			301	1.4	-		
239	0.4	0.4			302	0.3	0.3		
240	0.6	0.6			303	0.4	0.4		
241	1.1	0.8			304	0.2	0.2		
242	1.1	-			305	0.8	0.9	Distance between bus stops 305-308	645.97 m
243	1.8	0.8			306	4.5	3.6		
244	1.9	-			307	6.3	-		
245	1.9	0.9			308	0.9	0.6		
246	5.0	-			309	5.1	-	Distance between bus stops 308-312	1330.64 m
247	1.9	1.0			310	2.3	1.1		
248	6.3	-			311	1.6	-		
249	0.3	0.2			312	1.3	0.5		
250	0.9	0.9			313	2.6	-		
251	0.7	0.7			314	0.3	0.3		
252	0.3	0.3			315	0.4	0.5		
253	0.9	0.9	Distance between bus stops 253-256	555.06 m	316	0.1	0.1		
254	1.4	1.1			317	1.8	-		
255	2.8	-			318	0.5	0.4	Distance between bus stops 318-322	971.82 m
256	1.4	1.0			319	7.3	-		
257	0.7	0.6			320	1.1	1.2		
258	2.2	-			321	0.7	1.2		
259	0.7	0.5			322	0.3	0.5		
260	0.7	0.8			323	2.3	-		
261	0.9	0.9			324	0.9	0.9	Distance between bus stops 324-329	1,474.28 m
262	0.6	0.6			325	1.4	1.1		
263	0.3	0.2			326	9.2	-		
264	1.5	-			327	6.2	4.2		
265	1.0	0.7			328	2.1	-		
266	0.6	0.5			329	1.1	1.0		
267	5.3	-			330	4.9	-		
268	0.4	0.2			331	0.3			
269	1.2				**T. Iturregui**				
Total	**14**	**1**			**Total**	**14**	**2**		

Four-Step Process Iteration

The iteration in the four-step process was basically applying again the Removal Score part but eliminating the bus stops that were selected to be removed the first time of the process. Table 19 and Table 20 show the second iteration of the four-step process. There are four bus stops selected to be removed by the second iteration; 230, 234, 254 and 328. The only case where the removal of one of the selected bus stops meets the requirements of the 400 meters around the bus stop is when bus stop 254 is removed; it results in less than 800 meters between the remaining bus stops. The other three cases (230, 232 and 328) exceed the 800 meters, with values no more than 900 meters. At the end, the four-step process recommends a total of 20 bus stops to be removed.

The last step of the four-step process is to calculate the savings resulting from bus stops removal. After the second iteration of the method it is necessary to calculate again those savings because now there are four additional bus stops (compared to the first iteration). Table 21 shows the new calculations of the savings from the removal of the 20 final bus stops.

Table 19: Second Iteration of the Four-Step Process from Covadonga to Iturregui Station.

Stop Name	Class	PaxQuality*	Stops Before	Stops After	Removal Score	Mark as Potential	Mark for Removal
287	F	0.14	0	1	-	-	-
288	D	0.64	1	1	-	-	-
289	F	0.12	1	1	-	-	-
290	B	0.83	1	1	-	-	-
291	D	0.57	1	1	-	-	-
44	B	0.89	1	1	-	-	-
45	A	3	1	1	-	-	-
46	A	3	1	1	-	-	-
47	A	3	1	1	-	-	-
294	A	3	1	1	-	-	-
295	A	4	1	1	-	-	-
296	B	4	1	1	-	-	-
297	D	3	1	1	-	-	-
299	A	3	1	2	-	-	-
300	A	4	1	1	-	-	-
301	A	3	2	1	-	-	-
302	B	4	1	1	-	-	-
303	A	4	1	0	-	-	-
304	B	4	0	1	-	-	-
305	B	0.79	1	1	-	-	-
306	E	0.36	1	1	-	-	-
308	D	0.73	1	1	-	-	-
309	A	0.24	1	1	-	-	-
310	A	0.50	1	1	-	-	-
311	E	0.39	1	0	-	-	-
312	D	0.59	0	1	-	-	-
313	E	0.38	1	1	-	-	-
314	B	0.80	1	0	-	-	-
316	B	0.89	0	0	-	-	-
318	D	0.69	0	1	-	-	-
320	D	0.57	1	1	-	-	-
321	D	0.69	1	1	-	-	-
322	B	0.83	1	0	-	-	-
323	E	0.36	0	1	-	-	-
324	D	0.70	1	1	-	-	-
325	D	0.67	1	2	-	-	-
326	E	0.38	1	0	-	-	-
328	E	0.33	0	1	1	*Potential removal*	For removal
329	E	0.40	1	1	-	-	-
330	E	0.25	1	1	-	-	-
331	E	0.33	1	0	-	-	-
T. Iturregui	**N/A**	**-**	**-**	**-**	-	-	-

Table 20: Second Iteration of the Four-Step Process from Iturregui to Covadonga Station.

Stop Name	Class	PaxQuality*	Stops Before	Stops After	Removal Score	Mark as Potential	Mark for Removal
T. Iturregui	N/A	-	-	-	-		
221	A	0.67	0	1	-		
222	F	0.12	1	1	-		
223	F	0.15	1	1	-		
224	F	0.14	1	0	-		
225	E	0.26	0	0	-		
226	D	0.63	0	1	-		
227	D	0.53	1	0	-		
229	D	0.60	0	1	-		
230	F	0.15	1	0	1	*Potential removal*	*For removal*
232	D	0.60	0	1	-	-	-
234	F	0.17	2	0	1	*Potential removal*	*For removal*
236	D	0.50	2	0	-	-	-
237	F	0.07	0	1	-	-	-
238	B	0.93	0	0	-	-	-
240	D	0.74	1	1	-	-	-
241	E	0.39	1	1	-	-	-
242	E	0.40	1	1	-	-	-
243	F	0.23	1	1	-	-	-
244	A	0.24	1	0	-	-	-
245	A	0.32	0	1	-	-	-
246	F	0.19	1	1	-	-	-
247	E	0.37	1	1	-	-	-
248	F	0.15	1	1	-	-	-
249	B	4	1	0	-	-	-
250	A	2	0	1	-	-	-
251	D	3	1	1	-	-	-
252	A	4	1	1	-	-	-
253	A	4	1	2	-	-	-
254	D	3	1	1	1	*Potential removal*	*For removal*
256	A	3	1	1	-	-	-
257	A	3	1	1	-	-	-
258	A	3	1	2	-	-	-
259	A	4	1	1	-	-	-
261	A	3	2	1	-	-	-
262	D	3	1	1	-	-	-
263	A	4	1	1	-	-	-
264	D	3	1	1	-	-	-
266	A	0.81	1	1	-	-	-
267	E	0.27	1	1	-	-	-
268	A	0.86	1	1	-	-	-
269	E	0.46	1	0	-	-	-

Table 21: New Calculations Process of Savings from Removing a Bus Stop | Four-Step Process

1. Buses	**4**
2. Average Cycle Time (min)	**84.23**
3. Average Headway (min)	**21.06**
4. Time Savings from Removing Stops (sec)	**128.18**
5. New Cycle Time (min)	**82.09**
6. New Headway (min)	**20.52**

Final Results

The results of the application of these two methodologies are very interesting and very simple. They are shown in Table 22. In Table 22 it is seen a comparison of both methodologies, pointing out the fact that the B/C ratio method indicates a higher number of bus stops to be removed compared to the four-step process. If for any reason it is pretended to use a combination of both methods, only 11 bus stops are selected by both methodologies.

Both methodologies are very good to identify which bus stops have to be evaluated for removal consideration. However, it is necessary to look beyond and comprehend the details at the bus stop-level and user-level analysis.

The final results that each method provides are summarized as follows:

1. Benefit-Cost ratio methodology suggests 32 bus stops for removal (See Table 22).
2. Four-step process methodology suggests 20 bus stops for removal (See Table 22)
3. Both methodologies suggest the same 11 bus stops for removal (See Table 22).
4. Running times improve 2.5% due to the bus stop removal of the four-step methodology.

Table 22: Final Results of the Suggested Bus Stops to Be Removed from Both Methodologies.

Stops	Methodology 1 (B/C Ratio)	Methodology 2 (Four-Step Process)	Methodology 1, 2 or BOTH
222	2.3		1
224	2.9		1
228	1.8	E	BOTH
230		F	2
231	9.8	F	BOTH
233		F	2
234	4.1	F	BOTH
235		F	2
237	2.7		1
239		D	2
242	1.1		1
244	1.9		1
246	5		1
248	6.3		1
254	1.1	D	BOTH
255	2.8	D	BOTH
258	2.2		1
260		B	2
264	1.5		1
265		B	2
267	5.3		1
289	3.1		1
292	1.2	C	BOTH
293		B	2
297	1.5		1
298	1.8	D	BOTH
299	1.1		1
301	1.4		1
306	3.6		1
307	6.3	F	BOTH
309	5.1		1
311	1.6		1
313	2.6		1
315		D	2
317	1.8	F	BOTH
319	7.3	F	BOTH
323	2.3		1
326	9.2		1
327		F	2
328	2.1	E	BOTH
330	4.9		1
Total	**32**	**20**	

Combination of Methodologies

In order to provide clear and confident results of which bus stops finally will be selected to be removed, a combination of methodologies is provided. The main idea of this combination is to identify the bus stops that the four-step process considers as Class A and choose them as not-for-removal. Then, the benefit-cost ratio method is used to complement the four-step process to combine the final results of both methods. Basically the four-step process helps to filter the results from the benefit-cost ratio, making sure that the bus stops with a social importance do not be removed by the benefit-cost ratio method. Table 23 shows the final bus stops to be removed by direction. From the Covadonga to Iturregui station, and vice versa, a total of 17 and 19 bus stops, respectively, were selected to be removed. The total bus stops to be removed from Route 5 are 36 bus stops, representing almost a 37% of all the bus stops in Route 5 of the MBA.

Table 23: Final Bus Stops to be removed by Both Methodologies

ID Cov-Itu	Final Bus Stop to Remove	ID Itu-Cov	Final Bus Stop to Remove
287	-	221	A
288	-	222	x
289	X	223	-
290	-	224	x
291	-	225	-
292	X	226	-
44	-	227	-
45	A	228	x
46	A	229	-
47	A	230	xx
293	Xx	231	x
294	A	232	-
295	A	233	xx
296	-	234	x
297	x	235	xx
298	x	236	-
299	A	237	x
300	A	238	-
301	A	239	xx
302	-	240	-
303	A	241	-
304	-	242	x
305	-	243	-

ID Cov-Itu	Final Bus Stop to Remove	ID Itu-Cov	Final Bus Stop to Remove
306	x	244	A
307	<u>x</u>	245	A
308	-	246	x
309	A	247	-
310	A	248	x
311	x	249	-
312	-	250	A
313	x	251	-
314	-	252	A
315	xx	253	A
316	-	254	<u>x</u>
317	<u>x</u>	255	<u>x</u>
318	-	256	A
319	<u>x</u>	257	A
320	-	258	A
321	-	259	A
322	-	260	xx
323	x	261	A
324	-	262	-
325	-	263	A
326	x	264	x
327	xx	265	xx
328	<u>x</u>	266	A
329	-	267	x
330	x	268	A
331	-	269	-
Total	**17**	**Total**	**19**

x – Removed by the first methodology (B/C Ratio)
xx – Removed by the second methodology (four-step process)
<u>x</u> – Removed by both methodologies
A - Not for removal

V. CONCLUSIONS AND RECOMMENDATIONS

An analysis of the quantity of bus stops and the space between them is necessary in order to determine which bus stops should be removed. With the application of the benefit-cost ratio and the four-step process analyses, the bus stops that have low passenger activity and are too close to each other can be identified. Identifying those bus stops suggests the need for a thorough analysis of their usefulness and the factors that have to be taken into account to conduct such analysis.

To accomplish this analysis, a passenger load study was performed to Route 5 of the Metropolitan Bus Authority (MBA) in the Metropolitan Area of San Juan. Route 5 starts in Covadonga Terminal in Old San Juan, and ends in Iturregui Terminal, in Carolina. The passenger load study includes all the boarding and alighting data in every bus stop along Route 5. Also, the travel time between each bus terminal was calculated. With these data two different methods were applied to identify which bus stops should be removed from this route.

The first methodology was the benefit-cost ratio (B/C), where each one of the bus stops obtains a ratio of the benefit and cost of removing them. The second methodology is the four-step process, where the main purpose is to give a class (i.e. importance) from A to F to each stop, A being the most important and F the least important. The B/C ratio method recommended 32 bus stops to be removed from Route 5 and the four-step process recommended 20 bus stops to be removed from the same route. The final bus stops to be removed by the combination of both methodologies are 36 bus stops, representing a 37% of the bus stops along Route 5.

Conclusions

The consolidation analyses performed attend the main goal and each one of the objectives of this project. The main goal was reached demonstrating two standardized procedures that identify and recommends the bus stops that should be removed. Both procedures take into account the ridership of every bus stop, as well as the land use around them.

The objectives were fulfilled to assure an accurate analysis and best results. At the beginning, a literature review was performed to study the actual procedures and methods for bus stops consolidation. It was found that several approaches to the bus stop consolidation were performed by Furth and Rahbee (2000), where both authors develop a complex dynamic programming algorithm to find the least expensive solution to stop location. Also, Li and Bertini (2008), on a less complex method, develop a stop spacing model that considered the passenger access cost and in-vehicle passenger stopping cost to minimize the total cost. El-Geneidy, Kimpel and Strathman (2006) performed a study that analyzed the change in the passenger activity and operating performance after the implementation of bus stops consolidation in Oregon. The Washington Metropolitan Area Transit Authority (2009) performed their own bus stops consolidation analysis using four different combinations of two aspects of time savings per removed bus stop along the line (10 and 20 seconds), and implementation of new spacing standards (4 or 5 stops per mile). Recent approaches are shown by Wagner and Bertini (2014) and Stewart and El-Geneidy (2014); the first describe a methodology that calculate the benefit and the cost of removing a bus stop to obtain a benefit-cost ratio, and the second describe a 5-step process to give importance to the bus stops from A to F.

The final product of the bus stop consolidation analysis for the MBA bus stops basically provides a useful tool for the evaluation of each one of them. The benefit-cost ratio and the four-step process recommend which bus stops have to be eliminated, but the application of the engineering judgment is still necessary to provide a final answer. The final results from both methodologies may not be the same, therefore someone with a transit or planning background should decide which bus stops should be finally eliminated. To attend this issue, a combination of both methodologies was applied, where basically the four-step process helps to filter the results from the benefit-cost ratio methodology, thus making sure that the bus stops with a social importance are not be removed by the benefit-cost ratio method. Therefore it is concluded that a combination of both methods is the best tool for the evaluation of bus stops.

It is important to recognize the importance and relevance of each bus stop, because every one of them might have a reason, with or without planning, for their location. If any of these bus stops have to be removed it is necessary to conduct surveys and gather deeper information about the activity around them and understand the purpose of their locations.

The application of these two methods is very simple to implement and easy to understand. It is very important to provide a simple tool to evaluate bus stops, so that agencies can easily use it. A great enhancement will be if a more comprehensive passenger load study, or automated counting data, was available. With such information the applications of both methods would be more accurate and could be applied to others MBA routes as well. The passenger load data study for this study was collected only for six hours during the morning.

Both methodologies are very flexible to use for all the others MBA bus routes and are relatively cost-free. The removal of bus stops is easier to implement in comparison to any other action, such as building a new bus stop or improving the geometry of the site.

The benefit-cost ratio analysis, in comparison with the four-step process method, favors the people that are riding the bus and actually using the bus stops. On the other hand, the four-step process takes into account a full range of possible users around the area of service of each bus stop.

Recommendations

From the results and conclusions of the present study, three recommendations were identified for the enhancement of using both methodologies. These are:

1. **Perform a third methodology to identify where the bus stops really should be along Route 5.**

A design from scratch of the locations of the bus stops and study all the areas around Route 5 is recommended. It is necessary to study the population, activity centers, and origin-destination places to design a new set of bus stops that serve, not only the actual needs, but the future needs of the users as well. The final design could be compared with the actual bus stop locations and, along with the benefit-cost ratio and the four step process, determine with more accuracy which bus stops are really important and which ones must be removed.

2. **Perform surveys to the actual users of Route 5**

The objective of this recommendation is to gather additional information about the people that use Route 5 in regards of the actual decisions of which bus stops they are currently using. In addition, the survey can gather information related to their willingness to walk to other locations in the case of removing some bus stops. The results of this survey could shed additional information to improve step 3 of the four step process, specifically the reevaluation of Class A bus stops.

3. **Perform a sensitivity analysis for the results of the benefit-cost ratio method**

The benefit-cost ratio method has several variables that have a range of values; for this study a midrange value was selected. It is recommended to perform a sensitivity analysis to analyze if a change in the results occurs with the use of different input values.

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VII. APPENDICES

Appendix A: Benefit-Cost Ratio Results

ITURREGUI - COVADONGA												
Stop ID	**Dn**	**Df**	**Dw**	**vw**	**Ta**	**Pa**	**Va**	**C**	**Pr**	**Tr**	**B**	**B/C**
T. Iturregui	-	-	-	-	-	-	-	-	-	-	-	-
221	813	1363	509.4184632	3.5	145.5481323	18	2	5239.732764	133	15	1995	0.4
222	813	1407	515.4590251	3.5	147.2740072	3	2	883.644043	136	15	2040	2.3
223	1014	1407	589.16	3.5	168.3314286	3	2	1009.988571	139	15	2085	2.1
224	1014	1768	644.2066981	3.5	184.0590566	2	2	736.2362264	141	15	2115	2.9
225	1768	2086	956.9337191	3.5	273.409634	6	2	3280.915609	145	15	2175	0.7
226	820	2086	588.6230248	3.5	168.1780071	16	2	5381.696227	155	15	2325	0.4
227	820	909	431.0056926	3.5	123.1444836	10	2	2462.889672	159	15	2385	1.0
228	453	909	302.1235663	3.5	86.32101893	8	2	1381.136303	167	15	2505	1.8
229	453	741	281.0347253	3.5	80.29563579	18	2	2890.642889	181	15	2715	0.9
230	741	1092	441.5854025	3.5	126.1672579	3	2	757.0035472	184	15	2760	3.6
231	895	1092	492.0487129	3.5	140.5853465	1	2	281.1706931	183	15	2745	9.8
232	895	1063	485.9674372	3.5	138.8478392	14	2	3887.739497	189	15	2835	0.7
233	1063	1128	547.268982	3.5	156.3625663	3	2	938.1753978	192	15	2880	3.1
234	653	1128	413.5095396	3.5	118.1455827	3	2	708.8734964	193	15	2895	4.1
235	653	899	378.1084144	3.5	108.0309755	4	2	864.2478043	193	15	2895	3.3
236	899	8715	814.7045513	3.5	232.772729	10	2	4655.454579	197	15	2955	0.6
237	2411	8715	1888.412618	3.5	539.5464623	1	2	1079.092925	196	15	2940	2.7
238	1427	2411	896.3230769	3.5	256.0923077	47	2	24072.67692	219	15	3285	0.1
239	787	1427	507.3066667	3.5	144.9447619	28	2	8116.906667	237	15	3555	0.4
240	787	1191	473.8865672	3.5	135.396162	22	2	5957.43113	243	15	3645	0.6
241	1191	1292	619.6990225	3.5	177.0568636	10	2	3541.137271	253	15	3795	1.1
242	1141	1292	606.1015633	3.5	173.1718752	10	2	3463.437505	253	15	3795	1.1
243	1027	1141	540.5003328	3.5	154.4286665	7	2	2162.001331	258	15	3870	1.8
244	1027	1410	594.1523553	3.5	169.7578158	6	2	2037.09379	256	15	3840	1.9
245	800	1410	510.589911	3.5	145.8828317	7	2	2042.359644	255	15	3825	1.9
246	800	1040	452.2307308	3.5	129.2087802	3	2	775.2526814	256	15	3840	5.0
247	761	1040	439.388561	3.5	125.5395889	8	2	2008.633422	258	15	3870	1.9
248	672	761	356.9720824	3.5	101.9920235	3	2	611.9521412	257	15	3855	6.3
249	672	1473	461.6324159	3.5	131.894976	62	2	16354.97702	299	15	4485	0.3
250	1168	1473	651.2898385	3.5	186.082811	14	2	5210.318708	305	15	4575	0.9
251	1168	1266	607.4453908	3.5	173.555826	20	2	6942.233038	311	15	4665	0.7
252	1125	1266	595.700192	3.5	170.2000549	44	2	14977.60483	325	15	4875	0.3
253	676	1125	422.1461566	3.5	120.6131876	22	2	5306.980255	335	15	5025	0.9

ITURREGUI - COVADONGA												
Stop ID	Dn	Df	Dw	vw	Ta	Pa	Va	C	Pr	Tr	B	B/C
254	630	676	325.9561809	3.5	93.1303374	19	2	3538.952821	338	15	5070	1.4
255	525	630	286.2545455	3.5	81.78701299	11	2	1799.314286	337	15	5055	2.8
256	525	731	305.5624021	3.5	87.30354345	20	2	3492.141738	323	15	4845	1.4
257	731	1256	462.279736	3.5	132.0799246	27	2	7132.315926	324	15	4860	0.7
258	541	1256	378.2474453	3.5	108.0706986	10	2	2161.413973	314	15	4710	2.2
259	541	554	273.8407186	3.5	78.2402053	36	2	5633.294782	278	15	4170	0.7
260	554	636	296.2481543	3.5	84.64232979	32	2	5417.109107	264	15	3960	0.7
261	636	777	349.902181	3.5	99.97205171	21	2	4198.826172	247	15	3705	0.9
262	754	777	382.8539615	3.5	109.3868461	28	2	6125.663383	231	15	3465	0.6
263	643	754	347.0948357	3.5	99.16995305	46	2	9123.635681	197	15	2955	0.3
264	584	643	305.9696257	3.5	87.41989305	12	2	2098.077433	207	15	3105	1.5
265	492	584	267	3.5	76.28571429	20	2	3051.428571	201	15	3015	1.0
266	492	1299	356.8351648	3.5	101.9529042	24	2	4893.739403	209	15	3135	0.6
267	836	1299	508.7778802	3.5	145.3651086	2	2	581.4604345	207	15	3105	5.3
268	836	928	439.9650558	3.5	125.7043016	32	2	8045.075305	191	15	2865	0.4
269	928	2487	675.9452394	3.5	193.1272113	6	2	2317.526535	187	15	2805	1.2

COVANDONGA - ITURREGUI												
Stop ID	**Dn**	**Df**	**Dw**	**vw**	**Ta**	**Pa**	**Va**	**C**	**Pr**	**Tr**	**B**	**B/C**
287	981	2487	703.353	3.5	200.958	2	2	803.832	80	15	1200	1.5
288	728	981	417.888	3.5	119.397	16	2	3820.69	96	15	1440	0.4
289	728	941	410.574	3.5	117.307	2	2	469.227	98	15	1470	3.1
290	827	941	440.116	3.5	125.748	17	2	4275.42	107	15	1605	0.4
291	731	827	388.048	3.5	110.871	12	2	2660.9	117	15	1755	0.7
292	502	731	297.634	3.5	85.0382	9	2	1530.69	124	15	1860	1.2
44	502	833	313.188	3.5	89.4822	27	2	4832.04	145	15	2175	0.5
45	833	909	434.603	3.5	124.172	11	2	2731.79	150	15	2250	0.8
46	663	909	383.151	3.5	109.472	21	2	4597.81	159	15	2385	0.5
47	466	663	273.499	3.5	78.1425	22	2	3438.27	159	15	2385	0.7
293	466	977	315.447	3.5	90.1276	46	2	8291.74	195	15	2925	0.4
294	856	977	456.372	3.5	130.392	13	2	3390.19	198	15	2970	0.9
295	853	856	427.218	3.5	122.062	13	2	3173.62	193	15	2895	0.9
296	626	853	361.164	3.5	103.19	16	2	3302.07	193	15	2895	0.9
297	626	735	338.148	3.5	96.6138	8	2	1545.82	195	15	2925	1.9
298	525	735	306.133	3.5	87.4667	9	2	1574.4	192	15	2880	1.8
299	469	525	247.678	3.5	70.7651	14	2	1981.42	188	15	2820	1.4
300	469	492	240.123	3.5	68.6065	21	2	2881.47	191	15	2865	1.0
301	492	1292	356.338	3.5	101.811	10	2	2036.22	193	15	2895	1.4
302	1023	1292	571.11	3.5	163.174	28	2	9137.76	195	15	2925	0.3
303	1023	1407	592.472	3.5	169.278	21	2	7109.66	182	15	2730	0.4
304	889	1407	544.756	3.5	155.645	37	2	11517.7	173	15	2595	0.2
305	725	889	399.273	3.5	114.078	14	2	3194.19	167	15	2505	0.8
306	590	725	325.383	3.5	92.9664	3	2	557.799	166	15	2490	4.5
307	590	823	343.829	3.5	98.2369	2	2	392.948	164	15	2460	6.3
308	823	932	437.031	3.5	124.866	11	2	2747.05	161	15	2415	0.9
309	745	932	413.806	3.5	118.23	2	2	472.922	161	15	2415	5.1
310	745	1266	468.842	3.5	133.955	4	2	1071.64	163	15	2445	2.3
311	1266	1417	668.639	3.5	191.04	4	2	1528.32	161	15	2415	1.6
312	571	1417	406.85	3.5	116.243	8	2	1859.89	159	15	2385	1.3

COVANDONGA - ITURREGUI												
Stop ID	**Dn**	**Df**	**Dw**	**vw**	**Ta**	**Pa**	**Va**	**C**	**Pr**	**Tr**	**B**	**B/C**
313	571	1220	388.842	3.5	111.098	4	2	888.782	155	15	2325	2.6
314	1027	1220	557.533	3.5	159.295	22	2	7008.99	133	15	1995	0.3
315	1027	1253	564.283	3.5	161.224	14	2	4514.26	119	15	1785	0.4
316	1253	1820	742.148	3.5	212.042	31	2	13146.6	100	15	1500	0.1
317	1820	6494	1421.85	3.5	406.243	1	2	812.486	99	15	1485	1.8
318	751	6494	673.254	3.5	192.358	8	2	3077.73	93	15	1395	0.5
319	620	751	339.621	3.5	97.0346	1	2	194.069	94	15	1410	7.3
320	620	1122	399.271	3.5	114.077	6	2	1368.93	96	15	1440	1.1
321	689	1122	426.757	3.5	121.93	8	2	1950.89	92	15	1380	0.7
322	689	1364	457.733	3.5	130.781	16	2	4184.99	96	15	1440	0.3
323	915	1364	547.755	3.5	156.502	2	2	626.006	96	15	1440	2.3
324	915	1450	561.003	3.5	160.287	5	2	1602.87	93	15	1395	0.9
325	489	1450	365.506	3.5	104.43	5	2	1044.3	96	15	1440	1.4
326	489	613	271.996	3.5	77.7131	1	2	155.426	95	15	1425	9.2
327	613	1174	402.904	3.5	115.116	1	2	230.231	95	15	1425	6.2
328	1118	1174	572.841	3.5	163.669	2	2	654.675	93	15	1395	2.1
329	984	1118	523.47	3.5	149.563	4	2	1196.5	89	15	1335	1.1
330	925	984	476.784	3.5	136.224	1	2	272.448	89	15	1335	4.9
331	925	1448	564.418	3.5	161.262	11	2	3547.77	78	15	1170	0.3

Appendix B: Four Step Process Results

Figure 36: Pax Quality Computations and Classification of Quartiles | COV-ITU.

Covadonga-Iturregui								
Paradas	**μ**	**σ**	**CV**	**PaxQuality**	**Percent Inc**	**Quartile**	**Percent Exc**	**Quartile**
T. Covadonga	6.88	3.681518	0.5354935	12.83862549	0.982	4	0.966	4
279	1.13	1.125992	1.0008814	1.124009247	0.561	3	0.559	3
280	0.25	0.46291	1.8516402	0.135015431	0.178	1	0.189	1
281	0.50	1.414214	2.8284271	0.176776695	0.272	2	0.28	2
282	0.50	0.755929	1.5118579	0.330718914	0.314	2	0.321	2
283	0.25	0.707107	2.8284271	0.088388348	0.15	1	0.163	1
284	0.13	0.353553	2.8284271	0.044194174	0.057	1	0.074	1
285	0.13	0.353553	2.8284271	0.044194174	0.058	1	0.075	1
286	0.00	0	#DIV/0!	0	0	1	0.019	1
287	0.25	0.46291	1.8516402	0.135015431	0.122	1	0.137	1
288	2.00	2.267787	1.1338934	1.763834207	0.645	3	0.64	3
289	0.25	0.707107	2.8284271	0.088388348	0.106	1	0.122	1
290	2.13	1.552648	0.7306577	2.908338805	0.847	4	0.833	4
291	1.50	1.603567	1.069045	1.40312152	0.577	3	0.574	3
292	1.13	0.991031	0.8809166	1.277078853	0.545	3	0.543	3
44	3.38	2.263846	0.6707693	5.031536407	0.906	4	0.888	4
45	1.38	1.407886	1.0239171	1.34288221	0.571	3	0.568	3
46	2.63	3.662064	1.3950721	1.881623206	0.682	3	0.674	3
47	2.75	3.615443	1.3147066	2.091721501	0.75	4	0.738	3
293	5.75	5.203021	0.9048732	6.354481245	0.948	4	0.926	4
294	1.63	1.767767	1.0878566	1.493763075	0.631	3	0.625	3
295	1.63	1.06066	0.652714	2.489605125	0.81	4	0.794	4
296	2.00	1.309307	0.6546537	3.055050463	0.888	4	0.868	4
297	1.00	1.069045	1.069045	0.935414347	0.6	3	0.594	3
298	1.13	1.642081	1.4596272	0.770744767	0.588	3	0.583	3
299	1.75	1.908627	1.090644	1.604556548	0.666	3	0.657	3
300	2.63	2.615203	0.9962677	2.634833897	0.875	4	0.852	4
301	1.25	2.54951	2.0396078	0.612862922	0.58	3	0.575	3
302	3.50	2.77746	0.7935601	4.410504086	0.9	4	0.875	4
303	2.63	3.622844	1.3801311	1.901993198	0.793	4	0.774	4
304	4.63	2.973094	0.6428311	7.194736421	0.964	4	0.933	4
305	1.75	1.669046	0.9537405	1.834880612	0.814	4	0.793	4
306	0.38	0.744024	1.9840635	0.189006048	0.346	2	0.357	2
307	0.25	0.46291	1.8516402	0.135015431	0.2	1	0.222	1
308	1.38	1.505941	1.0952295	1.255444589	0.75	4	0.73	3
309	0.25	0.46291	1.8516402	0.135015431	0.217	1	0.24	1
310	0.50	0.534522	1.069045	0.467707173	0.5	3	0.5	3

Covadonga-Iturregui								
Paradas	**µ**	**σ**	**CV**	**PaxQuality**	**Percent Inc**	**Quartile**	**Percent Exc**	**Quartile**
311	0.50	0.755929	1.5118579	0.330718914	0.38	2	0.391	2
312	1.00	1.690309	1.6903085	0.591607978	0.6	3	0.59	3
313	0.50	0.92582	1.8516402	0.270030862	0.368	2	0.38	2
314	2.75	3.327376	1.2099548	2.272812223	0.833	4	0.8	4
315	1.75	1.832251	1.0470004	1.67144152	0.764	4	0.736	3
316	3.88	2.695896	0.6957152	5.569807974	0.937	4	0.888	4
317	0.13	0.353553	2.8284271	0.044194174	0.133	1	0.176	1
318	1.00	1.414214	1.4142136	0.707106781	0.714	3	0.687	3
319	0.13	0.353553	2.8284271	0.044194174	0.153	1	0.2	1
320	0.75	1.164965	1.5532863	0.48284723	0.583	3	0.571	3
321	1.00	0.92582	0.9258201	1.08012345	0.727	3	0.692	3
322	2.00	1.603567	0.8017837	2.494438258	0.9	4	0.833	4
323	0.25	0.46291	1.8516402	0.135015431	0.333	2	0.363	2
324	0.63	0.744024	1.1904381	0.525016801	0.75	4	0.7	3
325	0.63	0.916125	1.4658006	0.426388143	0.714	3	0.666	3
326	0.13	0.353553	2.8284271	0.044194174	0.333	2	0.375	2
327	0.00	0	#DIV/0!	0	0	1	0.142	1
328	0.25	0.46291	1.8516402	0.135015431	0.25	2	0.333	2
329	0.50	0.755929	1.5118579	0.330718914	0.333	2	0.4	2
330	0.00	0	#DIV/0!	0	0	1	0.25	2
331	1.38	0.916125	0.666273	2.063718612	0	1	0.333	2

Figure 37: Pax Quality Computations and Classification of Quartiles | ITU-COV.

Iturregui-Covadonga								
Paradas	**µ**	**σ**	**CV**	**PaxQuality**	**Percent Inc**	**Quartile**	**Percent Exc**	**Quartile**
T. Iturregui	12.78	5.262551	0.411852	31.02518166	0.983	4	0.967	4
221	2.00	2.061553	1.030776	1.940285	0.677	3	0.672	3
222	0.33	1	3	0.111111111	0.103	1	0.116	1
223	0.33	0.707107	2.12132	0.15713484	0.14	1	0.152	1
224	0.22	0.440959	1.984313	0.111989473	0.125	1	0.137	1
225	0.67	1	1.5	0.444444444	0.254	2	0.263	2
226	1.78	2.048034	1.152019	1.54318404	0.629	3	0.625	3
227	1.11	1.054093	0.948683	1.171213948	0.528	3	0.527	3
228	0.89	1.054093	1.185854	0.749576927	0.442	2	0.444	2
229	2.00	2.783882	1.391941	1.436842416	0.607	3	0.603	3
230	0.33	0.707107	2.12132	0.15713484	0.14	1	0.153	1
231	0.11	0.333333	3	0.037037037	0.04	1	0.058	1
232	1.56	1.333333	0.857143	1.814814815	0.604	3	0.6	3
233	0.33	1	3	0.111111111	0.106	1	0.122	1
234	0.33	0.5	1.5	0.222222222	0.152	1	0.166	1
235	0.44	0.726483	1.634587	0.271900129	0.177	1	0.191	1
236	1.11	1.054093	0.948683	1.171213948	0.5	3	0.5	3
237	0.11	0.333333	3	0.037037037	0.046	1	0.066	1
238	5.22	3.153481	0.603858	8.648094648	0.952	4	0.931	4
239	3.11	3.29562	1.059306	2.936932164	0.731	3	0.72	3
240	2.44	1.740051	0.711839	3.433984608	0.75	4	0.738	3
241	1.11	1.964971	1.768474	0.628288096	0.384	2	0.39	2
242	1.11	1.763834	1.587451	0.699934209	0.394	2	0.4	2
243	0.78	1.301708	1.673625	0.464726453	0.216	1	0.23	1
244	0.67	0.866025	1.299038	0.513200239	0.222	1	0.236	1
245	0.78	0.971825	1.24949	0.622476346	0.314	2	0.324	2
246	0.33	0.5	1.5	0.222222222	0.176	1	0.194	1
247	0.89	0.927961	1.043956	0.851462173	0.363	2	0.371	2
248	0.33	0.707107	2.12132	0.15713484	0.125	1	0.147	1
249	6.89	2.976762	0.432111	15.94242083	0.967	4	0.939	4
250	1.56	2.006932	1.290171	1.205697337	0.433	2	0.437	2
251	2.22	1.922094	0.864942	2.569214725	0.689	3	0.677	3
252	4.89	2.934469	0.600232	8.144993416	0.964	4	0.933	4
253	2.44	1.509231	0.617413	3.959174713	0.777	4	0.758	4
254	2.11	1.833333	0.868421	2.430976431	0.73	3	0.714	3
255	1.22	1.20185	0.983332	1.242939329	0.52	3	0.518	3
256	2.22	2.108185	0.948683	2.342427896	0.666	3	0.653	3

Covadonga-Iturregui								
Paradas	**μ**	**σ**	**CV**	**PaxQuality**	**Percent Inc**	**Quartile**	**Percent Exc**	**Quartile**
257	3.00	2.598076	0.866025	3.464101615	0.739	3	0.72	3
258	1.11	1.269296	1.142366	0.972640243	0.545	3	0.541	3
259	4.00	2.061553	0.515388	7.761140001	0.952	4	0.913	4
260	3.56	2.788867	0.784369	4.53301517	0.85	4	0.818	4
261	2.33	2.54951	1.092647	2.135486805	0.736	3	0.714	3
262	3.11	4.621808	1.485581	2.094204673	0.722	3	0.7	3
263	5.11	3.655285	0.715165	7.146762611	0.941	4	0.894	4
264	1.33	1.414214	1.06066	1.257078722	0.75	4	0.722	3
265	2.22	2.048034	0.921615	2.411225063	0.8	4	0.764	4
266	2.67	1.658312	0.621867	4.288161345	0.857	4	0.812	4
267	0.22	0.666667	3	0.074074074	0.23	1	0.266	2
268	3.56	2.554952	0.71858	4.948029236	0.916	4	0.857	4
269	0.67	0.866025	1.299038	0.513200239	0.454	2	0.461	2
750	0.78	1.394433	1.792843	0.433823717	0.4	2	0.416	2
751	0.44	1.013794	2.281036	0.194843244	0.333	2	0.363	2
752	0.67	0.866025	1.299038	0.513200239	0.375	2	0.4	2
753	1.00	1.118034	1.118034	0.894427191	0.857	4	0.777	4
754	1.00	1.732051	1.732051	0.577350269	0.5	3	0.5	3
755	1.00	1.224745	1.224745	0.816496581	0.8	4	0.714	3
756	0.11	0.333333	3	0.037037037	0.5	3	0.5	3
757	0.89	1.269296	1.427957	0.622489756	0.666	3	0.6	3
758	0.00	0	#DIV/0!	0	0	1	0.25	2
759	0.00	0	#DIV/0!	0	0	1	0.333	2

Figure 38: Final Results for Stop Removal | ITU-COV.

Stop Name	Class	PaxQuality*	Stops Before	Stops After	Removal Score	Mark as Potential	Mark as Removal
T. Iturregui	N/A	-	-	-	-		
221	A	0.67	0	1	-		
222	F	0.12	1	1	-		
223	F	0.15	1	1	-		
224	F	0.14	1	0	-		
225	E	0.26	0	0	-		
226	D	0.63	1	2	-		
227	D	0.53	1	1	1	*Potentail removal*	-
228	E	0.44	2	3	2	*Potentail removal*	*For Removal*
229	D	0.60	1	3	-		
230	F	0.15	2	5	4	*Potentail removal*	-
231	F	0.06	1	4	6	*Potentail removal*	*For Removal*
232	D	0.60	1	2	-		
233	F	0.12	3	1	6	*Potentail removal*	*For Removal*
234	F	0.17	4	1	4	*Potentail removal*	-
235	F	0.19	4	1	3	*Potentail removal*	*For Removal*
236	D	0.50	4	0	-		
237	F	0.07	0	2	-		
238	B	0.93	0	0	-		
239	D	0.72	1	1	3	*Potentail removal*	*For Removal*
240	D	0.74	2	1	-		
241	E	0.39	1	1	-		
242	E	0.40	1	1	-		
243	F	0.23	1	1	-		
244	A	0.24	1	0	-		
245	A	0.32	0	1	-		
246	F	0.19	1	1	-		
247	E	0.37	1	1	-		
248	F	0.15	1	1	-		
249	B	4	1	0	-		
250	A	2	0	1	-		
251	D	3	1	1	-		
252	A	4	1	1	-		
253	A	4	1	2	-		
254	D	3	1	2	1	*Potentail removal*	-
255	D	3	2	2	4	*Potentail removal*	*For Removal*
256	A	3	2	1	-		
257	A	3	2	1	-		
258	A	3	1	3	-		
259	A	4	1	2	-		
260	B	4	2	1	3	*Potentail removal*	*For Removal*
261	A	3	3	1	-		
262	D	3	1	1	-		
263	A	4	1	2	-		
264	D	3	1	2	1	*Potentail removal*	-
265	B	0.76	2	1	3	*Potentail removal*	*For Removal*
266	A	0.81	2	1	-		
267	E	0.27	1	1	-		
268	A	0.86	1	1	-		
269	E	0.46	1	0	-		

Figure 39: Final Results for Stop Removal | COV-ITU

Stop Name	Class	PaxQuality*	Stops Before	Stops After	Removal Score	Mark as Potential	Mark as Removal
287	F	0.14	0	1	-		
288	D	0.64	1	1	-		
289	F	0.12	1	1	-		
290	B	0.83	1	1	-		
291	D	0.57	1	2	1	*Potentail removal*	-
292	C	0.54	1	1	1	*Potentail removal*	*For Removal*
44	B	0.89	2	1	-		
45	A	3	1	1	-		
46	A	3	1	2	-		
47	A	3	1	2	-		
293	B	4	2	1	3	*Potentail removal*	*For Removal*
294	A	3	2	1	-		
295	A	4	1	1	-		
296	B	4	1	1	-		
297	D	3	1	2	-		
298	D	3	1	2	3	*Potentail removal*	*For Removal*
299	A	3	2	2	-		
300	A	4	2	1	-		
301	A	3	2	1	-		
302	B	4	1	1	-		
303	A	4	1	0	-		
304	B	4	0	1	-		
305	B	0.79	1	2	-		
306	E	0.36	1	2	1	*Potentail removal*	-
307	F	0.22	2	1	3	*Potentail removal*	*For Removal*
308	D	0.73	2	1	-		
309	A	0.24	1	1	-		
310	A	0.50	1	1	-		
311	E	0.39	1	0	-		
312	D	0.59	0	1	-		
313	E	0.38	1	1	-		
314	B	0.80	1	1	-		
315	D	0.74	1	2	1	*Potentail removal*	*For Removal*
316	B	0.89	1	1	-		
317	F	0.18	2	0	1	*Potentail removal*	*For Removal*
318	D	0.69	0	2	-		
319	F	0.20	1	1	2	*Potentail removal*	*For Removal*
320	D	0.57	2	1	-		
321	D	0.69	1	1	-		
322	B	0.83	1	0	-		
323	E	0.36	0	1	-		
324	D	0.70	1	1	-		
325	D	0.67	1	2	-		
326	E	0.38	1	1	1	*Potentail removal*	-
327	F	0.14	2	1	1	*Potentail removal*	*For Removal*
328	E	0.33	1	1	-		
329	E	0.40	1	1	-		
330	E	0.25	1	1	-		
331	E	0.33	1	0	-		